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Does Training of Cognitive and Metacognitive Regulatory Processes Enhance Learning and Deployment of Processes with Hypermedia?

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Abstract

In this study we examined the effectiveness of self-regulated learning (SRL) training in facilitating college students' science learning with hypermedia. Sixty (N = 60) undergraduate students were randomly assigned to either a training condition or a control condition and used a hypermedia environment to learn about the circulatory system. On Day 1, all participants were administered a pretest and a self-report measure of SRL. On Days 2–4, participants in the experimental group underwent 3-day training on the use of specific, empirically based cognitive and metacognitive SRL processes (e.g., judgment of learning, making inferences) designed to foster their conceptual understanding; control students received no training. Three weeks later (on Day 5), all participants were administered a pretest on the science topic and a self-report measure of SRL, and then used a different version of the system to learn about another science topic (i.e., the central nervous system). Verbal protocol data were collected from both groups on Days 2–5. Overall, there were no significant differences on several learning outcome measures between conditions. However, those in the training condition remembered significantly more declarative knowledge of cognitive and metacognitive strategies. Lastly, think-aloud protocol data showed significant differences in the use of the SRL processes immediately following training, but not following a 3-week interval on a hypermedia transfer task.

Keywords: metacognition; self-regulated learning; hypermedia; learning; training; process data; think-alouds

Introduction

Learners can benefit from multimedia and hypermedia systems when they use key cognitive and metacognitive self-regulatory processes (Azevedo, 2015; Mayer, 2014). Yet the research shows that they rarely use these strategies, and as a consequence fail to develop a deep understanding of complex topics (Azevedo & Aleven, 2013). Being able to accurately monitor and regulate one's own cognitive and metacognitive processes and strategies requires a tremendous amount of knowledge and effort, but is required to be a successful learner (Winne & Azevedo, 2014). Several approaches have been used to model and scaffold learners' use of metacognitive strategies (see Veenman, 2014). Unfortunately, most of the approaches have led to diminutive effects and are difficult to interpret in the absence of process data (e.g., evidence of deployment of cognitive strategies and metacognitive processes based on coded concurrent think-aloud protocols). One explanation is that the acquisition, retention, use, and transfer of these processes develops over time and should be guided by well-designed, theoretically guided, and empirically driven training regiments (e.g., Azevedo & Cromley, 2004).

As such, interdisciplinary researchers are using advanced learning technologies (ALTs) to train students to acquire, retain, and transfer self-regulatory processes with several ALTs across multiple educational and professional domains (see Azevedo & Aleven, 2013). We argue that more research on training students, using different theoretically driven regimens, is necessary to enhance complex learning and transfer of SRL knowledge and skills. As such, this paper reports an empirical study where participants were randomly assigned to one of two conditions (i.e., control or SRL training condition) with a nonadaptive version of MetaTutor (a hypermedia system) during a 5-day laboratory study, to examine the effectiveness of SRL training on their use of SRL processes and its impact on learning gains.

Methods

Participants

Participants were 60 undergraduate students (70% female) from a large public university in the southeastern United States. The mean age of the sample was 23 years old (SD = 3.25), and the mean GPA was 3.12 (SD = 0.65). They were paid for participation in the research. Participants had little prior knowledge of the human circulatory and nervous systems, as indicated by pretest scores (circulatory system, M = 40.3%, and nervous system, M = 23.6%).

Research Design

We used a mixed-methodology approach that combined product and process data to examine the effects of computerized SRL training on learning outcomes and participants' deployment of SRL processes during learning. A 2 (condition: SRL training vs. control) × 2 (time: pretest vs. posttest) mixed factorial design was used to measure learning gains from pretest to posttest on several human body systems. Participants were randomly assigned to one of two conditions, and were asked to learn about two biological systems (human circulatory and nervous systems) using MetaTutor over the course of the 5-day experiment.

Paper and Pencil Materials and Measures

Pretests and Posttests Separate pretests were administered to assess students' existing knowledge of the human circulatory and nervous systems. The nervous system pretest included: (a) a labeling task, which required participants to label the brain and brainstem on a color diagram; (b) a matching task, which required participants to match seven components of the nervous system with their corresponding definitions; and (c) a 12-item multiple choice test, which required participants to answer questions pertaining to the nervous system by selecting one of four multiple choice foils. For both the circulatory and nervous systems, two equivalent forms were used for the pretest and posttest, and were counterbalanced across participants.

