Monitoring Sokoban Problem Solving: What a Case Study Implies for Metacognitive Support for Game-based Problem Solving?

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Abstract

This case study analyzes the cognitive process underlying a teenager's Sokoban problem solving within the framework of major learning theories. The effects of metacognitive inquiries and self-correction on latency in completing the game were examined. A major finding was that the gamer employed both forward- and backward-working strategies and tended to use a start-all-over-again strategy when faced with an impasse. Implications that support a game-based problem solving approach were also discussed.

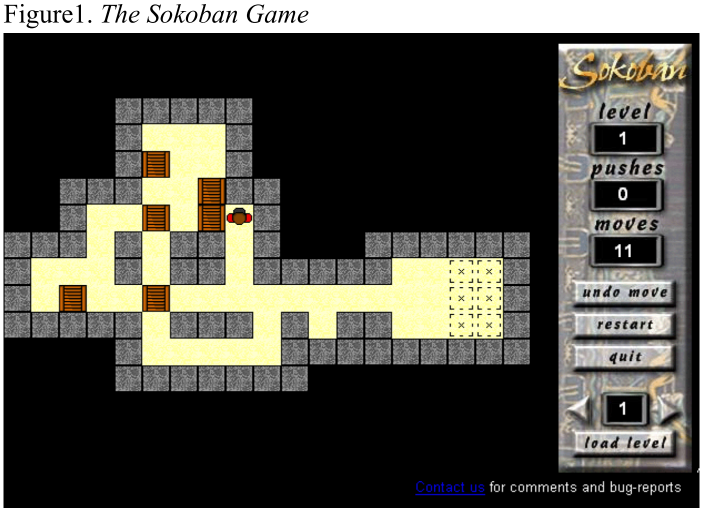
Introduction

What goes on a gamer's mind working on a play?

Game-playing was suggested to enhance young learners' critical thinking and problem-solving skills (Katz, 2000; Prensky, 2000). Over the past years, a great deal of attention has been paid to games as a powerful learning mechanism which goes beyond just a delivery context of content (Squire, 2005). However, there appears to be lack of research focusing on how game-playing boosts learners' critical thinking or problem solving skills. From a pedagogical perspective, it is critical to understand how learning occurs while young learners are engaged in problem solving given in a context of game play in order to provide them more timely and effective support for their learning. Consequently, the knowledge gained through studies about young learners' thinking via game play over a computer may allow us to anticipate potential obstacles that individuals may face in the problem solving process, thus making it possible to prescribe timely support for solving such problems.

Moreover, game-playing in a computerized setting is likely to demand different cognitive and metacognitive controls from the conventional, paper-pencil, problem solving approaches. Tracing a learner's thinking as well as learning processes in a computer game format of problem solving may disclose many unique aspects of cognition. From such a viewpoint, this study was intended to examine a 13-year-old boy's Sokoban computer game playing. The focus was on following the participant's flow of thinking while he was working on the game.

Figure1. *The Sokoban Game*



In Sokoban, a player acts as a person who must push a number of crates through passageways to a final destination area. The goal is to use minimum number of pushes. The player can only push one single crate at a time in one direction, and is not able to pull crates. The gamer can use Undo and Restart buttons when desired. Inevitably, the player faces an impasse; there is no way out. The game has a total of 20 levels, each level has an ascending level of complexity. Given the design and rules required, Sokoban provides an ideal training context for self-directed problem solving. Sokoban is available for free at www.pimpernel.com/sokoban/sokoban.html.

Studies have shown that a learner's metacognitive and adaptive self-correction of cognitive strategies enhance self-regulated learning (Butler & Winne, 1995; Zimmerman, 1989, 1994). Based on this idea, this study also examined how the learner's guided metacognitive visualizing of his own thinking process impacted his learning process. Metacognitive visualization referred to encouraging a learner to externalize orally and graphically his/her use of strategies or rules which led to either a success or failure and adaptively providing corrective feedback. This process was believed to aid the participant's self-regulated monitoring of his learning process. Implications for support of young learners' developing problem solving ability in a game-based learning environment were also explored.

