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The Idea Storming Cube: Evaluating the Effects of Using Game and Computer Agent to Support Divergent Thinking

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ABSTRACT

The objective of this article is to evaluate the effectiveness of a collaborative and online brainstorming game, *Idea Storming Cube* (ISC), which provides users with a competitive game-based environment and a peer-like intelligent agent. The program seeks to promote students' divergent thinking to aid in the process of problem solving. The participants consisted of 72 11[th] grade high school students who were assigned to one of three conditions: 1) information-based (ISC_{info}), 2) game-based (ISC_{game}) and 3) game-based with peer-like intelligent agent ($ISC_{game\text{-}agent}$) conditions. The results revealed that the ISC_{game} and the $ISC_{game\text{-}agent}$ facilitated diversified ideas in problem solving and were considered beneficial for brainstorming. Although the divergent thinking process may not transfer to problem solving results immediately, it is our hope that the empirical result can shed some lights on the development of game-based systems for collaborative learning and problem solving support.

Keywords

Game-based environment, Divergent thinking, Problem solving, Brainstorming

Introduction

An important objective of science education has been to enhance learners' literacy; this includes, but is not exclusively to science conceptual understanding, science procedural skills, and problem solving ability (American Association for the Advancement of Science, AAAS, 1993). Problem-solving ability is generally viewed as the ability to think divergently, to reason analytically, and to create productively. These tasks all involve quantitative, communication, manual, and critical-response skills (AAAS, 1993). Therefore, how effectively students solve problems depends upon their domain knowledge, creative thinking, reasoning ability, and attitudes.

In educational practice, several strategies and techniques, such as lateral thinking (De Bono, 1973) and brainstorming (Osborn, 1979), have been developed for stimulating/enhancing students' problem-solving ability. Furthermore, a number of previous studies and meta-analyses have demonstrated the use Computer-Assisted Instruction (CAI) in improving students' problem solving ability and academic achievement (Chang, 2001a, 2001b, 2002; Fletcherflinn & Gravatt, 1995). Multiple studies in computer support for creative thinking were conducted in the field of Group Support Systems (GSS) (Duncan & Paradice, 1992). The aforementioned evidences reveal that the use of computers in instruction can be an efficient instrument for enhancing students' problem solving ability.

Recently, game-based computer instruction has emerged as a new provider to support students in the area of scientific literacy. A number of studies indicate that computer game based environments are a powerful means to improve learners' learning motivation and conception acquisition (Ebner & Holzinger, 2007; Papastergiou, 2009). Empirical studies also suggested that computer games can favor the development of various skills, such as meta-cognition, critical thinking and problem-solving skills (Kim, Park, & Baek, 2009; Papastergiou, 2009; Prensky, 2003). O'Neil et al. (2005, p 456) summarizes that Computer games are potentially useful for instructional purposes and may provide multiple benefits, such as improving learning processes and outcomes, improving ability to address cognitive as well as affective learning issues, and enhancing motivation for learning. However, the application of appropriate theories to the design of effective game-based educational tools has not been sufficiently studied (O'Neil et al., 2005). The core question is still as follows: under what condition and in what form will game-based instruction become effective for students' learning?

In this study, two factors are considered while designing game-based educational tools. One of which is how to enable game-based tools to keep students' creative thinking functioning in the problem solving process.

Csikszentmihalyi (1997) suggested that the best state for idea production was the flow state, a mental state of full immersion, involvement and flexibility. From the perspective of cognitive psychology, how students can think flexibly and solve problem effectively depends on how efficiently they can retrieve key concepts relevant to solve the problem from their cognitive structure. In other words, student's thinking might be easily disrupted due to the fact that he/she lacks of knowledge or cannot retrieve key concepts. Therefore, identifying the key concepts that the students cannot retrieve in the problem solving process and providing appropriate information might be an effective way to promoting students' divergent thinking.

