Human Tutoring vs. Teachable Agent Tutoring: The Effectiveness of "Learning by Teaching" in TA Program on Cognition and Motivation

Karam Lim[1], Yeonhee So[2], Cheon-Woo Han[3], Su-Young Hwang[4],
Ki-Gon Ryu [5], Mo-Ran Shin [6], Sung-il Kim[7]
Korea University[1 2 3 4 7] Cheonan University[5 6]

ABSTRACT

The researchers in the field of cognitive science and learning science suggest that the teaching activity induces the elaborative and meaningful learning. Actually, lots of research findings have shown the beneficial effect of learning by teaching such as peer tutoring. But peer tutoring has some limitations in the practical learning context. To overcome some limitations, the new concept of "learning by teaching" through the agent called Teachable Agent.

The teachable agent is a modified version of traditional intelligent tutoring system that assigns a role of tutor to teach the agent. The teachable agent monitors individual difference and provides a student with a chance for deep learning and motivation to learn by allowing them to play an active role in the process of learning. That is, The teaching activity induces the elaborative and meaningful learning.

This study compared the effects of our teachable agent, KORI, and peer tutoring on the cognition and motivation. The field experiment was conducted to examine whether learning by teaching the teachable agent would be more effective than peer tutoring and reading condition.

In the experiment, all participants took 30 minutes lesson on rock and rock cycle together to acquire the base knowledge in the domain. After the lesson, participants were randomly assigned to one of the three experimental conditions; reading condition, peer tutoring condition, and teachable agent condition. Next, participants of each condition moved into separated place and performed their own learning activity. After finishing all of the learning activities in each condition, all participants were instructed to rate the interestingness using a 5-point scale on their own learning activity and leaning material, and were given the comprehension test.

The results indicated that the teachable agent condition and the peer tutoring condition showed more interests in the learning than the reading condition. It is suggested that teachable agent has more advantages in overcoming the several practical limitations of peer tutoring such as restrictions in time and place, tutor's cognitive burden, unnecessary interaction during peer tutoring. The applicability and prospects of the teachable agent as an efficient substitute for peer tutoring and traditional intelligent tutoring system were also discussed.

Keywords: Teachable agent, Learning by teaching, Peer tutoring, Individual difference, Interest

Introduction

The traditional computer assisted learning (CAL) system such as intelligent tutoring system was passive learning system because the computer provides learning materials and drills repetitiously to train students and, the level of student's learning is evaluated by computer. Because of this passive nature of leaning in computer assisted learning, the CAL has received the criticism in which the iterative and passive practice does not enhance the learner's motivational and cognitive process.

Additionally, the traditional CAL did not reflect an individual difference depending on learner's cognitive ability and motivational state. The identical interface regardless of the individual differences might be not only less effective in cognitive aspects of learning but also less interesting in terms of the motivation. To overcome

this limitation of CAL, associated with AI (Artificial Intelligence), ITS(Intelligence Tutoring System) has been emerged in learning situation.

The main focus of ITS is to provide the benefits of one-on-one instruction automatically and cost effectively. ITS system monitors each learner's actions within these interactive environments and develops a model of their knowledge. Thus, the ITS can consider the individual difference and provide a student with a chance for deep learning and motivation to learn by allowing them to play an active role in the process of learning. One way of providing an active role for the learners is to give them an opportunity to teach.

The researchers in the field of cognitive science and learning science suggest that the teaching activity induces the elaborative and meaningful learning. Actually, lots of research findings have shown the beneficial effect of learning by teaching. Bargh and Schul (1980) reported that teaching could facilitate to organize the specific knowledge structure associated with the particular subject matter. Chi, et al. (2001) showed that students who study with purpose of teaching others are more intelligent than students who study with the purpose of qualifying examination.