Theoretical framework

Problem Solving Stages

Problem solving generally undergoes the following four stages: representation of the problem, searching the problem space, evaluation of the solution, and application (Gagne, Yekovich, & Yekovich, 1993). Problem representation in the first stage includes defining the problem and exploring the required conditions of the given problem. Searching the problem space, the second stage, refers to exploring the ways that lead to a solution to the problem. In this stage, the problem solver may attempt to find a clue for the solution by trying to recall prior experiences of problem solving that were similar to, or associated to some extent with, the current problem. In the evaluation stage, the problem solver judges a hypothesized solution to the criterion of the goal or solution. The problem solver will also evaluate whether the required conditions are met by the solution he hypothesizes. In the application stage, the problem solver applies prior learning to a novel situation of problem solving. Although problem solving is generally described as a sequence of stages, problem solving would not necessarily always occur in the same sequence(Gagne, Yekovich, & Yekovich, 1993). It is assumed that a problem solver working on Sokoban goes through all stages of problem solving but the sequence would not be linear.

Procedural Knowledge Processing

Cognitive psychologists claim that the goal and sub-goal relations among productions (If-Then) promote the control of cognitive flow from one production to another within a given production system (Gagne, Yekovich, & Yekovich, 1993).

It appears to be almost impossible to get direct observation on how a person processes procedural knowledge based on any data obtained from the traditional paper-pencil assessment tools. In a problem solving scenario utilizing a game format, if the interaction process between the problem solver and a problem is recorded, the building process of procedural knowledge can be examined. In addition, the problem structure of the game may demand multiple layers of goal setting and decision making through the course of exploring a solution. The learner will not only attempt to recall the existing procedural knowledge to relate to the current problem but also create procedural knowledge that serves to identify a solution to the novel problem. In this analysis, the focus was the examination of the ways in which the gamer formulated goals and sub-goals during the game-play. Considering that Sokoban problem solving does not provide a specific goal state, the process of goal setting and goal-directed decision making are totally at the player's discretion.

Problem Solving Strategies

There are general strategies to guide exploring a solution in problem solving such as trial and error, means-ends analysis, and reasoning by analogy. Recent research findings have suggested that domain-specific strategies are also crucial for success in problem solving. Domain-specific knowledge helps construct a schema that "allows problem solvers to recognize a problem state as belonging to a particular category of problem states that normally requires particular moves" (Sweller, 1988, p. 259). Thus, possessing sophisticated schemas is an essential criterion on which an expert is distinguished from a non-expert. According to Sweller (1988), experts tend to employ more forward-working strategies than back-ward working (means-ends) strategies, which is attributable to their well-established knowledge structure in the form of schemas.

Sweller and Levine (1982) found that non-specific goals permitted more rapid learning of essential structural characteristics than providing a conventional goal. It was argued that in the conventional goal-directed learning settings the students had difficulty inducing the relevant rule without implicit or explicit additional information provided. According to Sweller (1988), learners use heuristics, such as means-ends strategies, in conventional goal-directed learning settings. The use of heuristics, consequently, interferes with "learning essential aspects of a problem's structure" (p. 4). Sweller also empirically showed that problem solving with a specific goal demands relatively large amounts of cognitive resources, thus resulting in additional expenditures of cognitive processing capacity required for constructing schemas.

From Sweller's perspective, a Sokoban problem solver was expected to discover both goals and methods for the play, relying mostly on a forward-working strategy because Sokoban does not have any specific goal statement. Considering that the participant in this study was new to Sokoban problem solving, he was anticipated to work forward without being controlled by a schema, simply exploring the problem space in order to see what moves were possible. (Sweller, 1988).

Learners' uses of cognitive strategies are likely to be influenced by the structure of a problem as well. Sokoban has a unique problem, structure and context; it has simple game rules and is played on a computer screen. As a computer game, Sokoban has a feature that the conventional paper-pencil problem solving does not have. In Sokoban a move made acts as a quick, visual clue for the following moves. For example, a wrong move would cause immediate, negative feedback to the problem solver because the wrong move inhibits any further action, which can inform the problem solver that his action intended was wrong. Sokoban is designed so that the problem solver inevitably arrives at many dead-ends. In this study it is also of interest to see what kinds of strategies benefit the gamer when put in no-way-out situations.

Metacogniton and Metacognitive Visualizing

According to Flavell (1979), metacognition is "knowledge and cognition about cognitive phenomenon"(p. 906) and involves deliberate, intentional, and goal-directed mental operations. Metacognition comprises two related aspects: understanding what kind of skills, strategies, and resources a task requires and knowing how and when to use the skills or strategies to ensure the task is successfully completed (Schunk, 2004). Studies indicate that regulatory strategies to accomplish specific learning goals are positively related to self-regulating ability (e.g. Printrich, 2000; Zimmerman, 2000; Schunk, 2001).

Problem solving such as Sokoban requires a relatively high level of self-regulated ability in monitoring progress, predicting outcomes, and evaluating the effectiveness of strategies or skills. Thus it was considered that through scaffolding, the participant visualizes ways to regulate the learning process or uses cognitive strategies to enhance his self-regulated problem solving skills.

Method

Participant

The participant in this case study was a 13-year-old boy. From prior conversation with the participant, he indicated that his weekly computer game playing totaled approximately five hours per week, mostly for entertainment purposes. The participant reported that he has never played Sokoban prior to his participation in this study. When he was questioned about other activities with his computer, he responded that he also uses his computer to complete homework assignments and class projects several times per week. Based on this information, it was regarded that the participant was relatively familiar with playing computer games, mostly entertainment types of games, and had fair experience in using a computer for his academic work.

About the Method

For the analysis of the thinking process of playing Sokoban, the classical 'thinking aloud' approach was used along with video- recorded monitoring. In applying these methods, the participant was asked to state aloud whatever ideas came to mind while playing the game.

The traditional method of 'thinking aloud' has a distinct advantage in that it allows researchers to obtain information not only about the final result of problem solving but also about the learner's thinking process which underlies the game playing. However this method has a limitation in that it demands dual cognitive duties from the participant. The participant has to work on the problem while simultaneously recalling from his memory what he has done in order to describe it orally. During this process, it's probable that the limited capacity of our short-term memory would not allow the participants to remember all ideas or thoughts that would come up while interacting with a problem.

However this limitation of the 'think aloud' method can be canceled out if the overall performance of the game player is recorded. On top of that, an audio-visual recording of the overall process of problem solving would be useful for timely locating the very points over the course of problem solving where the gamer is in need of any cognitive support. The computer screen and the learner's voice while playing were recorded. The recorded voice was transcribed for analysis.

Procedure

Two rounds of game plays were conducted. In order to examine the effects of scaffolding metacognitive visualization and guided self-correction of misconception or inefficient use of skills, the participant was intervened after the first session of game-playing. In the initial play, the player was directed to state aloud whatever ideas or thoughts come up with while playing. There was no restriction to the number of game levels that the participant can attempt up to a maximum of 20 levels. On the following day, the participant engaged in the second play.

Prior to the second game-plying, the participant was guided to visualize his thinking based on the recording of the initial game-playing and accordingly asked to self-correct misconceptions or inefficient use of strategies. The participant reviewed his recorded game-playing from the previous day, and was asked to respond to the following question: "Tell me some rules or strategies that you found useful for the game from the previous play". This question was intended to allow the learner to recall any conditional knowledge that he learned from the prior game-playing. It was assumed that answering this question would be possible when the participant figured out what conditions signify a success or a failure.

Then, the participant was also asked to illustrate patterns that might lead to a dead end, which was intended to help the learner regulate his own use of conditional knowledge to solve the problem. He was then asked to draw the patterns that led to a dead end in the previous play. Next, the researcher and the participant went back to the Sokoban screen and the participant was asked to make up situations that might be problematic. Finally, the participant was questioned as to why the situations that he created were puzzling to him. This question was intended to allow the participant to probe any misconceptions and use of inefficient strategies. In response to the answers from the participant, the researcher manipulated a few examples and non-examples of solution paths over the computer.

The second session of play was carried out in a condition identical to the initial play session with the exception of allowing an upper cap of the fourth level in order to equate the number of levels attempted between two game sessions. The difference on the completion level between two game sessions was examined. The details of study procedures are seen in Table 1 below.

Table 1. *Details of the Study Design*

	Session 1	Session 2
Interventions	No intervention.	Before beginning the game-playing, the participant a) was asked by the question, "Tell me some rules or strategies that you found useful for the game from the previous play and b) was requested to "Draw the patterns that led to a dead end in the previous play". After reviewing of the recorded, previous play, the participant was guided by an oral discussion and encouraged to self-correct his misconception or use of inefficient strategies.
Directions provided	The participant was asked to say aloud whatever ideas or thoughts come up with.	The participant was asked to say aloud whatever ideas or thoughts come up with.
Levels	No upper limit	The highest level was the fourth to match the final session

* Note: the second playing was carried out on the following day of the initial game-playing.

Results

Effect of Metacognitive Visualizing

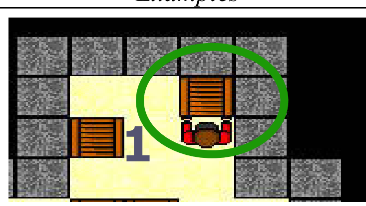
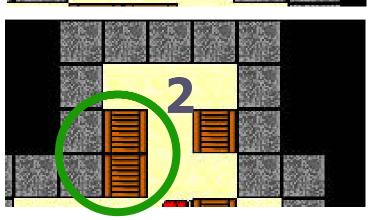
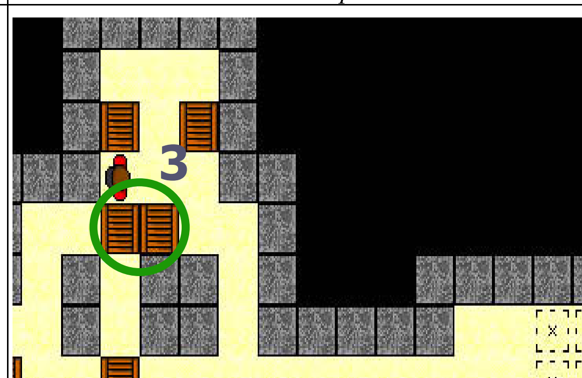
In the initial play, the player attempted the first four out of the total 20 levels for 24 minutes. The player completed only the first level out of the four attempted. On the other hand, in the second session of playing, the player attempted the first four levels for 28 minutes and completed all four levels attempted; specifically, in the first session, the player completed the first level, gave up the second level after several attempts, almost skipped the third level, and almost completed the fourth level. In contrast, in the second session of playing, the player was successful in completing all four levels within less time than that spent in the first session.

Table 2. *Summary of time spent and completion levels of two game plays.*

	Session 1 (day 1)	Session 2 (day 2)
Total spent time	24 minutes	28 minutes
Levels attempted	Level 1 to 4.	Level 1 to 4
Levels completed	Only the first level	All 4 levels attempted

Prior to beginning the second session of playing, the player responded to two requests. First, the participant was asked, "Tell me some rules or strategies that you found for the game from the previous trial." The player responded as the followings: 1) "Don't place the box in a corner"; 2) "Don't place two boxes side by side"; 3) Find the "four-way intersection"; and 4) "Think ahead". These responses showed that although the player ended up completing only one level of the game in the initial game-playing, he was able to discover the crucial rules and strategies for playing Sokoban in that session. . When asked, "Draw the patterns that led to a dead end in the previous trial.", the player graphically described multiple situations that he figured out as being problematic in his play. The descriptions showed that the player discerned most of the potential problematic situations. One misunderstanding concerned play patterns or rules that led to a dead end. The player might consider that 'placing two boxes side by side' is consistently problematic in Sokoban problem solving based on his statement, "Don't place two boxes side by side" as a rule for the play. Accordingly, a few situations of examples and non-examples of "boxes placed side by side" that leads to a no-way-out situation were modeled onto the Sokoban (see Figure 1).