Computerized Materials and Measures

Demographic Questionnaire Participants used a computer to complete the participant questionnaire, which solicited information concerning age, sex, current undergraduate GPA, number and title of undergraduate biology courses completed, and prior experience with biology and the circulatory system.

Self-Regulated Learning Quiz The SRL quiz was a matching task in which participants were required to match 13 student-generated quotes with the corresponding SRL processes. The 13 SRL processes were: content evaluation, feeling of knowing, judgment of learning, goal-directed search, drawing/taking notes, planning, setting subgoals, prior knowledge activation, monitoring progress toward goals, coordination of informational sources, rereading, making inferences, and summarizing (based on Azevedo & Cromley, 2004). For example, when participants read: "I've learned all about the different parts, and now I have 10 minutes left, so I should try and learn about how these parts work together to aid in digestion," they would select monitoring progress toward goals as the correct answer from the word bank at the top of the screen.

MetaTutor MetaTutor is a computer-based learning environment composed of two modules (Azevedo et al., 2013). The MetaTutor training (MTT) module trains participants about the effective use of SRL during the learning of complex science topics. The MetaTutor learning (MTL) module is a hypermedia learning environment that is designed to teach students about the circulatory, digestive, and nervous systems.

MetaTutor Training MTT presented participants in the SRL training condition with declarative and procedural knowledge concerning the effective deployment of SRL (the control condition did not interact with MTT). The underlying assumption of MTT is that students should regulate key cognitive and metacognitive processes in order to learn about complex topics. Gavin the Guide provided procedural messages, while three other pedagogical agents (PAs: Pam the Planner, Mary the Monitor, and Sam the Strategizer) provided instructions intended to build participants' emerging understanding of SRL processes. Pam the Planner instructed participants about three SRL processes related to planning, including setting subgoals, making plans for completing these subgoals, and activating prior knowledge. Mary the Monitor instructed learners about metacognitive monitoring processes, such as content evaluation, feelings of knowing, and judgments of learning. Sam the Strategizer taught learning strategies, such as summarizing and taking notes.

The MTT interface included the following elements: (1) one of the four PAs in the top-left corner of the screen, (2) a running textual dialogue history, (3) audio streaming of PAs' voices presented through headphones, (4) a video display that presented digitized video clips of other students deploying SRL processes while learning with a computer, and (5) radio buttons and textboxes for participants' responses.

The MTT module provided participants with definitions of 13 SRL processes and procedural knowledge of the most effective means of and conditions for deploying these processes. The training for each SRL process followed a three-step procedure: (1) definition of the processes and explanation of procedures for deployment, (2) discrimination task, and (3) recognition task. After the module presented the definition and procedures for each SRL process, a discrimination task required participants to view a good example video and a poor example video of the SRL process being deployed by a learner, and then accurately discriminate the good example from the bad example. For this task, a good example video showed a student appropriately using an SRL strategy, and a bad example video showed a student inappropriately using an SRL strategy. During the discrimination task, the PAs in MTT assessed participants' understanding of SRL by presenting simple, closed-response questions (e.g., *Do you understand why this is a good example of the SRL activity you just learned about?*), and more-complex, open-ended questions (e.g., *In the textbox below, explain why you think this is a poor example of the SRL activity you just learned about*). A recognition task required participants to watch two 4-minute videos of a student learning to deploy various SRL processes during hypermedia learning. For this task, participants were asked to pause the video when they recognized the deployment of an SRL process and identify the process by selecting it from a list of 13 items. If participants correctly identified the SRL process, they were given positive feedback and prompted to proceed to the next process. If they incorrectly identified an SRL process (e.g., they indicated that the student in the video used content evaluation, when the student actually used a judgment of learning), they were prompted to review that segment of the video and try again. Participants who did not accurately identify the SRL process after three attempts were given the correct answer and instructed to continue to the next process. The overall purpose of the MTT training module was to develop participants' understanding of the use of effective SRL processes that can lead to increased learning of complex science topics, such as human body systems.