Peer tutoring is already known as a kind of effective learning methods based on the concept of learning by teaching. Practically, previous studies provide plenty of evidence that peer tutoring is an effective method of leaning for both tutee and tutor. Through many studies, peer tutoring was proved to have many advantages such as learning outcome, social relationship, self-concept and learning motivation for tutee.(Kulik and Kulik , 1982; Ginsbug-Block & Fantuzzo, 1997). Similarly, it has been proving there are also several advantages in peer tutoring for tutor which are related to cognition, emotion and motivation. Lepper et al. (1990) reported that peer tutoring improved tutor's feeling of patience and ability for task performance, individual control, and motivation Also, Cohen et al. (1982) reported that tutor not only developed more positive attitudes toward tutee, but they also gained a better understanding of the subject areas.

Thus, these peer tutoring activities have been regarded as the meaningful learning method for improving the comprehension and motivation for both tutee and tutor.

Despite its potential benefits, sometimes peer tutoring has some limitations in the practical learning context. Kim et al. (2003) indicated several limitations of peer tutoring specifically. First, in the face-to-face tutoring, tutors might stagger under the cognitive burden because they could be overwhelmed by the amount of information to remember for teaching. Second, if tutees do not understand what tutor teaches, tutor is likely to get frustrated and lower their self-efficacy. Third, the peer tutoring has restrictions in space and time. Moreover, providing diverse and immediate feedback is difficult in face-to-face tutoring situation. Finally the unnecessary interactions between tutor and tutee might occur, which can interfere with the learning process.

To solve these potential problems of peer tutoring, Schwartz and his colleagues (2000) proposed the new concept of learning by teaching through the agent called Teachable Agent (TA). Teachable agent is the computer program in which students teach computer agent to enhance student's motivation and cognitive ability based on the instructional method of 'learning by teaching'.

In this study, we developed a kind of TA, KORI (KORea university Intelligent agent), and tested the effect of KORI on learning. Teaching KORI is expected to not only maximize the users' motivation and cognitive ability, but also increase their self-efficacy and responsibility through various interactions and an immediate feedback. Basically, TA is a kind of ITS (intelligent tutoring system), which is a computer-based learning system. But in contrast to other ITS, TA has a unique aspect, which is an interaction with a agent through learning by teaching. The previous TAs - e.g., Betty, Milo, Orbo which were developed at AAA lab in Stanford university - have common modules: the teach module, the dialogue module, the resource module, the test module. In the teach module, the user draws the

concept map on the learning material to TA. While the user teaches TA, he/she learns the basic knowledge or concept incidentally trough the interaction with the interface tools. When the user had hard time to teach, the resource module helps the user to find a proper knowledge to teach TA. Also in a dialogue module, students can interact with TA whenever they want through the dialogue box. Finally, in the test module, TA takes a test that is evaluated by hidden expert system. At the same time, students also receive a feedback.

The main purpose of this study is to investigate the effectiveness of the intelligent teachable agent (KORI). We compared the effect of the learning through teachable agent (KORI) with peer tutoring and traditional method of learning by reading on learners' interests and comprehension.

Implementing Teachable Agent, KORI

KORI is the new type of teachable agent developed to enhance the user's motivation to learn and facilitate learning, which is supposed to learn about rock cycle. Similar to the typical TA, KORI program consists of four independent modules, which are the planning module, the teach module, the test module and the resource module. In contrast to previous TA, it contains a narrative structure and various learning activities, which was designed to enhance the motivation to learn. and above all, our TA, (KORI) have an adaptive interface system depending on the learner's individual characteristic and to motivate leaner. Figure 1 shows four independent modules and elements for promoting motivation associated with adaptive system in the narrative structure.

In the planning module, the user makes the specific teaching plan for teaching KORI and collects and sorts the learning materials to teach from the learning resource. In the teach module, the user teach KORI by providing the basic characteristics of various rocks and constructing concept map on the transformation of the rocks. In the test module, KORI is evaluated by an expert system in program engine. Although KORI seems to take the quiz, in fact, it evaluates the user's level of the knowledge and comprehension. The learning resource module provides basic and expanded knowledge about rocks and their transformation. The user can access to this module by clicking the icons whenever they want to know more about rocks while teaching KORI. The resource is made of hypertext that is linked the basic concepts to concrete images and examples.

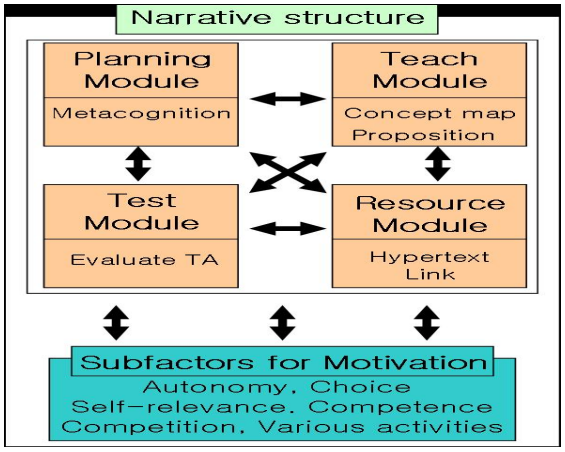

Figure 1. KORI modules

KORI also has introduced fantastic narrative structure. As the story-like context of KORI are presented, the user perceives that the interaction with the KORI would be more like a game rather than a boring instructions or practices and drills. That is, the user would not consider KORI as the instructional tool, so that he/she feels more amusing and interesting. Finally, In the KORI program, to increase interest and motivation we have made a various interface and have caused active interaction in related subfactors for motivation.

Planning module

Metacognition is one of the critical factors for learning. The learner with higher metacognitive skill shows better learning achievement (e.g. Peterson, 1998). Metacognition consists of planning, monitoring, strategy use and evaluation. Among them, planning about learning

is very important process when learning a new topic in an educational situation.

The planning module asks the user to write the teaching plan for three rocks and rock cycle. There are four empty boxes to type their own teaching plan on three kinds of rocks and their transformation cycle. This module would have the user realize the role of a tutor, get involved in teaching situation deeply, and have more responsibility. In a planning module, the user can make the plan for teaching by themselves, which includes collecting and sorting the learning materials to teach from the learning resource, the order of teaching certain materials, amount of teaching time, the frequency of teaching, key point. It is expected to reflect the user's metacognitive ability.

✓ Making a lesson plan: it refelects learner's metacognition

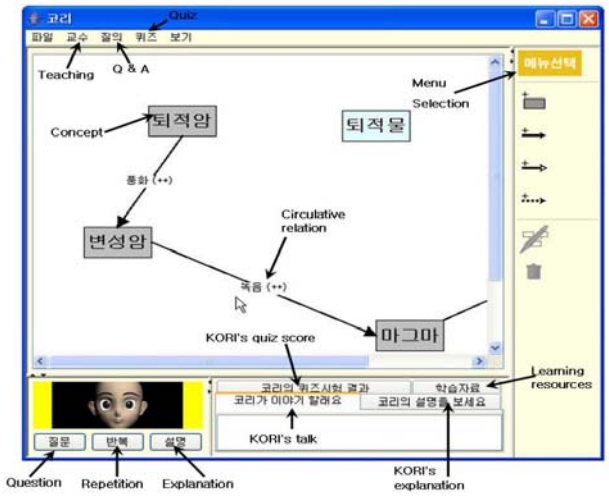

Figure 2. Concept map

Teach module

The teach module consists also of two units: concept teaching and relation teaching. In concept teaching, the user can teach the true propositions to KORI and correct the false propositions in KORI's knowledge structure through teaching tools. In the concept teaching activity, the user teaches the basic concepts of three kinds of rocks: igneous rock, sedimentary rock, and metamorphic rock. They teach KORI by putting in five correct propositions and taking out five incorrect propositions among 15 given propositions. While teaching KORI, students can also use the resource module whenever they want to know. In relation teaching, as shown in Figure 2 that shows concept map interface, the user can teach KORI by drawing the concept map using of tool box. Like concept teaching, the user can also use the resource module while interacting with KORI,

✓ Concept teaching: providing basic knowledge through the interaction with KORI using the resource module

✓ Relation teaching: sharing of mental model for the user and KORI through concept mapping

Test module

KORI's knowledge is evaluated in the test module. KORI takes a quiz at the end of teaching. The quiz consists of 6 questions on the rocks. Although KORI seems to take the quiz, in fact, it evaluates the user's level of the knowledge and comprehension. Since KORI's answers for the quiz are based on the information taught by the user, KORI's achievement level means the cognitive learning outcome of the user.

✓ Evaluation of KORI's learning state: it reflects students' knowledge

Resource module

The user can access to this module by clicking the icons whenever they want to know more about rocks while teaching KORI. The resource is made of hypertext that is linked the basic concepts to concrete images and examples. There are two different levels of learning resource related goal orientation as an individual difference: basic learning resource and additional learning resource. The goal orientation of the learner

might be the critical factor influencing intrinsic motivation. Dweck (1986) introduced the goal pursued by the dimension of individual personality or preference. This goal was classified with two major goal orientations: the learning goal orientation more focused on the learning itself than the social comparison and the performance goal orientation consistent with demonstrating own ability. The basic learning resource is the minimum amount of knowledge that is essential to teach KORI. Additional learning resource is the expanded knowledge that is not directly related to teach KORI. So it is expected the additional learning resource might reflect the learning goal orientation of learner.

- ✓ Basic learning resource: the minimum amount of knowledge that is essential to teach and test KORI

- ✓ Additional learning resource: expanded knowledge about rocks and rock cycle which are not related to teach KORI

Narrative structure

a narrative structure which is a powerful way to make the user engage in the learning material because it is likely to activate the story schema and also stimulate a variety of emotions. The narrative used in KORI is as follows:

> A knight (KORI) and a princess have lived in a remote planet. Satan has taken her from him. To rescue her, KORI needs to have armors and arms made of various rocks. But KORI didn't know anything about rocks and asked you for help through four-dimensional space….

Since fantasies are usually novel and offer analogies or metaphors for the real world, it is likely to allow the user to experience the phenomena from various perspectives, thus increase the interests (Malone & Lepper, 1987). As the story-like context of KORI is presented, the user perceives that the interaction with the KORI would be more like a game rather than a boring instructions or practices and drills. That is, the user would not consider KORI as the instructional tool, so that he/she feels more amusing and interesting.

Activities for promoting motivation and measuring individual difference

According to motivation theory (Deci & Ryan, 1985), competence, autonomy and social affiliation are the three basic needs that affect motivation. In designing and implementing KORI, those motivational factors were included to make the user engage in the teaching activity more actively and persist in teaching for longer period of time.

First, while teaching KORI, the user can provide his/her own feedback with KORI through a dialogue box depending on the unexpected KORI behavior, which is predetermined, such as falling into a doze, or paying no attention, or studying hard during learning.

Second, to enhance the user's autonomy and self-determination, diverse choice situations are given to make a decision by themselves on the various issues such as taking KORI as a pupil, learning level, competition of KORI with another TA and so on.

Third, competence is known as the most critical factor in learning motivation. Competence is the belief in oneself as capable of producing desired outcomes and avoiding negative outcomes (Jacobs & Eccles, 2000). Since the negative feedback is known to reduce competence to learn, especially the normative (relative) feedback for those who have low ability or low motivation, in our TA diagnostic feedback focusing on own performance is provided to keep and increase the level of competence.

Fourth, to increase the self-relevance about rocks and the rock cycle, the useful, practical and life-related examples are provided. For example, to explain on the metamorphic rock, we use process of diamond which coal becomes with heat and pressure. It is expected that

the self-relevant materials lead the users to engage more actively.

In addition to several properties included in modules, to measure the individual difference various activities during KORI teaching are implemented, for example, preparing for teaching material, estimating of the KORI's test score and monitoring KORI' progress.

Experiment

The purpose of this experiment is to validate the effectiveness the intelligent teachable agent (KORI) which was described in previous section. We investigated the effect of KORI system on motivation and cognition comparing with the peer tutoring and traditional learning through reading.

In this experiment, three learning conditions, learning by reading, peer tutoring, and teachable agent, were compared with regard to interests and comprehension in the learning material.

In addition, a separate analysis was conducted to investigate the differential effects between tutor and tutee in peer tutoring condition, and the effect of feedback in teachable agent condition.

Method

Participants

Thirty-four (20 male and 14 female) fifth graders participated in the experiment. They were randomly assigned to one of three learning conditions, resulting in 10 in learning by reading condition, 12 in peer tutoring condition, and 12 in teachable agent condition.

Materials and Measures

The basic learning material was the eight-page long text on 'rock cycle' extracted from textbook for the 7th grade. Since 'rock cycle' is the content for seventh graders, the text of 'rock cycle' was revised to be suitable for fifth graders.

The post experimental questionnaire to measure interestingness included 9 items among which 6 items regarding the enjoyment and the interests in the activity and content and 3 items regarding the feeling of the satisfaction and challenge. This scale was developed by Kim et al (2004), and the items were suitably revised. Reliability coefficient of interest questionnaire was .746. The comprehension test score composed of 20 true-false questions on 'rock cycle'.

Procedures

All participants took 30 minutes lesson on 'rock cycle' together to acquire the base knowledge in the domain. After the lesson, participants were randomly assigned to one of the three experimental conditions; reading condition, peer tutoring condition, and teachable agent condition. Next, participants of each condition moved into separated place and performed their own learning activity.

Participants in the reading condition studied 'rock cycle' with the eight-page long text for 30 minutes by themselves. Participants in the peer tutoring condition were paired based on their previous science test score and were asked to teach each other by playing either a tutor or a tutee role. Experimenter assigned a tutor role for those who have higher science test score and a tutee role for those who have lower science test score because previous studies have shown that students with less ability tends to have serious difficulty in peer tutoring (King. 1998). Both tutor and tutee believed that they were randomly assigned to the role although, in fact, their role was predetermined based on test score. Both tutor and tutee were given the same text as was in the reading condition and asked to read it during 10 minutes. After finishing reading, tutors were instructed to teach your tutee freely during 20 minutes at least.

In teachable agent condition, each participant was asked to teach KORI individually and was informed of the basic concept of KORI and how to use it. And then, participants were asked to estimate KORI's final test score. In order to investigate the effect of feedback, KORI's test score was manipulated by providing either

five points more than predict score or five point less than predict score. Thus participants in this condition were randomly assigned to one of the two feedback subgroups. Participants taught KORI for approximately 30minutes, using concept teaching module and concept map module. After finishing all of the learning activities in each condition, all participants were instructed to rate the interestingness using a 5-point scale on their own learning activity and leaning material, and were given the comprehension test.

Results

An ANCOVA was conducted on the interestingness ratings and the comprehension test scores, using participant's previous test score as a covariate. Mean interestingness ratings and standard errors are shown in Table 1 and mean comprehension scores were shown in Table 3.

Interestingness Ratings

The three experimental conditions differed significantly on the interestingness, F (2.31) = 8.75**,** p < .05. Results of LSD analysis indicated that both conditions of the peer tutoring and teachable agent showed more interests in the learning than reading condition.

Table 1: Mean interestingness rating of three conditions

Conditions	Mean	SD	N
Reading	3.702	.123	10
Peer tutoring	4.402	.112	12
Teachable agent	4.090	.112	12

In addition, both of peer tutoring condition and teachable agent condition were divided into two subgroups. They were tutor and tutee subgroups within peer tutoring condition and positive and negative feedback subgroups within teachable agent condition. As a result of these additional analysis, four subgroups differed on participants' interestingness ratings, F (3.20) = 7.17, p < .05, indicating that tutee subgroup and positive feedback subgroup were more interested in the learning than tutor subgroup and negative feedback subgroup (see the Table 2).

Table 2: Mean interestingness rating of four subgroups

Subgroups		Mean	SD	N
Peer tutoring	Tutor	4.180	.120	6
	Tutee	4.621	.126	6
Teachable agent	Positive feedback	4.254	.114	6
	Negative feedback	3.895	.110	6

Comprehension Ratings

There was no significant difference in the comprehension test scores among three conditions. Mean comprehension test scores and standard errors are shown in Table 3. To test the difference among the four subgroups, a separate ANCOVA was conducted. The results indicated no significant subgroup differences.

Table 3: Mean comprehension scores and standard errors

Conditions	Mean	SD	N
Reading	16.076	.586	10
Peer tutoring	16.631	.535	12
Teachable agent	15.805	.532	12

Conclusion

In this study, three conditions were compared in terms of interestingness and comprehension: reading, peer tutoring, and teachable agent, and subgroups were also compared: tutor versus tutee, positive versus negative feedback. It was found that both the peer tutoring and the teachable agent conditions were more interesting than the reading condition and there was no difference in comprehension test scores among three subgroups. The results indicated that the learning by teaching KORI is more interesting than the traditional method of learning by reading, Moreover, the learning through the interaction with KORI were interesting as much as the

peer tutoring. Generally, peer tutoring has been effective in a variety of learning contents and age group. previous researches have demonstrated positive effects on academic achievement and motivation (Cohen, Kulik, & Kulik, 1982). Particularly, tutors in peer tutoring make an effort to engage in active monitoring to probe and correct error and to reorganize their own knowledge and to elaborate their explanation, in order to provide tutee with the useful information (Fuchs et al., 1997). Therefore, tutors seem to benefit even more from tutoring a peer, namely, the opportunity to act as tutor may increase self-efficacy, metacognition skill, and motivation (Keer, 2004; Keer & Verhaeghe, 2005). KORI might reflect the advantages of tutor such as higher competence, autonomy, and responsibility. In this respect, we could predict that KORI showed the similar interestingness to peer tutoring

In fact, teachable agent has more advantages in overcoming the several limitations of peer tutoring. For example, the tutor-tutee was paired with the same gender and only the high achievers were assigned the tutor role, which is impractical in real classroom setting. Nevertheless, the reason for the same interestingness ratings between the teachable agent condition and the peer tutoring condition might be due to the low interestingness ratings for subgroup receiving negative feedback in the teachable agent condition. That is, the negative feedback on their performance in the teachable agent condition might lower the learners' competence and thus decrease their interests. To verify that, we compared positive feedback subgroup with negative feedback subgroup, the result indicated that the positive feedback subgroup was much more interested in the learning than the negative feedback subgroup. It suggests that providing the negative feedback would decrease the interests in learning and should be avoided as much as possible.

Additionally, we compared tutor with tutee in peer tutoring, the result revealed lower interest in tutor condition. The finding is inconsistent with those obtained in previous studies (e.g. Cohen, Kulik, & Kulik, 1982 ; Fantuzzo et al., 1992). We can interpret that because tutor should teach tutee many contents related to rock cycle in a short period of time, tutor might be troubled with the cognitive load of teaching. In designing the teachable agent, it is essential to provide the interface to reduce the users' cognitive load by providing the diverse menu and the abundant learning resources to help them to teach.

In the comprehension, there is no significant difference in three conditions of peer tutoring, teachable agent, and reading. Despite of the significantly less reading time for the learning material in the teachable agent condition, the comprehension test scores were almost identical among three conditions. The previous study related to computer based peer tutoring (e. g. Betty) indicated that teachable agent more actively assist learners in deeper learning and mastering domain knowledge (Leelawong et al, 2003). In this respect, we can predict that if learners continuously perform teachable agent during a long time, they may increase comprehension achievement.

However, there are several limitations in our experiment. Since the number of participants in each condition was small, there are restrictions to generalize the findings to the population. In addition, since participants have only one chance to interact with KORI, they might not be accustomed to the KORI environment and thus have some difficulties to interact with it. If they have more chances to interact with them, learning teachable agent would be more interesting.

