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Learning from the folly of others: Learning to self-correct by monitoring the reasoning of virtual characters in a computer-supported mathematics learning environment

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ABSTRACT

Two studies examined the social basis of self-assessment for learning through the application of creative computer tools that can help students assess and self-correct their own learning. Students are not usually inclined to check their own answers, but they find it relatively motivating to catch other people's mistakes. A total of 62 students, ranging in age from nine to 11, participated in two studies that tested the hypothesis that monitoring "someone" else (i.e., computer character) can help students learn to self-assess their own learning. Two computer-supported learning environments, i.e., "Doodle Math" and "Puzzle Math," were developed as training environments for monitoring. The environments also allowed a direct comparison between self training and self-other training. In the training environment, a computer character, "ProJo," openly displayed its reasoning when solving math problems and allowed children to "look for mistakes." The students in self training solved all the problems on their own, while the students in self-other training worked with the computer character, ProJo, taking turns to solve problems and monitor for any mistakes. The measures on calculation time and accuracy showed that self-other training might be an effective way to help students develop metacognitive skills to self-correct and improve performance in elementary mathematics. The log file tracked the students' progress in various data forms and displayed evidence that self-other training students monitored and self-corrected more than students who experienced self training.

1. Introduction

A critical skill in helping children continue to learn after they leave school is the ability to self-assess the progress of one's learning. This is because students need to be able to "learn for themselves" and make informed decisions in the future. This metacognitive skill of self-assessing and self-correcting also may help students address their difficulties in mathematics at the elementary grade level. Often, students understand the principles and procedures, but they make careless mistakes. These mistakes can range from process problems and precedence errors to substitution and procedural errors, which are common among elementary and middle-school students. Repeating these errors can be quite serious because it often can lead to long-term difficulties with mathematics (Watson, 1980) and the development of a negative perception of math and science (Steele, 2003).

Careless mistakes can easily be avoided if children learn to check their answers. Metacognitive skills to self-assess and self-correct are critical, but teachers have little time to spend on these problems in school, as habit-correcting behavior requires personal attention, time, and consistency on the part of the enforcer (Blando, Kelly, Schneider, & Sleeman, 1989; Wells & Coffey, 2005). One way for children to minimize mistakes and avoid discouragement is to monitor their own thinking and activity. This way, they can catch potential mistakes or avoid confusion. However, the thought of checking their answers may not occur voluntarily in children unless they have developed metacognitive skills to recognize confusion and articulate their reasoning to some degree.

This research examines the hypothesis that children learn to self-monitor by monitoring other people, and with practice, they turn this external monitoring inward. By practicing the metacognitive strategy on others, children develop awareness and proficiency in monitoring,

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and ideally, they turn the external monitoring behavior inward after the behavior becomes natural. One inspiration for this theory was that self-monitoring is cognitively demanding because children confront the dual task of solving and checking problems at the same time. Letting children monitor other people's problem-solving activities may alleviate some of the pressure of the dual demands, because children do not need to fully attend to solving the problem themselves when they are observing others.

The second inspiration for the theory was evidence that children find it relatively easy and motivating to catch other people's mistakes, even if they are not inclined to catch their own. This led to the thinking that monitoring may be easier if practiced on others than on oneself. Children may find it difficult to be attentive to their own mistakes when they are concentrating on a problem or task. However, they may find it relatively easy to catch other people's mistakes (Gelman & Meck, 1983).

The third inspiration was the strength of technology in creating specifiable environments in which the system can simulate the thoughts an individual might use to reason about a situation. This is different from most simulations that depict empirical sequences of actions that resemble the phenomena the system presents (e.g., cellular processes displaying changes over time, continental drift). For example, Chin, Dohmen, and Schwartz (2013) created a series of software environments called 'Teachable Agents' that visually modeled how to reason through causal chains. Monitoring the computer character's reasoning helped students learn relational predicates and recognize gaps in their own understanding (Okita & Schwartz, 2013). The ideal, computer-supported learning environment would be a situation in which students could practice their monitoring skills externally on a computer character that openly solved math problems. Then, students could monitor the computer character's reasoning when solving math problems. Developing monitoring skills on the external plane (e.g., artifacts, agents) may put children in a better position to internalize these skills. This type of support seems ideal in a computer-supported learning environment that can assist students as they practice monitoring and self-correcting.

