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Shallow strategy development in a teachable agent environment designed to support self-regulated learning

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A B S T R A C T

To support self-regulated learning (SRL), computer-based learning environments (CBLEs) are often designed to be open-ended and multidimensional. These systems incorporate diverse features that allow students to enact and reveal their SRL strategies via the choices they make. However, research shows that students' use of such features is limited; students often neglect SRL-supportive tools in CBLEs. In this study, we examined middle school students' feature use and strategy development over time using a teachable agent system called Betty's Brain. Students learned about climate change and thermoregulation in two units spanning several weeks. Learning was assessed using a pretest–posttest design, and students' interactions with the system were logged. Results indicated that use of SRL-supportive tools was positively correlated with learning outcomes. However, promising strategy patterns weakened over time due to *shallow strategy development*, which also negatively impacted the efficacy of the system. Although students seemed to acquire one beneficial strategy, they did so at the cost of other beneficial strategies. Understanding this phenomenon may be a key avenue for future research on SRL-supportive CBLEs. We consider two hypotheses for explaining and perhaps reducing shallow strategy development: a student-centered hypothesis related to "gaming the system," and a design-centered hypothesis regarding how students are scaffolded via the system.

1. Introduction

Self-regulated learning (SRL) is a crucial factor in academic success (Boekaertz, Pintrich, & Zeidner, 2005) and computer-based learning environments (CBLEs) are being developed to support SRL skills (Winters, Greene, & Costich, 2008). However, the complex nature of self-regulation poses a challenge for CBLE designers. Although terminology and details vary across specific SRL models, most models describe multiple and recursive stages incorporating cognitive and metacognitive strategies (Butler & Winne, 1995; Greene & Azevedo, 2007; Pintrich, 2004; Schraw, Crippen, & Hartley, 2006; Zimmerman & Schunk, 2001). In a *planning stage*, self-regulated learners may begin by metacognitively analyzing the learning task, setting goals, and seeking out necessary background information. In this phase, learners determine what needs to be learned or accomplished and decide how best to achieve those aims. Subsequently, in an *enactment* or *learning phase*, learners employ their chosen strategies to learn, solve problems, and complete the tasks at hand. The most effective cognitive strategies tend to be "active, constructive, and interactive" (Chi, 2009), involving the integration of new and prior knowledge or the development of ideas through inference and reasoning. Finally, in a *monitoring* or *self-assessment phase*, learners may metacognitively evaluate their errors and comprehension, and then use these evaluations to alter their goals and strategies. Importantly, these phases are interactive and recursive. For example, learners' chosen goals can constrain their strategy selection and evaluation criteria, and learners' self-assessments may cause them to refine or abandon their current goals or strategies.

To measure and support students' engagement in these complex processes, CBLEs often provide students with numerous choices for completing their learning tasks. Many CBLEs are multidimensional and incorporate diverse features (Winters et al., 2008) and potential

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solutions (Waalkens, Aleven, & Taatgen, 2013), and students enact or reveal their SRL strategies through the decisions they make (Azevedo, Witherspoon, Chauncey, Burkett, & Fike, 2009). How do students make use of such features and develop within feature-rich environments? SRL skills might improve as students practice the strategies afforded by the CBLE, but students can also neglect these features (Land, 2000; Narciss, Proske, & Koerndle, 2007). That is, SRL-supportive CBLEs may offer many *opportunities* for learning, but students may not take advantage of these opportunities (Quintana et al., 2004). Indeed, evidence shows that SRL-based CBLEs can improve student learning in math (e.g., Kramarski & Gutman, 2006), reading (e.g., McNamara, O'Reilly, Best, & Ozuru, 2006), and science (e.g., Biswas, Leelawong, Schwartz, & Vye, 2005; White, Shimoda, & Frederiksen, 1999). However, less research has directly studied students' feature use via trace data, and converging evidence suggests that students often ignore SRL features.

Aleven and Koedinger (2002) examined high school students' use of the Geometry Cognitive Tutor glossary of definitions and examples. Students used the glossary less than 4% of the time on numerical problems and 15% of the time for explanation problems. Similarly, Lust, Vandewaetere, Ceulemans, Elen, and Clarebout (2011) studied undergraduates' use of scaffolding tools built into a content management system. Although a number of scaffolding tools were available, they were only regularly utilized by 55.7% of the students enrolled in the course. Witherspoon, Azevedo, and Cai (2008) studied high school and college students' use of navigation features in MetaTutor. Analyses revealed that successful learners exhibited "balanced" navigation: they moved forward through the text (76%), but accessed prior text (8%) and diagrams (39%) as needed. In contrast, less successful learners focused on a forward linear progression (90%), with minimal back navigation (2%) or image use (3%). Note that many navigation categories were not mutually-exclusive, and thus percentages do not necessarily add to 100%.