Acknowledgments

This research was supported as a Brain Neuroinformatics Research Program sponsored by Minister of Commerce, Industry and Energy

References

Bargh, J.A., and Schul, Y. (1980). On the cognitive benefits of teaching. *Journal of Educational Psychology. 72(5),* 593-604.

Chi, M.T.H., Siler, S.A., Jeong, H., Yamauchi, T., & Hausmann, R.G. (2001). Learning from Human Tutoring. *Cognitive Science, 25*(4), 471-533.

Cohen, P.A., Kulik, J.A., & Kulik, C.C. (1982). Educational outcomes of tutoring: A Meta-analysis of findings. *American Educational Research Journal 19*, 237-248.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. New York; Plenum.

Dweck, C. S. (1986). Motivational process affecting learning. *American Psychologist,* 41, 1040-1048.

Fantuzzo, J. W., King, J. A., & Heller, L. R.(1992). Effects of reciprocal peer tutoring on mathematics and school adjustment. *Journal of Educational Psychology, 28,* 309-323

Fuchs, D., Fuchs, L. S., Mathes, P. G., & Simmons, D. C. (1997). Peer-assisted learning strategies: Making classrooms more responsive to diversity. *American Educational Research Journal, 34,* 174-206.

Ginsburg-Block, M., & Fantuzzo, J. (1997). Reciprocal peer tutoring: An analysis of "teacher" and "student" interactions as a function of training and experience. *School Psychology Quarterly, 12*(2), 134-149.

Jacobs, J.E., & Eccles, J.S. (2000). *Parents, task values, and real life achievement choices.* In C. Sansone & J. Harackiewicz (Eds.), Intrinsic motivation (pp. 408-433). San Diego, CA: Academic Press.

Keer, H. V. & Verhaege, J. P. (2005). Effects of explicit reading strategies instruction and peer tutoring on second and fifth graders' reading comprehension and self-efficacy perceptions. *The Journal of Experimental Education, 73*(4), 291-329.

Keer, H. V. (2004). Fostering reading comprehension in reading strategies and peer tutoring. *British Journal of Educational Psychology, 74,* 37-70.

Kim, S., Yeonhee, S., Misun Y., et. al (2004). The Effect of Performance assessment on intrinsic motivation. *In the Proceedings of the 3th Annual Conference of Korea Educational Psychology.*

Kim. S., Kim, W.S., Yun, M.S., So, Y.H., Kwon, E.J., Choi, J.S., Kim, M.S. Lee, M.J., & Park, T.J. (2003). Conceptual understanding and Designing of Teachable Agent. *Journal of Korean Cognitive Science, 14(3),* 13-21.

King, A. (1998). Transactive Peer Tutoring: Distributing Cognition and Metacognition. *Educational Psychology Review, 10(1),* 57-74.

Kulik, C.-L. C., & Kulik, J. A. (1982). Effects of ability grouping on secondary school students: A meta-analysis of evaluation findings. *American Educational Research Journal, 19,* 415-428.

Lepper, M.R., Aspinwall, L.G, Mumme, D.I., & Chabay, R.W. (1990). Self-perception and social perception process in tutoring: Subtle social control strategies of expert tutors. *Self-inference processes: The Ontario symposium. (pp.217-237).* Hillsdale, NJ: Lawrence Erlbaum.

Malone. T. W., & Lepper M. R. (1987). Making learning fun: taxonomy of intrinsic motivation for learning. *Cognitive and affective process analyses (pp. 223-253).* Hillsdale, NJ: Lawrence Erlbaum.

Peterson, C. (1988, August). Explanatory style and academic performance. *Paper presented at the annual meeting of the American Psychological Association, Atlanta.*

Schwartz, D. L., & Lin, X. D. (2000). Computers, productive agency, and the effort after shared meaning. *Journal of Computing in Higher Education, 12, 3-33.*