MetaTutor Learning MTL is a nonlinear, self-paced hypermedia learning environment that was designed to teach students about human body systems, such as the circulatory, digestive, and nervous systems. For the circulatory system, the MTL environment consisted of 41 pages of text with a total of 7,288 words (M = 177.76 words per page). The digestive system consisted of 34 pages of text with a total of 7,661 words (M = 225.32 words per page), and the nervous system consisted of 37 pages of text with a total of 6,949 words (M = 187.81 words per page). Each page of text within the circulatory, digestive, and nervous systems contained one corresponding static diagram, and the Flesch–Kincaid readability scores for each body system were 9.9, 11.4, and 12.2, respectively. The MTL environment included a pane for each of the following key elements designed to assist all participants in regulating their learning: (1) An overall learning goal remained at the top of the screen for the entire learning session with the intention of aiding all participants in creating *subgoals* and *monitoring progress toward goals*. (2) A timer in the top-left corner counted down from 60 minutes to allow participants to *monitor time*. (3) A table of contents with headings and subheadings of each key topic was located on the left side of the screen to allow participants to *preview* and *evaluate content*. (4) Instructional materials of each body system with text and static diagrams were shown side-by-side in the middle of the screen to promote *coordination of informational sources*. (5) Navigational buttons were located on the left of the screen, which participants could use to navigate linearly by clicking the *previous* and *next* buttons, or nonlinearly by clicking on headings and subheadings from the table of contents.

Images were not automatically displayed in the pictorial representation pane; participants had to opt to open the image by clicking on a thumbnail below the pane. Because MTL could be used linearly or nonlinearly and was self-paced, participants had the freedom to make decisions regarding the order in which they read the pages, which images they inspected, and how much time they spent on any given page. MTL tracked the following four learner interactions: (1) navigational path (linear vs. nonlinear, revisits to previously opened pages, skipping pages); (2) time spent on each page; (3) whether the image on a page was opened (by clicking the thumbnail below the content); and (4) time spent inspecting the image (if the image was opened). The system logged every action taken by the participant in a log-file. These log-files were uploaded to a database for later data mining on participant interactions within MetaTutor.

Apparatus

All participants used MetaTutor on a desktop PC with a 17-in. color monitor. Participants' concurrent think-aloud protocols (Azevedo & Cromley, 2004) and nonverbal behaviors, such as body posture, gestures, and note taking, were captured using a digital video camera and digital microphone. All procedural instructions and instructional messages from the PAs were delivered through headphones worn by participants, and were also displayed visually in the dialogue history box on the interface. A digital stopwatch was used to monitor participants' time spent on various paper-and-pencil materials.

Experimental Procedure

This study involved a 5-day experiment in which participants learned about several complex human body systems. Days 1–4 were completed within a 1-week span. Day 5 occurred 3 weeks after Day 4 was finished to determine if participants in the training condition retained the SRL training they had received and could transfer their knowledge to a new learning task. Because we used a concurrent think-aloud protocol during this experiment, all participants were tested individually.

Day 1 On Day 1 of the experiment, participants were randomly assigned to one of two MetaTutor conditions (SRL training vs. control). All participants completed several self-report measures and a pretest of the nervous and digestive systems.

Day 2: SRL Training Condition On Day 2, participants in the SRL training condition spent approximately 1 hour learning declarative and procedural knowledge about SRL processes using MTT. When the session began, Gavin the Guide instructed participants that they would be using MTT to learn about 13 SRL processes.

Day 2: Control Condition Participants in the control condition, rather than receiving the SRL training, spent 1 hour using MTL to learn about the human digestive system. First, participants watched a 2-minute video that described how to engage in a think-aloud protocol. After watching this video, participants viewed a 2-minute MTL tutorial video that modeled the use of MTL, including navigating through the learning environment, using the table of contents, clicking thumbnails to enlarge images, and using the embedded timer to monitor how much time was left in the session. Learners were then provided instructions for the learning task and began the 60-minute learning session. All verbalizations and behaviors were video- and audio-recorded for later coding.

Day 3: SRL Training Condition On Day 3, participants in the SRL training condition spent approximately 30 minutes completing their SRL training with MTT. This portion of training included the recognition task described in the MetaTutor Training section.

Day 3: Control Condition On Day 3, participants in the control condition spent 30 minutes using MTL to continue learning about the digestive system. They were instructed to engage in the think-aloud protocol as they did on Day 2, and the learning goal for this session was identical to the goal on Day 2. Video and audio recording devices logged all verbalizations, and MTL recorded all interactions between the participant and the system.

Day 4: SRL Training and Control Conditions On Day 4, all participants used MTL to learn about the circulatory system. Before the learning session began, all participants received instructions for the session. Participants in the SRL training condition watched the think-aloud and MTL tutorial videos that the control condition had already viewed on Day 2. Because the control condition already viewed these instructional videos and had two sessions of practice using the think-aloud protocol and the MTT environment, they did not view the videos again on Day 4. All participants received instructions for the learning task, after which they began the 60-minute learning task.