The research presented here proposes a somewhat self-driven, but social approach. Two studies examined the hypothesis that helping children learn to monitor other people's problem solving can, in turn, help them learn to monitor their own problem solving and learning. In the context of learning, self-monitoring usually depends on self-assessments. Self-other monitoring is a particularly powerful form of self-assessment in which students assess the knowledge of someone else and, implicitly, assess their own knowledge. While the belief was that this work would lead to the improvement of all students, another interest was to create model technologies that demonstrated how to implement conditions that train students in conducting self-assessment and that generate interest in mathematics among elementary school students in underserved communities.

The following sections include an analytical review of the relevant background literature. In the first experiment, a game-like learning environment, "Doodle Math," was developed to allow a direct comparison between self-other training and self training. The second experiment examined self-other training and self training behaviors over a slightly longer intervention. The new game-like environment, "Puzzle Math," consisted of shorter subtasks to make the reasoning process more explicit for students to monitor and to add a detection feature that recorded the students' self-correcting behaviors. In both studies, the computer character, "ProJo," was designed to openly display its reasoning when solving math problems, allowing children to "check for mistakes."

2. Background

One question that inspired this research was whether the thought of monitoring occurs automatically or whether it is a metacognitive skill that must be learned. The literature addressed different ways in which children learned to monitor and indicated that children might find it relatively easy to catch other people's mistakes, even if they were not inclined to catch their own. This led to the concept that monitoring might be easier if practiced on others' mistakes rather than on one's own mistakes. The section includes background literature on (a) why the dual task of problem solving and monitoring may be difficult for children due to the intuitive and analytical modes of thinking in elementary mathematics, (b) different ways children learn to develop metacognitive monitoring skills in peer learning, and (c) the strength of computer-supported learning environments for practicing monitoring skills.

2.1. Intuitive and analytical modes of thinking and problem solving in elementary mathematics

In the domain of mathematics education, Stanovich and West (2003) found that students were easily susceptible to distractions and irrelevant external cues when solving simple mathematics problems. Gilovich, Griffin, and Kahneman (2002) examined the dual-process theory as a unified framework for explaining people's decision-making and problem-solving behaviors and for explaining the reasons behind responses that contradict the norm (Stanovich & West, 2000, 2003). Dual-process theory (Kahneman, 2002) involves cognition and behavior, operating in parallel in two different modes. Kahneman identified the modes as two different types of cognitive processes, i.e., intuition (referred to as System 1) and reasoning (referred to as System 2). The operations of System 1 (S1) are fast, automatic, usually based on habit, and difficult to control or modify. The operations of System 2 (S2) monitor mental operations that usually involve rule-governed conscious judgments (Stanovich & West, 2000). Usually, S1 and S2 work together, but there are situations in which S1 produces quick, automatic, non-normative responses, while S2 may or may not intervene as the monitor or critic. According to Leron and Hazzan (2006), S1 and S2 in dual-process theory have strong similarities that correspond to intuitive and analytical modes of thinking relevant to mathematical problem solving. The two systems differ mainly with regard to accessibility and how fast and how easily things come to mind. Different nuances exist in dual-process theory, but the work here is focused mainly on the generic framework by Kahneman (2002), Stanovich and West (2000), and Leron and Hazzan (2006), which applies well to the area of mathematics education.

Kahneman (2002) found that both S1 and S2 are prone to errors under complex and abstract conditions, and that S1 can be distracted by irrelevant external clues. Kahneman gave a striking example in elementary mathematics of how S1 can generate a cognitive illusion that overrides the usual analytical reasoning of S2 in people who understand the concept but give fast, reactive responses without thinking. Kahneman found that, when college students were asked to solve this problem: *A baseball bat and ball together cost $1.10. The bat costs one dollar more than the ball. How much does the ball cost?*, they showed an initial tendency to answer 10 cents, because the sum $1.10 could easily separate into $1 and 10 cents, and 10 cents sounded right. Kahneman mentioned that the description of the problem and the rough approximation that sounds "about right" causes S1 to jump to the answer of 10 cents. The result showed that people yielded to this immediate impulse, and under certain circumstances, ignored relevant facts for the sake of immediacy (or competence). This explanation was