Secondly, the type of game-based educational tool should be considered. For example, with respect to the development of game-based environment, competitive oriented cooperation oriented, fantasy oriented and task oriented approaches are adopted widely. Among the approaches, it has been suggested that competitive environment had a positive impact on learning motivation and achievement (Lam, Yim, Law, & Cheung, 2004; Phye, 1997). Students may have better motivation and higher achievement when they are situated in a competitive environment.

For use in the study reported herein, we developed a game-based tool called the "Idea Storming Cube (ISC)" to promote students' divergent thinking in solving the Debris Flow Hazard (DFH) problem. For this tool, we developed a competitive computer game-based environment and peer-like intelligent agent technologies. In Taiwan, the topics related to debris flow hazard are covered extensively in the subjects of physics, geography, and earth sciences (Chang, 2005). Given that the processes by which debris flow hazard occur are frequent in Taiwan, it is crucial to design appropriate tools to promote students' thinking in this topic. We hypothesized that by determining the knowledge of students and then providing them with appropriate key concepts what students cannot retrieve in competitive computer game-based problem solving process, we might improve their divergent thinking and subsequent learning. We compared the effects of different approaches (non game-based with non intelligent-agent support, competitive game-based, and competitive game-based with intelligent-agent support) in promoting divergent thinking and learning outcomes.

System Design

Idea Storming Cube: an Idea Generation Game

It is suggested that the associative basis of the creative process is to combine the usual, unusual, and original ideas for incubating innovations (Mednick, 1962). We adopted Magic Cube (Rubik's Cube) as a metaphor for our creativity support tool called *Idea Storming Cube* (*ISC*). The mechanism of the Rubik's Cube is used to facilitate the combination and association of existing ideas. ISC is also designed as a game, in which the users are encouraged to generate creditable ideas. As a return, the users can get the privilege of rotating the cube and seeing ideas from their peers to stimulate more ideas.

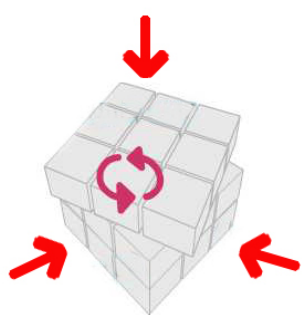

Figure 1: Each participant works on his/her own face of the cube

Conceptually, the game is designed for users to input ideas for brainstorming on a given topic on different faces of a cube as Figure 1 and Figure 2 show. The procedure of playing the ISC game consists of the following steps.

User A *User B*

Figure 2: A user gets another user's idea card by rotating a row through the cube interface

Initiation: Once online, the users are instructed to write down ideas about a problem-solving task. Every user will get a 3x3 array made of 9 cards from a face of the cube.

Brainstorming: The system will ask the users to generate ideas from different perspectives and then fill them into the blank cards with phrases in natural language. The user who proposes a new idea will get a unit of credit and instant response after the idea is validated by the system. The validation will be described in more details in the subsection of user modeling in ISC.

To get more credits, a user who has proposed valid new ideas is allowed to exchange a row or column of his/her cards with another users' row or column, to see potentially new ideas under the direction of the system. If a user writes an unaccepted idea at present, he/she may still get credits later if someone else comes up with the same idea. This encourages users to propose more original ideas as early as possible.

Table 1: Scoring Rules of the Game

Names of rules	Statements of rules
R1	A user can get a full credit and a chance to rotate the cube when he/she proposes a valid idea which no one has written before. R1-1: The suggestions for rotation will be provided by the system for the user to learn other users' valid ideas that he/she has not seen before.
R2	A user can get a partial credit when he/she gets to see others' ideas that he/she has not seen before.
R3	A user does not get any credit if he/she proposes an idea that has been proposed before.
R4	A user does not get any credit when he/she proposes an invalid idea that is not in the current domain model. However, he may get a credit in the future if another user proposes the same idea after him/her.

Evaluation: Finally, a user wins if he/she has generated the largest amount of valid new ideas in a given period of time.

Designing an appropriate set of scoring rules is crucial for an interesting game. In the game of ISC, we have designed special scoring rules, as described below, to encourage users to propose more innovative ideas as early as possible. Table 1 shows a summary of the scoring rules of the game.

The R1 rule is to encourage users to write ideas as soon as possible and as many as possible to get higher credits. The R2 rule is to encourage users to gain better understanding of the current status of the proposed ideas. The R3 rule is to reduce duplicated ideas. The R4 rule is to encourage users to think of more out-of-box ideas even though they are not valid in the immediate context.

The system was designed with the intention of lowering the cognitive load of a user by providing only a partial view of the cube with the hope of increasing the quality of generated ideas. As the game goes on, this partial view of the cube is gradually changed to inspire new ideas. In order to realize this objective, we have developed two techniques to facilitate the monitoring and intervention of the idea generation process: 1) *formal User Profile* (*fUP*) for tracing users' idea generation and perspective shifting and 2) *peer-like intelligent agent* to interact/brainstorm with users.

User modeling in ISC

The user modeling technique we used in ISC is *formal User Profile* (*fUP*), which corresponds to our previous work (Wang, Li, & Chang, 2005; Wang, Chang, & Li, 2008), to model relations between ideas (i.e., divergent thinking) and the justification of ideas (i.e., convergent evaluation) for a creative problem solving task. In ISC, a *fUP* denotes the set of unique ideas in the form of distinct keywords generated by a user. These keywords are extracted automatically from the user's input phrases in natural language. The Domain *fUP* is a special *fUP* developed by a panel of domain experts to capture ideal solutions for the given task. The current version of Domain *fUP* for the DFH task consists of 19 ideas identified by domain experts is classified into 5 categories: geology, ecology, natural factor, urban development, and policy. An idea inputted by a user is validated immediately by the system through keyword matching and put into the profile (*fUP*) of the user. Based on the user model, appropriate feedback is generated and returned to the user as a response.

Peer-like Intelligent Agent

Idea blocking is a common phenomenon in brainstorming activities when the users enter a stage of low productivity. As mention previously, how to enable game-based tools to keep students' creative thinking flexibly in problem solving process is a crucial issue in game-based educational tools design. External stimulations are usually needed for users to overcome the problem and produce more perspective-modifying thoughts. Paradigm preserving and paradigm modifying thinking are two crucial abilities in solving problems (Bostrom, 1998). Paradigm preserving denotes the thinking style that people think within the bounds of the problem context while paradigm modifying denotes the style that their thinking shifts away from the context. As mentioned by Bostrom (1998), paradigm modifying is considered to be a more divergent and creative mode for thinking. Therefore, in ISC, we use a peer-like intelligent agent (denoted by U_{fake}) to act as a perspective-modifying pseudo thinker in order to provide a rich set of ideas as stimuli that the real users might not think of. The agent provides its support only when the user is considered in the state of "idea blocked".

Individual-Level Support

As depicted in Figure 3, fUP_{fake} is a dynamic set. It is constantly updated during the game according to the ideas generated by the users. The objective of this agent is to help the users explore all the ideas in all *fUP*s in a collaborative manner. In other words, ideally different users should explore different parts of all *fUP*s such that the overlap between individual *fUP*s can be minimized for the sake of efficiency.

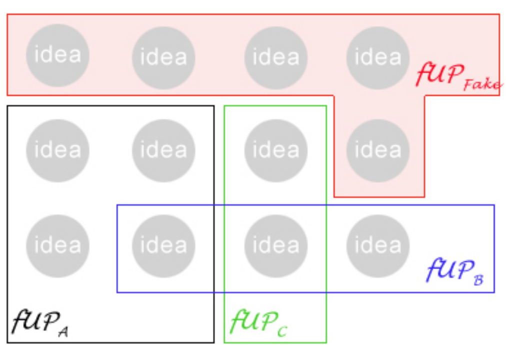

Figure 3: Illustration of using the differences among user models (including the intelligent virtual agent) to stimulate paradigm-modifying ideas

When there is more than one idea in fUP_{fake}, the system selects the one that is most likely to inspire paradigm-modifying thinking. We assume that the coverage rate of each idea category is a good indication of whether a user is at a thinking impasse. We classify the ideas in all *fUP*s into categories and compute the coverage rate of each category for the group. Then an idea from a category with the lowest coverage rate is selected as the contribution by the agent.

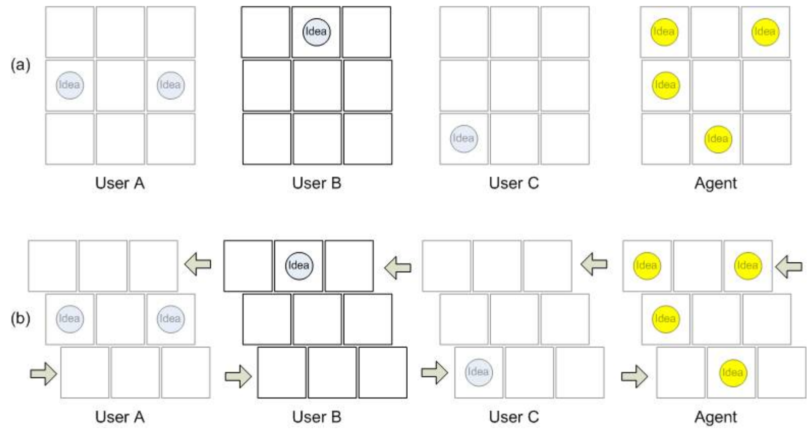

Figure 4: (a) Generating ideas in the agent's view (b) obtaining new ideas from the agent by rotating the cube

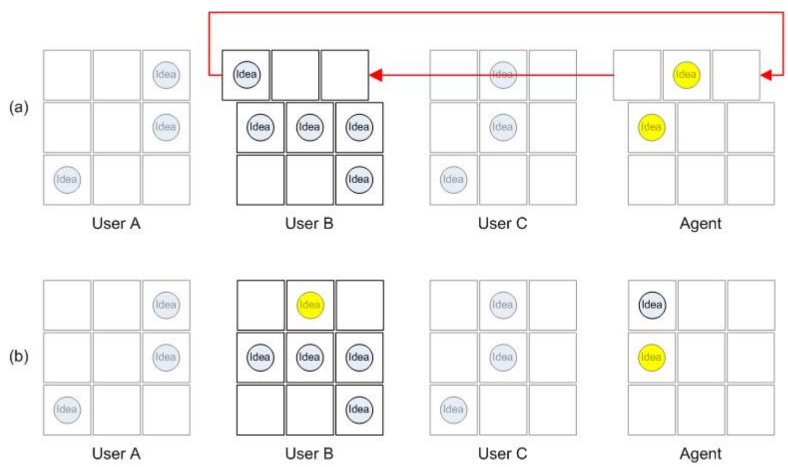

Figure 5: (a) Only rotating an individual user's view with agent (b) after rotating an individual user's view with agent

Group-Level Support

The agent acts as a pseudo user and generates a new idea for all *fUP*s that can potentially benefit all users at the face of the cube managed by the agent, as shown in Figure 4(a). Other users may acquire the idea from the agent by rotating the cube when they are allowed to do so, as shown in Figure 4(b). However, in order to provide timely support for each individual, our system allows the physical constraint of the Magic Cube to be violated (in this special case). We have designed a special mechanism that allows the agent to exchange his row or column with the user's without affecting other users'. An illustration of this mechanism is shown in Figure 5.

Coding Schemes

In this study we analyze following variables:

- the number of submitted ideas: n_{submit},

- the number of new potential ideas: which are the ideas that are not in the current domain model but are identified as good thoughts in the data coding stage: n_{new},
- the number of valid ideas: n_{valid}, and
- the coverage of idea categories (i.e. the number of valid ideas in each idea category): $c_{category}$.

Table 2: The Comparison of the Measurements between ISC and TTCT

Idea Storming Cube	*Torrance Tests of Creative Thinking
Individual-level	
The number of new potential ideas	Originality (statistical rarity of the responses)
The number of valid ideas	Fluency (total number of meaningful ideas)
The coverage of idea categories	Flexibility (the number of different categories)
Group-level	
The number of unique valid ideas	Fluency (total number of meaningful ideas)
The number of unique valid ideas of each category	Flexibility (the number of different categories)

* The measurement 'elaboration' was not matched here

These measurements described above match most of the criteria used in a commonly used test called the Torrance Test of Creative Thinking (TTCT) (Torrance, 1974), as shown in Table 2.

Method

Participants

The participants were selected from a public senior high school in Taiwan. A total of 72 11th graders participated in this study. The current study was conducted in the fall semester in June 2007, in a computer classroom at a public high school in Taiwan. All of them have taken an introductory course on Earth science. Participants were randomly grouped as triads and assigned to one of the three conditions, *information-based* (ISC_{info}) (8 groups), the *game-based* (ISC_{game}) (8 groups), and the *game and intelligent-agent-based* ($ISC_{game\text{-}agent}$) (8 groups).

Experimental Design

A quasi-experimental format was used in this study. The data collection consisted of three phases: (1) assessing the conception of the students before the ISC experiment, (2) doing the ISC experiment, and (3) exploring students' idea generation ability during ISC implementation and the conception learning after ISC experiment. Table 3 shows the research procedures and overall architecture of the study.

Table 3: Instructions and Times for the Steps in the Experiments

Steps	**Instructions**	**Time**
Pre-experiment test	Asking participants to take the Domain-Specific Knowledge Test (DSKT) and the Reasoning Skill Test (Hasler, Kersten, & Sweller) (Chang et al., 2007) for assessing prior knowledge and reasoning skills.	15 min
Brainstorming	Asking participants to work on the DFH task.	15 min
Post-experiment test	A second idea generation task as the transfer test for generating ideas for a related but distinct problem	20 min

In the first phase, all subjects were assessed by Domain-Specific Knowledge Test (DSKT) and the Reasoning Skill Test (Hasler et al.) to measure student's prior knowledge relevant to the DFH topic. In phase two, students were assigned randomly to three groups and the students were asked to complete the ISC_{info}(non game-based with non intelligent-agent), ISC_{game},(game-based with non intelligent-agent), and $ISC_{game\text{-}agent}$ (game-based and intelligent-agent). Finally, in the third phase, all subjects were assessed by an open-ended question "*Please describe what facilities or solutions may prevent a debris flow hazard from happening?*" to explore their learning outcome from brainstorming activity.

Table 4: The Comparison of Three Conditions

	Info-based ISC	Game-based ISC	Game&Agent-based ISC
Information-sharing window	√		
Game competition rules		√	√
Agent support			√

In order to investigate the effect of game and agent support on idea generation and learning, we compared the results obtained in the system with three different conditions as shown in Table 4. In ISC_{info}, ideas entered into the system by any of the group members were shared immediately in an information-sharing window. There was no rule to limit information sharing. It was similar to information exchange through instant messaging. An information-sharing window was used to show the ideas submitted by the group members as illustrates in Figure 6. A user did not get any credits if her proposed ideas had already appeared.

Figure 6: The user interface with the information-sharing window in the ISC_{info} group

In ISC_{game}, game rules were applied but there was no support from the intelligent agent in the form of inserting artificial ideas as stimuli. $ISC_{game-agent}$ is a comprehensive system that applies both game rules and an intelligent agent support. A student only had a limited view of ideas in a face of the cube, and she/he could see other group members' ideas only if she or her peers rotated the cube. The intelligent agent, as mentioned in previous section, is used to provide inspiring ideas as a pseudo user. Figure 7 shows the user interface used in ISC_{game} and $ISC_{game-agent}$.