During the learning session, concurrent think-aloud protocols were collected for each participant for subsequent transcribing and coding of SRL processes used during learning. All interactions within the environment (i.e., navigational patterns through the content, time spent reading a page of content, opening images, and time spent examining images) were collected and recorded with MTL. Following the learning session, participants were given 20 minutes to complete a posttest about the circulatory system. Upon completion of the posttest, all participants used the computer to complete an identical version of the 13-item SRL quiz that they took on Day 1 of the experiment. The rationale for including this measure at the end of the experiment was to determine whether participants in the SRL condition demonstrated increased understanding of SRL processes from Day 1 to Day 4 (i.e., following exposure to the computerized SRL training).

Day 5 The final day of this 5-day experiment took place 3 weeks after Day 4. All participants used MTL to learn about the human nervous system. Instructions and procedures were identical to those on Day 4. After completing the 1-hour learning session, participants were given 20 minutes to complete a posttest about the nervous system. When the posttest was complete, all participants used the computer to complete the same 13-item SRL quiz that they took on Days 1 and 4.

Coding and Scoring of Data

In this section, we describe the scoring of participants' responses for the matching, labeling, and multiple choice tasks for the circulatory and nervous systems pretest and posttest, and for the SRL quiz pretest and posttest (product data). We also describe the coding of participants' verbalizations while learning about human body systems (process data).

Product Data The product data for this experiment included a 3-component pretest and posttest for the circulatory and nervous systems, as well as a 13-item SRL quiz. Items on the pretest and posttest for the circulatory system were scored on a 0 to 1 scale, where participants were awarded 0 points for each incorrect or blank answer and 1 point for each correct answer. The three components of the pretest and posttest were the labeling task (range 0 to 7), the matching task (range 0 to 7), and the multiple choice task (range 0 to 12). Participants received four total scores, including an overall score for all items across all three components (range 0 to 26), and one score for each individual component. The nervous system pretest and posttest were scored on an identical scale. The SRL quiz was scored by awarding 0 points for each incorrect match and 1 point for each correct match (range 0 to 13).

Process Data The raw data collected from this study consisted of 7,080 minutes (118 hours) of audio- and video-recordings from 60 participants who gave extensive verbalizations while they learned about the circulatory and nervous systems. During the first phase of data analysis, several trained graduate and undergraduate students transcribed the think-aloud protocols from the videotapes and created a text file for each participant. This phase of the data analysis for Day 4 (circulatory system) yielded a corpus of 1,640 double-spaced pages (M = 27.3 pages per participant) with a total of 402,435 words (M = 6,707.3 words per participant). Data analysis for Day 5 (nervous system) yielded a corpus of 1,660 double-spaced pages (M = 27.7 pages per participant) with a total of 386,903 words (M = 6,448.4 words per participant). These data were used to assess participants' use of SRL processes.

SRL Process Data We used Azevedo and colleagues' (2004, 2009, 2013) coding scheme to analyze participants' SRL behavior during learning with hypermedia. The coding scheme is based on several recent models of SRL (e.g., Winne & Azevedo, 2014). It includes key elements of self-regulation as a 4-phase process, and extends these key elements to capture a total of 28 different self-regulatory variables used to regulate students' learning of complex science topics with hypermedia. Briefly, the coding scheme includes the following variables: (a) *planning processes*, including planning, setting subgoals, activating prior knowledge, recycling goals in working memory, and planning time and effort; (b) *monitoring processes*, including feeling of knowing, judgment of learning, monitoring progress toward goals, content evaluation, identifying the adequacy of information, self-testing, monitoring the use of strategies, and time monitoring; and (c) *learning strategies*, including coordinating informational sources, drawing and taking notes, making inferences, elaborating knowledge, memorizing, using mnemonics, previewing headings and subheadings, reading notes, rereading the content, and summarizing.

Interrater Agreement To establish interrater agreement, a second trained researcher independently coded each transcript. For Day 4, there was agreement on 3,696 out of 3,810 coded verbalizations, yielding an interrater agreement of 97.0%. For Day 5, there was agreement on 3,305 out of 3,470 verbalizations, yielding an interrater agreement of 95.2%. Inconsistencies were resolved through discussion between the two raters.

Results

Question 1: Does SRL Training Delivered by MetaTutor Lead to Increased Learning?