Other researchers have examined students' CBLE actions more comprehensively. Muir and Conati (2012) used eye-tracking to analyze hint usage in Prime Climb, an educational game for learning number factorization skills. Findings indicated that fewer than half of the middle school students utilized the hint feature. Further, students fixated on the system's unsolicited hints for an average of about 2 seconds, far less time than would be required to read the hints carefully. Narciss et al. (2007) traced college students' use of text resources, learning tools, elaboration resources, and monitoring tools within Study Desk. Despite rich opportunities, students spent the most time reading the text. Learning (<10%) and elaboration (<6%) tools were used infrequently, with very little note-taking (<.3%), use of experiment simulators (<.5%), or reading of research articles (0%). Use of metacognitive progress reports and learning task reports was less than 2%. Winne and Noel-Jamieson (2002) analyzed undergraduates' use of PrepMate software for planning, note-taking, and reviewing. They found that students set goals but rarely reviewed them, and note-taking consisted of copying the text verbatim. Analogies, examples, and self-questions were uncommon. Surprisingly, this did not match students' self-perceptions. Students believed they were using the strategies. Comparable results were obtained by Hadwin, Nesbit, Jamieson-Noel, Code, and Winne (2007) with students using gStudy. Students narrowly focused on highlighting text, labeling ideas for importance, making lists, and editing the glossary. Students rarely asked questions or disagreed with the material, indicated confusion, or linked their notes to information sources. As above, students' actual behaviors matched their self-perceptions only about 30% of the time.

Overall, students' feature use in SRL-supportive CBLEs appears limited, and students especially seem to neglect features designed to support SRL development. One factor missing from many studies, however, is a comparison of students' feature use over time. It is unclear whether students' usage might improve with time and practice.

1.1. *Betty's Brain: a feature-rich learning environment*

The current study was conducted within a teachable agent system called Betty's Brain (Leelawong & Biswas, 2008; Segedy, Kinnebrew, & Biswas, in press) designed to support students' self-regulated learning and strategy use (see Fig. 1). In Betty's Brain, students learn by reading about scientific phenomena and representing their emerging understanding of the information via *causal concept maps*. The student's goal is to construct a map that matches a hidden, expert causal map of the domain knowledge. Concept mapping (Hilbert & Renkl, 2008; Nesbit & Adesope, 2006; Novak, 1998) involves translating one's knowledge into a verbal–visual representation consisting of concept nodes (e.g., "vegetation" and "oxygen") and relational links (e.g., vegetation "releases" oxygen). Building these maps allows learners to integrate new and prior knowledge as they reorganize their understanding and connect related ideas. Such integration and organization may help students understand how individual concepts (e.g., vegetation and sunlight) cohere within deeper principles (e.g., photosynthesis). The network of causal connections also facilitates inferences. By tracing connections among ideas, students can infer both proximal and distal causal relationships. Finally, students can apply metacognitive processes to detect and repair map errors to improve accuracy and completeness.

To further motivate the construction of students' causal concept maps and promote self-regulation, Betty's Brain activities are embedded within a *teaching narrative*. One of the agents, Betty, is presented as a middle school student close in age and ability to participants. Students "teach" Betty by building a causal map depicting entities (e.g., blood vessels) in a system (e.g., the body) and their cause-and-effect relations. In essence, students are constructing Betty's representation of the domain. A second agent, Mr. Davis, is introduced as the student's mentor who provides advice on how to research topics, connect ideas, and teach and assess Betty. Research on peer tutoring and teaching has shown that students can learn new information and reinforce prior knowledge by teaching a peer and answering questions (King, Staffieri, & Adelgais, 1998; Roscoe & Chi, 2007, 2008). Formulating explanations helps students organize their knowledge, making it more coherent and memorable. Once explanations are verbalized, students can self-monitor to detect contradictions and gaps. Subsequently, knowledge integration processes can be used to enhance the explanations and students' own understanding. Lastly, pupil questions ("Could you explain that again?") can prompt students to reflect on their knowledge and produce better explanations (Roscoe & Chi, 2008). Thus, the teaching narrative provides a familiar and supportive framework for students to set goals and make plans, research and integrate information, and evaluate the correctness and completeness of their efforts.

Betty's Brain is an open-ended learning environment (Land, 2000). Although students are presented with a fixed task (teaching Betty), they are free to choose how to use the various features included in the environment to learn the domain material, build the map, and assess their understanding and map quality. In Betty's Brain, causal concept mapping and the teaching narrative are implemented via features allowing students to search for information, modify their map, and assess the quality of their map. As students work on the Betty's Brain system, they are free to use any of the available tools at any time. Our research questions concern how students use such SRL-supportive features in a CBLE across time, and the impact of feature use on learning and comprehension: