

Effects of Meta-cognitive Strategies on Problem Solving Ability in Construction Education

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The complexity and uniqueness of today's construction projects makes problems difficult to define, makes finding solutions extremely difficult, and therefore highlights the need for college graduates to learn new skills in problem solving. Incorporating metacognition into the classroom can help students to improve their learning, to better define problems, and to identify and overcome obstacles to problem solving. Metacognition is defined as one's ability to understand and monitor one's own learning and how to use a particular learning strategy in problem solving. In this regard, game play is a promising approach for activating metacognition, because it is a series of activities that considers metacognitive knowledge and allows us to plan, monitor and constantly evaluate our actions. Three metacognitive strategies are used for game play in this study: self-assessing, thinking aloud, and checklist. These three strategies are considered as independent variables and academic achievement and scores in the game are chosen as dependent variables. A questionnaire is designed and distributed through a game play experiment to measure the dependent variables. The effectiveness of meta-cognitive strategies in enhancing the students' achievements both in learning and gaming is discussed.

Key Words: Problem Solving, Metacognition, Game-based Learning, Self-assessing, Thinking Aloud, Checklist

Introduction

The increasing complexity and sophistication of the construction environment, the use of new materials and technologies, and greater performance expectations by clients results in new challenges and opportunities for construction engineers. Therefore it is important to provide students with problem solving skills needed for successful decision making. Problem solving learning is used for expanding the curriculum to include critical cognitive skills and a problem-solving experience in civil engineering (Quinn and Albano 2008). It is very important to understand how students perform a task and solve problems, in addition to the skills required to perform the task. The key to developing scientific and engineering thinking in students is to create a rich, problem-based learning environment, where students need to apply the same cognitive process used by scientists (or engineers) in inquiry-based tasks (Araz and Sungur 2007). Incorporating metacognition into the classroom can help students to better define the problems and to structure the problem solving process (Prins et al. 2006).

Metacognition is defined as one's ability to understand and monitor one's own learning and how to use a particular learning strategy in problem solving (Swanson 1990). Metacognitive knowledge contributes to successful problem solving, regardless of IQ or task-relevant strategies. It suggests that one who has average ability but possess a high degree of regulatory knowledge, might solve problems more effectively than low-metacognition students (Schraw 1998). In one study, Bulu and Pedersen (2012) found that, using different scaffolding characteristics, students with lower prior knowledge and lower metacognitive skills can attain the same level of competence in problem solving as the students with higher prior knowledge and higher metacognitive skills. To increase students' metacognitive abilities, at least three different kinds of metacognitive awareness should be considered: (1) declarative knowledge refers to knowledge that a person may have about his or her abilities, (2) procedural knowledge refers to knowledge of how to perform the steps in a process, and (3) conditional knowledge refers to knowledge about when and why to use procedures or strategies (Reynolds and Miller 2002).

Kluwe (1987) argued that problem-based learning uses real-word problems as the starting point, and the processes involved in solving these problems should lead to the development of metacognition awareness. Therefore, the student knows something about his or her abilities, and can change his or her procedures or strategies. Downing et al. (2009) asserted that metacognitive strategies such as planning, monitoring and evaluating one's own learning evolve more effectively when students are engaged in problem-based learning environment. However, the learning environment should support the activity of the student as well as peer interaction and social negotiation (Driscoll and Driscoll 2005). The research presented in this paper aims at studying the efficacy of using game play for learning purposes, particularly for activating metacognition.

Game-based Learning

Game play provides the opportunities to supplement and elaborate course content in an innovating, challenging and meaningful manner. The term is generally associated with video games, but is not limited to this form of media; for example, it is also used in board card and puzzle games. During game play students actively see and do, which are less accessible in regular educational settings (Vos et al. 2011). When playing games, students can collaborate in teams, each using a different, but overlapping, set of skills, and adjust their hypotheses and test them again, if needed (Gee 2003). The games may be designed to promote learning or the development of logical thinking and problem-solving skills by involving players in storylines (Erhel and Jamet 2013). Dickey (2007) stated that interactive learning environments, such as the game play experiment considered in the present study, provide learners a cognitive framework for problem-solving. These interactive learning environments also provide a context for players to collaborate with other learners within the game, which integrates information, tools, and materials and fosters metacognitive skills.