To answer this question, we conducted two separate analyses of covariance (ANCOVAs) to determine if the SRL and control conditions achieved significantly different scores on the posttest on Days 4 and 5. For these analyses, we used posttest scores from Days 4 and 5 as dependent variables, pretest scores from Day 1 as a covariate, and condition as a fixed factor. See Table 1 for means, standard errors, and effect sizes for all learning outcome measures.

Table 1: Adjusted Marginal Means (Standard Errors) for the Labeling, Matching, and Multiple Choice Posttest Learning Measures, and SRL Quiz on Day 4 and Day 5 by Condition

	Condition		
	SRL Training (n = 30)	Control (n = 30)	
Posttest Task	*Mean (SE)*	*Mean (SE)*	Effect Size $\eta^{2(\partial)}$
Day 4 Labeling	36.5% (5.4%)	51.1% (5.4%)	0.06
Day 4 Matching	76.9% (4.8)	90.7% (4.8)	0.07*
Day 4 Multiple Choice	65.1% (3.2%)	72.4% (3.2%)	0.04
Day 5 Labeling	22.4% (4.0%)	32.4% (4.0%)	0.05
Day 5 Matching	62.9% (4.7%)	65.2% (4.7%)	0.00
Day 5 Multiple Choice	55.1% (3.2)	59.1% (3.2)	0.01
Day 4 SRL Quiz	65.6% (0.3)	45.1% (0.1)	0.20**
Day 5 SRL Quiz	69.2% (0.2)	50.5% (0.2)	0.19**

Note. * $p < .05$. ** $p < .001$.

Day 4: Circulatory System An ANCOVA on the posttest scores for Day 4, using pretest scores as a covariate, failed to find a significant difference between the SRL training and control conditions for the *labeling* task, $F(1, 57) = 3.66$, $MSE = .04$, $p = .06$, and the *multiple choice* task, $F(1, 57) = 2.58$, $MSE = .02$, $p = .11$. However, there was a significant difference between conditions on the *matching* task, $F(1, 57) = 4.12$, $MSE = .03$, $p = .05$, $\eta^{2(\partial)} = .07$. Specifically, the mean adjusted posttest scores for the control condition were significantly greater than posttest scores for the SRL training condition (see Table 1).

Day 5: Nervous System An ANCOVA conducted on posttest scores for Day 5, using pretest as a covariate, failed to find significant differences between the SRL training and control conditions for the *labeling*, $F(1, 57) = 3.10$, $MSE = .03$, $p = .08$; *matching*, $F(1, 57) = 0.12$, $MSE = .03$, $p = .73$; or *multiple choice* tasks, $F(1, 57) = .79$, $MSE = .03$, $p = .38$.

Question 2: Does SRL Training with MetaTutor Significantly Improve Participants' Understanding of SRL Processes?

To answer this question, we conducted a separate ANCOVA for Days 4 and 5 to determine if there were significant differences in posttest scores on the SRL quiz on both days between conditions (SRL training vs. control). For these analyses, we used posttest SRL quiz scores from Days 4 and 5 as dependent variables, pretest scores from the SRL quiz (completed on Day 1) as a covariate, and condition as a fixed factor. The purpose of conducting this analysis was to determine: (1) if participants in the training condition scored significantly higher than the control condition immediately after receiving SRL training, and (2) if participants in the SRL training condition retained this knowledge and outperformed the control condition 3 weeks after they received training. These analyses indicated that participants in the SRL training condition scored significantly higher on the SRL posttest on both Day 4, $F(1, 57) = 18.17$, $MSE = .03$, $p < .001$, $\eta^{2(\partial)} = .24$, and Day 5, $F(1, 57) = 15.37$, $MSE = .03$, $p < .001$, $\eta^{2(\partial)} = .21$ (see Table 1).

Question 3: Do Participants Use SRL Processes Differentially on Days 4 and 5 between Conditions?

To more fully examine participants' deployment of SRL at the *class* level, a separate 2 × 3 repeated measures analysis of variance (RM-ANOVA) was conducted for each of the three SRL classes (planning, monitoring, and learning strategies) to determine whether there were significant differences in participants' deployment of these classes on Days 4 and 5 between conditions (SRL training vs. control). For this analysis, *condition* was a between-subjects factor, and *day* was a within-subjects factor.