Figure 7: The user interface without the information-sharing window in the ISC_{game} group and the $ISC_{game-agent}$ group

Data analysis

To analyze how the idea generation and learning outcomes of the students in the three groups were affected by the design of the ISC, two tasks were performed: (a) a univariate analysis of covariance (ANCOVA) was performed on the post-test learning results from brainstorming activity with the pretest results as the covariate and (b) univariate ANOVA was used to determine separately the statistical significance of ideas generation among the three ISC groups. The level of confidence was set at the 0.05 significance level. To meet contemporary calls for improvement in the interpretation and reporting of quantitative research in education, we have reported the practical significance (effect magnitudes) along with each statistical significance test. The effect size indices *f* were calculated because it is appropriate for the analysis of variance (Cohen, 1988). According to Cohen's rough characterization, $f = 0.1$ is deemed to be a small effect size, $f = 0.25$ a medium effect size, and $f = 0.4$ a large effect size. Post-hoc testing was performed using Scheffe's F test because this has been demonstrated to be the most powerful post-hoc multiple comparison procedure. Tests of the assumptions used for the ANCOVA and inferential statistical analyses were performed using SPSS ver. 13.0 (Chicago, IL, USA).

Results

Due to an unexpected system failure, with some groups of students at a later time in the experiment, only 54 students' data were completely recorded (these students were from different groups: 18 students counter system failure, 12 of them were from ISC_{info} group and 6 were from $ISC_{game\text{-}agent}$ group). Nevertheless, the Kolmogorov-Smirnov tests show that n_{submit} (p =1.00), n_{new} (p =.37), n_{valid} (p =.35), and $c_{category}$ (p =.53) all conformed to the assumption of normality (i.e., p >.05). Besides, the Levene's tests of the homogeneity of variance also revealed that the error variance for each dependent variable was approximately equal across groups. Although, the sample size was reduced, the sample may be deemed as representativeness for the purpose of the study under investigation.

Table 5: Statistics of the Numbers of Submitted Ideas, Valid ideas, and New Potential Ideas among the ISC_{info} group, ISC_{game} group, and $ISC_{game\text{-}agent}$ group

Condition	*Mean (SD)*	*ANOVA F*	*P*	*f*	Post hoc Sheffe
Submitted ideas (n_{submit})					
ISC_{info} (n=12)	20.17 (8.85)	5.90	0.00^{**}	$0.48^{‡}$	$ISC_{game}>ISC_{info}^{**}$
ISC_{game} (n=24)	33.58 (11.80)				$ISC_{game\text{-}agent}>ISC_{info}^{**}$
$ISC_{game\text{-}agent}$ (n=18)	34.00 (14.15)				
Valid ideas (n_{valid})					
ISC_{info}	6.42 (2.15)	6.58	0.00^{**}	$0.51^{‡}$	$ISC_{game\text{-}agent}>ISC_{info}^{**}$
ISC_{game}	7.71 (1.37)				
$ISC_{game\text{-}agent}$	8.94 (2.26)				
Potential ideas (n_{new})					
ISC_{info}	2.83 (1.85)	1.71	0.19	$0.26^{†}$	
ISC_{game}	4.00 (2.54)				
$ISC_{game\text{-}agent}$	4.72 (3.41)				