Game-based learning is a type of game play that engages students in a learning activity through a competitive exercise. It is a promising approach for activating metacognition, because it is a series of activities that consider the three kinds of metacognitive knowledge and allows us to plan, monitor and constantly evaluate our actions. It has been reported that a game-based learning approach is a good tool to encourage metacognitive practices in the classroom (Yien et al. 2011), to stimulate students' cognitive processing (Carbonaro et al. 2010), and to help them develop problem-solving skills (Lee and Chen 2009). Also, games include many characteristics of problem solving, such as accommodation of various learning styles, existence of multiple paths to a goal, collaboration in the case of multiple players, and the elements of competition and chance (Ebner and Holzinger 2007). Similar to a problem solving situation, meta-cognitive strategies play a key role in the adoption and effective use of educational games. Lin (2001) examined the effects of metacognitive strategies on student engagement in metacognitive activities and found that practicing meta-cognitive strategies would help students to enhance their problem solving abilities (Lin 2001).

Kim et al. (2009) defined meta-cognitive strategies as strategies that empower learners to take charge of their own learning in a highly meaningful fashion. They help students in focusing their attention, understanding content, gaining confidence and become more independent as learners in learning with games. Despite significant research efforts on metacognition strategies in learning, there are still questions that must be further studied; when are metacognitive strategies applied and which metacognitive learning strategies are most effective in a learning process? In order to answer such questions, three metacognitive strategies are used for game play in this research: self-assessing, thinking aloud, and checklist. These three strategies are considered as independent variables and academic achievement and scores in the game are chosen as dependent variables. A questionnaire is designed and distributed through a game play experiment to measure the dependent variables. The game encompasses different issues regarding project management concepts such as Work Breakdown Structure (WBS), method statement, Gantt chart, and network diagram. Figure 1 shows the framework used in this study.

Game Play Experiment

The game play consists of two or three players building a house with LEGO blocks. During the experiment, 10 minutes were spent for each meta-cognitive strategy, which resulted in 30 minutes for the game play. In addition, 20 minutes were required for the questionnaire and to present the learning concepts to the participants. In total, each experiment took approximately 60 minutes to complete. The experiment times were scheduled according to the time availability of each participant. This criterion was also used to assign the participant (or player) to a group. The experiments took place at the same location but at different points in time.

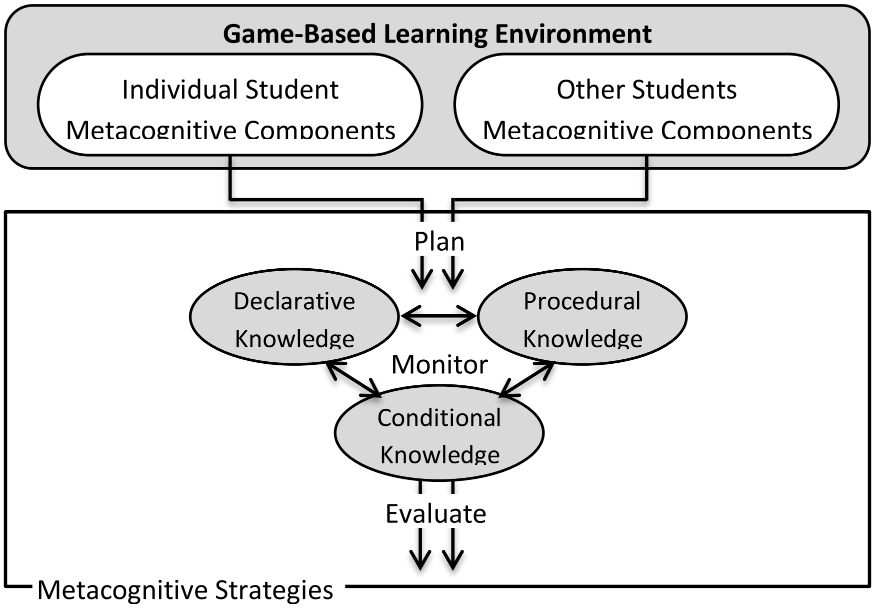

Figure 1: Diagram showing the metacognitive strategies during game play

The Architecture, Construction, and Engineering (ACE) Mentor Program activity that the authors of the study developed in 2011-2012 (ACE 2013) served as inspiration for the game play experiment and its scoring system. The ACE mentor program, offers high school students the opportunity to pursue careers in the Architecture, Construction, and Engineering industry through mentoring The players are provided with a set of LEGO blocks and a detailed, fully illustrated construction manual outlining the construction (or building) process (i.e. sequence of activities). For instance, "1st Floor Upper Walls" is an activity that should be completed before another activity, "1st Floor Door/Window", begins. As mentioned earlier, the metacognitive strategies are considered as independent variables and academic achievement and scores in the game are chosen as dependent variables.

Figure 2 shows the components of the game. This is a within-subjects experiment in which the same group of subjects serves in more than one metacognitive strategy. Each group of two to three subjects is expected to use one meta-cognitive strategy, so by using the same number of subjects in a within-subjects design, we can increase the number of "subjects" relative to a between subjects design. Moreover, the conditions are exactly equivalent with respect to individual difference variables since the participants are the same in the different metacognitive strategies. As the focus of the research is on construction education, all the subjects used for this experiment were drawn from the major fields of construction engineering, such as building construction, civil engineering, and architecture.

The primary dependent variable is the achievement in learning project scheduling principles. A questionnaire is designed and distributed through a game play experiment to measure subjects' achievement in learning, which is to assess subjects' knowledge of scheduling principles covered in the game (e.g. WBS, activity duration, sequence of activities). The learning goal of the LEGO game is to understand and apply the concepts and tools of project management including WBS, method statement, Gantt chart, and network diagram. The first section of this questionnaire was aimed at gathering demographic information such as years of experience and academic rank. A series of questions were then asked about the level of understanding before and after the game and each question was weighted equally.

The secondary dependent variable is the achievement in gaming. The LEGO game scoring system includes completeness score and accuracy score. For completeness score, at the end of the allowed time (i.e. 30 minutes), team progress is assessed by completed activities according to the provided schedule. It is important that if the team used pre-fabrication, that the pre-fabricated component be installed for the activity to count as complete. This requirement is worth a maximum of 50 points. Team accuracy is assessed by comparing the structure assembled with the visual model provided to the team. This requirement is also worth a maximum of 50 points.

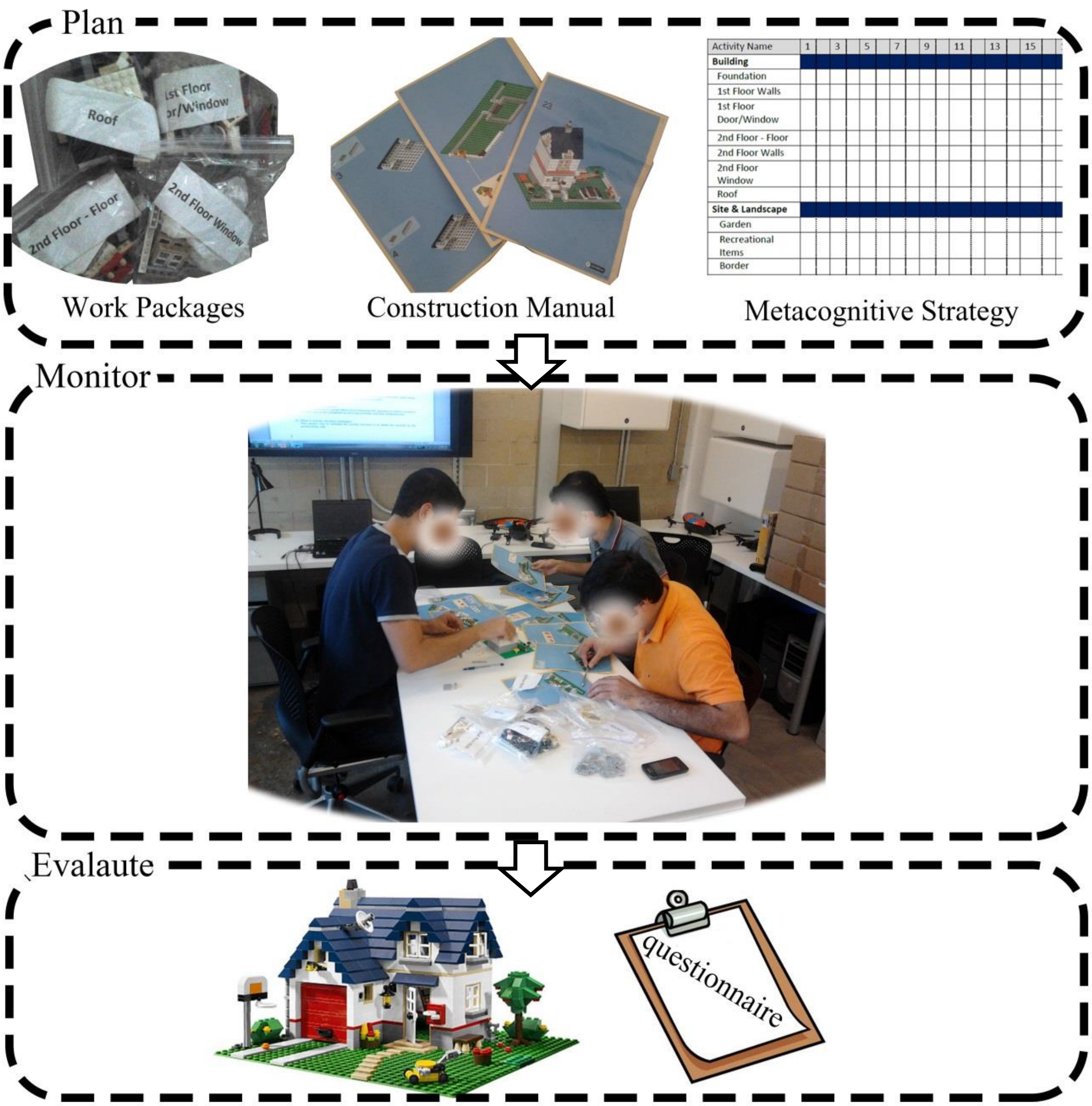

Figure 2: Components of the game play

The following considerations were made in developing meta-cognitive strategies:

- The strategies should be implemented after the introduction of the concepts and skills,
- The strategy should provide students the opportunity to practice new skills independently,
- The progress of learning and the performance of student should be monitored while using the strategies.

The experiments began with the instructor explaining how to play the game and how to use meta-cognitive strategies. Students played the game three times using each metacognitive strategy. The evaluation for learning achievement and game scores for gaming achievements were administered after the game.

As mentioned before, three metacognitive strategies are used for game play in this research. Self-assessing is a strategy to record experiences by looking back on the gaming activities. This strategy has three phases in the proposed game-based activity. The first phase is recording students' prior knowledge before they start the game. The instructor presents the learning concepts about scheduling (e.g. duration and sequence of activities). These concepts should be learned through the game play. Students choose one learning concept and write on their recording sheets what they already know and what they do not know yet. The second phase is completing a table based on the time they spent on each activity (in minute) while they are working on the LEGO structure. The third phase is recording reflections. In this phase, upon finishing their game play, students write a short reflective summary about their game play.

Thinking aloud is a verbal expression of the normally covert mental processes. Students should talk to their fellow students about their game play during game session. Students apply the thinking aloud strategy in the game through the following steps: First, the instructor makes a cooperative gaming group and explains how to use the thinking aloud strategy. Then, students explain their game process to their fellow players throughout the game play. They explain what is on mission, what is off mission, and what they will do for the next activities. As one player describes his or her thoughts to another person, the other player and problem-solvers listen and attend to their own thoughts as well.

In the checklist strategy, the instructor directs the students to ask themselves the questions presented in the checklist while they are working on the LEGO building. The checklist is presented on an overhead projector while the instructor discusses the meaning of each question. Students are then given copies to refer to when completing all activities. The questions in the checklist encourage students to examine the game more closely and to think about what they already done.

The data sample comprised of 18 college students in the major fields of construction engineering, who volunteered to participate in the experiment. In order to control for carry-over effects and issues in sequence effects, we must consider all possible combinations of the strategies (at least six groups of participants). The conditions are exactly equivalent with respect to individual difference variables since the participants are the same in the different metacognitive strategies. Prior to the experiment, all participants were required to give informed consent which explains to an individual who volunteers to participate in the study, the goals, processes, and risks involved. Therefore, each participant was presented with an Informed Consent Form for him or her to read in agreement to participate in the study. The university's Institutional Review Board (IRB) evaluated and approved the study protocol.

The demographic characteristics include gender, age, years of experience, education level, and whether the participant used any project management software tools etc. According to the survey, 58% of the participants had work experience and only one third of them have used any project management tools. In addition to this information, Table 1 presents a summary of the major demographic characteristics of the participants in the study.

Table 1

Demographic and work-related statistics of participants

Variable	**Percentage**	**Variable**	**Percentage**
Gender		Age	
Male	78	20-25	33
Female	22	25-30	50
		30-35	17
Academic rank			
Freshman	11	Work experience	
Sophomore	22	none	50
Junior	17	0-1 year	11
Senior	22	1-3 years	33
Graduate	28	more than 3 years	6
Experience with project management tools			
Yes	56		
No	44		

Experiment Results

A multivariate analysis of variance (MANOVA) is used to describe the directed dependencies between meta-cognitive strategies and both academic achievement and game performance. These two dependent variables are commonly measured by examinations, however, in this study, the questionnaire and game completeness and accuracy scores are used as the assessment to incorporate metacognition (i.e. incorporate both procedural knowledge and declarative knowledge aspects). This assessment is used based on the assumption that metacognition can promote academic learning. With the multivariate analysis there are two dependent variables (academic achievement and game performance) that are examined across one dependent variable (meta-cognitive strategy). Thus, for this one-way MANOVA, we would measure how academic achievement and game performance scores (in combination) differ in respect of the used meta-cognitive strategy (multivariate effect). There should be some correlation between the academic achievement and game performance scores, otherwise there is no multivariate effect. On the other hand, to maintain the validity of statistical analysis, that correlation should not be too strong. When the dependent variables are too highly correlated, it could be assumed that they are measuring the same variable. MANOVA is most effective when dependent variables are moderately correlated (0.4 - 0.7). As can be seen from Table 2, the correlation between the dependent variables (i.e. -0.187) is within acceptable limit for MANOVA outcomes. Although negative, it does not exceed the suggested range ($r= -0.4$). As a result, the correlation is not too high between the dependent variables so we can proceed with the univariate test.

Table 3 displays the results of the one-way MANOVA. It indicates that there is homogeneity of between-group variance for academic achievement scores (significance < 0.05), but not for game performance scores (significance < 0.05). Therefore, we could examine equality of between-group variance only for the academic achievement scores. The research model was established based on the idea that the meta-cognitive strategies have an effect on the achievements of both in gaming and academic learning. However, this hypothesis is not supported. According to the univariate analysis, the academic achievement and the game performance scores are not significantly different in respect of the meta-cognitive strategy: game score: $F(2, 51) = 1.585$, $p= 0.215$; academic achievement score: $F(2, 51) = 1.523$, $p= 0.228$.