For *planning*, the results showed a significant main effect for day, $F(1, 58) = 6.20$, $p < .05$, $\eta^{2(\partial)} = .10$; a significant main effect for condition, $F(1, 58) = 10.11$, $p < .01$, $\partial\eta^2 = .15$; and a significant interaction between day and condition, $F(1, 58) = 6.20$, $p < .05$, $\eta^{2(\partial)} = .10$. Post hoc analyses revealed that participants, overall, deployed more planning processes on Day 4 than Day 5. Additionally, participants in the training condition, overall, deployed more planning processes than those in the control condition.

For *monitoring*, the results showed a significant main effect for day, $F(1, 58) = 15.35$, $p < .001$, $\eta^{2(\partial)} = .21$, and a significant main effect for condition, $F(1, 58) = 7.35$, $p < .01$, $\eta^{2(\partial)} = .11$. There was no significant interaction between day and condition. Similar to *planning*, post hoc analyses revealed that participants in the SRL training condition, overall, deployed significantly more *monitoring* processes on Day 4 than Day 5. The SRL training condition, overall, deployed more monitoring processes than the control condition.

For *learning strategies*, we found a significant main effect for day, $F(1, 58) = 30.06$, $p < .001$, $\eta^{2(\partial)} = .34$; a significant main effect for condition, $F(1, 58) = 3.99$, $p = .05$, $\eta^{2(\partial)} = .06$; and a significant interaction between day and condition,

$F(1, 58) = 7.58$, $p < .01$, $\eta^{2(\partial)} = .12$. Post hoc analyses revealed that participants in the SRL training condition deployed significantly more learning strategies on Day 4 than Day 5. The SRL training condition deployed significantly more learning strategies than the control condition on Day 4. However, the two conditions did not differ significantly in their deployment of learning strategies on Day 5 ($p > .05$).

Discussion

With regard to the first research question, the results of this study show that learners in both conditions failed to significantly outperform each other on several learning outcome measures. This finding is not consistent with previous research, indicating that learners trained to regulate aspects of their learning have demonstrated significant learning gains in a variety of domains and tasks (e.g., Azevedo & Cromley, 2004). Our results run counter to the fundamental assumption that training, aimed at acquiring, using, and transferring SRL knowledge and skills students need to regulate the complex SRL processes and mechanisms, leads to superior learning gains during learning with hypermedia.

With regard to the second research question, our results show that those in the training condition were able to significantly retain the declarative knowledge related to cognitive and metacognitive SRL processes. The results also illustrate that students are capable of enacting key cognitive and metacognitive SRL strategies immediately following training, but not after a prolonged period. The findings highlight a key feature of SRL training—that is, acquiring and transferring procedural and conditional knowledge and skills requires extensive training (Veenman, 2014). These results raise several key questions—that is, what is the optimal amount of time needed for training on each phase (e.g., declarative vs. conditional knowledge), what are differences between availability versus production deficiencies associated with the enactment of SRL skills, and what is a more effective approach to training than the typical "one-size-fits-all."

With regard to the third research question, our extensive think-aloud protocols indicated that learners in the SRL training condition more frequently deployed planning, monitoring, and learning SRL processes that taught them to effectively regulate their learning with hypermedia. However, the increased use of SRL processes was only observed during Day 4, and not on Day 5. In fact, evidence shows that those in the training condition deployed equal numbers of SRL processes on Day 5 (i.e., following a 3-week interval) as those in the control condition. This finding challenges published findings in several ways: (1) it is the only study thus far to provide think-aloud data on task performance immediately following training and following a 3-week interval; (2) it provides evidence that lack of practice (during the 3-week interval) using SRL processes leads to SRL deployment frequency rates similar to the control condition; and (3) it challenges the assumption that increased frequency of use of SRL processes is directly related to increases in learning gains.

Understanding the acquisition, retention, use, and transfer of SRL skills is key to enhancing comprehension in science learning. The use of ALTs remains a key tool in training students to effectively enhance these skills (Azevedo & Aleven, 2013). However, the results raise issues regarding the sequencing, type, and duration of training for specific aspects of metacognition (e.g., declarative and conditional knowledge, procedural skills). Therefore, we argue that future SRL training with ALTs may require individualized, adaptive training regiments that are catered to each learner's individual needs—for example, more time on conditional knowledge than declarative knowledge, modeling subtle differences between sophisticated strategies, such as making inferences versus hypothesizing, using pedagogical agents to model optimal gaze behavior patterns related to monitoring one's comprehension of a diagram.

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