Figure 1. *Illustration of Examples and Non-examples of the side by side situation leading to a dead end*

Examples	*Non-examples*
 	

* Although both picture 2 and 3 describe a 'side by side' situation, only picture 2 leads to a dead end. This was articulated to the participant to help his forming a correct concept about the rule.

Then, the participant was asked if all of those situations were likely to end up with a dead end. The learner could arrive at the correct response after actually performing a few moves for the situations on the computer. During the discussion, the participant indicated that anticipating a few moves ahead was a useful strategy to produce a successful result of the playing.

Based on the analyses of the video-recorded data, some commonalities and differences were examined between the two game sessions. Commonalities included: 1) At times, the player reminded himself of the rule of 'minimum moves' saying "Since I have to make as minimum moves as possible"; 2) The player arranged objects in a way to accommodate later moves, a strategy formed based on his prior, general game-playing experiences; 3) The player often employed a "start all over again" strategy when stuck; and 4) The player often applied what he learned from the previous level to the next level (e.g., the player attempted take a detour at the place where the obstacles resembled a four-way intersection in a new level of play). From this observation it was obvious that the player was regulating his own playing in order to make his move more efficient.

On the other hand a few differences were also observed between two play sessions. For example, in the second play session: 1) The player used the strategy of seeing a few moves ahead ('think ahead', in the participant's words. See Table 3 for details) more frequently; 2) The player spent more time at the beginning of a level and at the points of making any change to a move that was already made; and 3) A reduction in the number of dead end occurrences were observed. This result indicates that, with increased game playing experience, the player relied more on the forward-working; additionally, his use of skills became more automatic, in which it can be assumed that he had formed schemas for playing Sokoban.

Analysis of the Recorded Game-playing

Use of General Problem Solving Strategies

It was found from the two trials of game-playing that the participant used both forward- and backward-working strategies of problem solving. In the first game playing session, Level 1, the participant appeared to engage in forward-working from time to time, as evidenced by the occurrences in which he reminded himself of the 'global goal', moving all the objects to the destination location, and the general game rules such as only pushing and minimum moves:

> My goal is to get all these boxes into six stacks on the right...I have to get the boxes to the four way intersection [the place where the array of the obstacles takes the shape of a four-way intersection on a road]….I have to make as minimum moves as possible…

At the same time he repeated trials and errors and often arrived at a no-way-out situation before finding a solution path. Backward-working strategies were also observed in instances when, for example, he evaluated whether his moves had been working or not based on the rules that he figured out for himself. In Sokoban playing, such autonomous evaluations of the game player appeared to be promoted by the immediate visual feedback given by the consequence of an action, which is clear from the following statement of the player:

> I will try this one…I am stuck again. I am not going to try with that box any more… I need to try to move with something else….Oh I got an idea….If I move one more step, I will be stuck. Oh I got it… I messed up. I am going to try all over again.

It was also found that the player figured out by himself essential rules for the game play from the early stage based on the following statement, "I have to get the boxes four-way intersection" A four-way interaction is located in Table 4, in the area labeled 1.

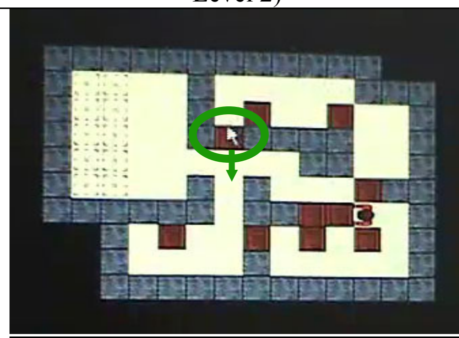
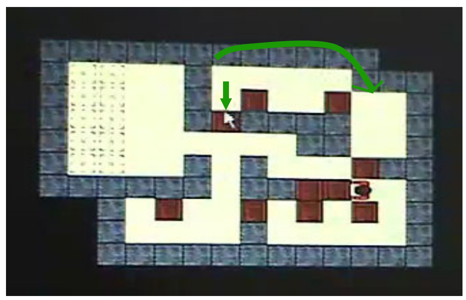
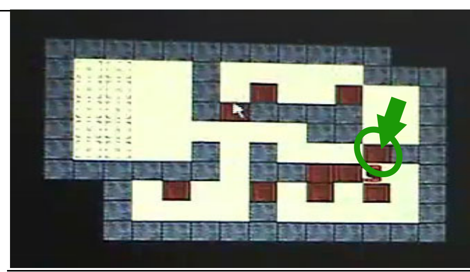
As he obtained more skills, he employed more often forward strategies, visioning ahead a set of moves. At the start of Level 2 in the second session, he stated, "I have to try to get this one out and then I can come back the other way. Then, this box should be in the intersection." (See the figure in Table 4 below).