The initial statistics in terms of the Mean and Standard Deviation suggest that among three meta-cognitive strategies developed for effective game-based learning, the "self-assessing" strategy (Mean = 36.78) is the strongest variable in enhancing the students' performance in gaming and the "checklist" strategy (Mean = 21.94) is the strongest variable in enhancing the students' performance in learning. However, the "thinking aloud" strategy does not have a significant effect on the achievements in gaming or learning. In the multivariate analyses, Wilks' Ramba (λ) is chosen as there are three strategies. The results indicate that there is a significant multivariate effect for the combined dependent variables of academic achievement and game performance in respect of the meta-cognitive strategy: $\lambda = 0.964$, $F(4, 100) = 1.895$, $p > 0.05$ (significance < 0.05).

Additionally, participants were asked to comment on their learning experience. Thirteen of the 18 participants (72%) provided written comments revealing that the game did not fit into contemporary pedagogical approaches. Students seemed to feel more comfortable with the "self-assessing" and "checklist" strategies compared to the "thinking aloud" strategy that required them to talk to their fellow students about their game play during game session. There is agreement by the large majority of the respondents (54%) that game-based learning cannot replace the traditional forms of education completely. Learning can be optimized by the combination of different approaches of knowledge transfer.

Table 2

Correlations between variables

	Meta-cognitive strategy	Achievement in gaming	Achievement in learning
Meta-cognitive strategy	1		
Achievement in gaming	-0.070**	1	
Achievement in learning	0.075**	-0.187**	1

Note: ** Correlation is significant at the 0.05 level (2-tailed); correlations calculated using Pearson's *r*.

Table 3

MANOVA statistics with game and learning scores by meta-cognitive strategy

		Game score		Learning score	
Strategy	**N**	**Mean**	**Stand. dev.**	**Mean**	**Stand. dev.**
self-assessing	18	36.78	3.91	18.89	17.54
thinking aloud	18	31.47	15.05	12.50	13.09
checklist	18	35.19	3.34	21.94	18.56
Levene's test for equality (homogeneity) of variances			**F**	**Sig.**	
Game score			18.29	0.000	
Learning score			0.224	0.800	
Univariate outcome			**F**	**Sig.**	
Game score			1.585	0.215	
Learning score			1.523	0.228	
Wilks' Ramba		**Value**	**F**	**Sig.**	**Partial eta sq.**
meta-cognitive strategy		0.864	1.895	0.117	0.70

Conclusions

Literature shows that incorporating metacognition in the classroom can help students to improve their learning and their problem-solving success. Metacognitive strategies are used to increase students' metacognitive abilities. They include activities that involve self-evaluation of learning strengths and weaknesses, and take into account three kinds of content awareness: (1) declarative knowledge, (2) procedural knowledge, and (3) conditional knowledge. As game play considers the three kinds of metacognitive knowledge, this study conducted a game play experiment to investigate the effectiveness of meta-cognitive strategies in enhancing the students' achievements both in learning and gaming. Three strategies (i.e. self-assessing, thinking aloud, and checklist) are considered as independent variables and academic achievement and scores in the game are chosen as dependent variables.

By comparing the mean values for the meta-cognitive strategies across the gaming and learning scores, it can be noted that "self-assessing" and "checklist" strategies are more effective than "thinking aloud" strategy in enhancing the students' achievements both in learning and gaming. The "self-assessing" strategy and the "checklist" strategy resulted in the highest mean for the gaming and learning scores, respectively. This may be because of the similarities between the project management concepts and these two strategies. In the "self-assessing" strategy, for instance, students are filling a table based on the time they spent on each activity (in minutes) while they are working on the LEGO building. This is very similar to a Gantt chart. Thinking aloud, as a verbal expression of the mental processes, might be significantly related to the social problem solving ability. Although there is a significant multivariate effect (at the 0.05 level) for the combined dependent variables of academic achievement and game performance in respect of the meta-cognitive strategy, there is a lack of statistical significance in supporting the effect of the meta-cognitive strategies on the achievements in gaming and academic learning. This is most likely a result of the small sample sizes in the experiment. In this game play experiment, comments made by the participants were also incorporated. Although there were a variety of issues addressed by more than one respondent, there was agreement that game-based learning can be an important support in the whole learning process.

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