Use of Domain Skills and Strategies

In Sokoban, as true for many other game plays, the participant was not pre-trained with uses of skills or strategies that were useful for the game. The participant was entirely left to discover the rules or skills through his game-playing. As the participant played more levels, use of strategies was more often observed, indicating that the participant's level of understanding was increasing with time. The player used strategies such as 'think-ahead', 'taking a detour', 'minimum moves', and 'start all over again'.

'Think-ahead,' as named by the player, was commonly observed in this game play. 'Think-ahead' strategy was apparent based on the participant's statement in the second session, in which he stated, "I have to try to get this one out and then I can come back the other way. This box should be in the intersection." Thinking ahead often involved the detour strategy as seen in the table 3.

Table 3. *Elaborations of the participant's use of the 'Think-ahead' strategy*

Statements	Graphic Elaborations (Second Session, at the start of Level 2)
"This box should be in the intersection."	
"…and then I can come back the other way."	
"I have to try to get this one out"	

It was clear that the player was intentional in employing the 'think ahead' strategy in an effort to make his actions more successful. This indicated that he was taking a metacognitive control over his Sokoban game-playing. In using this strategy, the player's oral reporting appeared to influence him. Saying loud what he has on his mind while playing the game probably facilitated his planning a few steps in advance and thus reinforced his use of the 'think ahead' strategy because he possibly recognized that the strategy was useful to prevent an incorrect path.

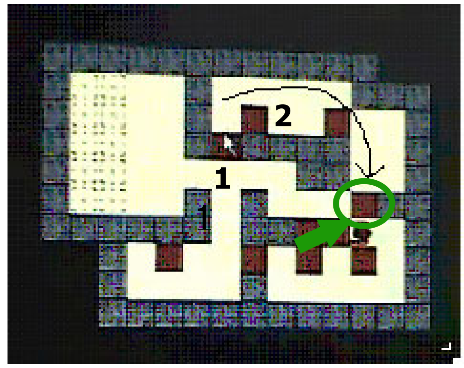
The player also attempted to make 'minimum moves' if possible. From time to time, he reminded himself of this rule, saying, "I have to make as minimum moves as possible." Although this 'minimum moves' rule was offered as a game rule at the outset, the player appeared to utilize this strategy in an attempt to save his cognitive efforts as well.

The player also often played the game from scratch by pressing the reset button, which action was referred to as 'start all over again" by the player. This 'start all over again' was used whenever the participant recognized 'no way out', which is obvious from the following statement: "If I move one more step, I will be stuck. Oh I got it… I messed up. I am going to try all over again." The player's multiple applications of this strategy over different game levels showed that the game player had acquired the pertinent conditional knowledge; that is, knowing how and when to use the skill or strategy to ensure optimal performance.

Developing Procedural Knowledge

Analyses of Sokoban game-playing with 'think-aloud' strategies provided a snapshot about how a game player obtained procedural knowledge. In this study, the problem solver developed procedural knowledge based on the game goals that were discovered by the player himself rather than provided externally. In Table 4, the development of player procedural knowledge is further elaborated.

Table 4. *Elaboration of production development –related to Table 3*

If the sub-goal is moving the crate (with the white arrow) to the destination area **Then** I have to put the target crate into the location of 1. **And then** I have to go way back (arrow 2) in order to push the target crate into the destination area. **If** the sub-goal is to move the crate with the white arrow to the place of 1 and go around back to the location of 1 to push the target crate into the destination, **Then** I need to get rid of this crate (pointed by the green arrow) first.	

Forming procedural knowledge was evidenced generally after the player failed in his repeated attempts to find a solution. Thus, it was regarded that producing procedural knowledge was also kind of a strategy that the player employed in an attempt to recover, an anticipated difficulty in the course of problem solving. Based on video recording of game playing, it was obvious that the development of the participant's procedural knowledge increased and became more automatic as the total time engaged in Sokoban playing increased.

Conclusion

In this study we analyzed how a young game player learns and uses skills or strategies to play the Sokoban computer game. The focus was on the player's metacognitive control over his thinking processes to complete the game. In addition, the effect of the player's metacognitive monitoring and adaptive self-correction of misconceptions or ineffective uses of strategies for the game-play were also examined.

Based on the comparison of the two sessions of game-playing, it was discovered that the participant benefited from monitoring and visualizing his problem solving process and guided self-correction of misconceptions. In order to separate the possible practice effect from the intervention, further studies may include a control condition including multiple subjects or additional game-playing sessions. These findings imply that helping a problem solver monitor his learning and to recognize the efficient and inefficient use of skills or strategies is an effective pedagogical method. This study also corroborates the findings of Schunk and Swarts (1993), who suggest that young learners need feedback to apply strategies in order to improve their problem solving skills.

Two trials of game-playing indicated that the participant used both forward- and backward-working strategies. The backward-working strategy was also observed within a forward-working strategy. Sweller (1988) once categorized forward-working strategies. A schema driven approach used by an expert is a common example of a forward-working strategy. Further, forward-working strategies can occur during means-ends analysis. The problem structure, which has a non-specific goal, can lead to more forward-working (Sweller, 1988). Therefore, forward-working strategies were observed in this study and appeared to be related to the structure of the Sokoban play that had a non-specified goal. As expected, it was observed that as the problem solver gained more expertise over time, his process of playing became more automatic. This suggested that the player had obtained schemas of Sokoban playing. Obtaining schemas of Sokoban game playing were clearly seen in this study, based on the participant's use of procedural knowledge. The participant also used backward-working strategies such as means-ends analysis and trials and errors. It is probable that the participant began working forward with the non-specified game goal and without prior experience of Sokoban playing, thus simply exploring the problem space in order to see what moves were possible (Sweller, 1988), without being controlled by a schema. However, when he encountered a difficulty, he seemed to employ more of the means-ends analysis. This potential relationship between difficulties and use of backward-working strategies may be tested in future studies of problem solving with computer games.

It was also observed the player used domain-specific strategies such as 'think-ahead', 'taking a detour', 'minimum moves', and start all over again'. He seemed to consciously use such strategies as ways to make his moves more successful, which indicated that the player kept on monitoring his metacognitive control over his problem solving process. The method of 'think-aloud' was utilized to reinforce the player's use of strategies. The demand of speaking about his work processes possibly encouraged the participant to think about a set of moves ahead and finally helped the player learn that those strategies were useful.

Based on the recorded data, the participant was also observed to form procedural knowledge in the event he perceived a difficulty in finding a solution. Thus it seemed that the player who was working on Sokoban produced procedural knowledge in part as a strategy to overcome the difficulty in problem solving. This aspect also confirmed the work of Schunk (2004) that, "young learners are more likely to monitor their activities on tasks of intermediate difficulty as apposed to easy tasks"(p. 193).

As a case study, this study has a few limitations. One limitation is that the results may not be generalized with other participants, or other types of computer games. This study includes only one participant; therefore, the findings may be only relevant to similar ages or developmental levels; simply put, the findings from this study might not be consistent with learners at different levels of cognitive ability, computer experience, or motivation. In future studies the effects of such variables may be tested to take into further account learner variables. Second, in this study, the Sokoban computer game play involves only one gamer without any specific goal statements built-in. The findings of this study may vary with other types of game-playing in terms of the number of players, degree of entertainment, type of reward, and difficulty. Futures studies may take into account these task variables and test effects of such variables with both Sokoban and other types of plays. In addition the results from this analysis imply that Sokoban game-playing can be useful in studying cognitive and metacognitive thinking process.

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