* $p < 0.05$, ** $p < 0.01$, Effect size: ‡large, †medium

Students' ideas Generation Among Different Conditions

As shown in Table 5, significant differences were identified among the three groups with respect to n_{submit} (F (2, 51) = 5.90, $p < 0.01$, $f = 0.48$, large effect size), and n_{valid} (F (2, 51) = 6.58, $p < 0.01$, $f = 0.51$, large effect size). There was no significant difference among groups in terms of n_{new} (F (2, 51) = 1.71, $p = 0.19$, $f = 0.26$, medium effect size). Note that though the result was marginally statistically significant, a practical significance (effect size) has been observed (medium effect size). Cohen (1988) and Daniel (1998) pointed out that it is inherently more difficult for a small size of samples to achieve the statistical significance than a large one even if both have the same effect size. Therefore, it is quite possible to observe a statistical significance with a larger sample size for the results of this study. The result of medium effect size may signify the possibility of finding statistical significance of this comparison with a future replication of study with a larger sample size.

Post Hoc Scheffe test analysis revealed that, for n_{submit}, students' ideas in ISC_{info} was significant lower than ISC_{game} and ISC_{info}-$ISC_{game\text{-}agent}$;and for n_{valid}, students' ideas in ISC_{info} was significant lower than $ISC_{game\text{-}agent}$. These results suggested that participants were more active and engaged in the brainstorming task when the game competition rules were applied.

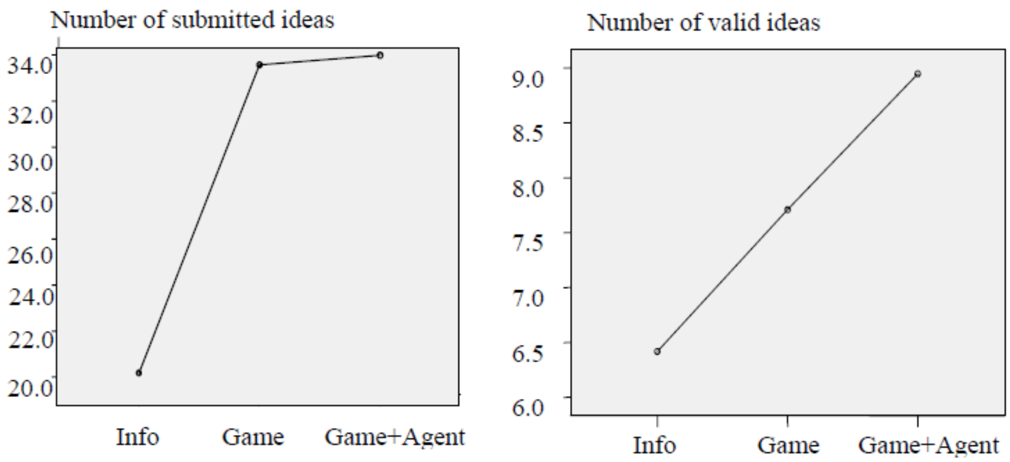

Figure 8: The plot on the numbers of submitted ideas and valid ideas

Figure 8 shows that the competitive computer game environment significantly improved the attempts to generate ideas, and the intelligent agent further improved the efficiency of idea generation. While n_{submit} were about at the same level for ISC_{game} and $ISC_{game\text{-}agent}$, $ISC_{game\text{-}agent}$ outperformed ISC_{game} in n_{valid} that had been generated. In other words, $ISC_{game\text{-}agent}$ was the most effective and efficient condition based on the ratio of valid ideas to submitted ideas.

Next, in order to understand the diversity of participants' ideas, we looked into $c_{category}$, which is the number of valid ideas falling into five categories under this domain. Table 6 presents the descriptive statistics of ideas associated with each category.

Table 6: Descriptive Statistics on the Idea Coverage of Each Category for Individual Participants

Condition	*Mean (SD)*	*ANOVA F*	*p*	*f*	Post hoc Sheffe
Geoglogy					
ISC_{info} (n=12)	1.75 (0.62)				
ISC_{game} (n=24)	2.04 (0.75)	0.89	0.42	0.19†	
$ISC_{game\text{-}agent}$ (n=18)	2.11 (0.83)				
Ecology					
ISC_{info}	1.67 (0.65)				
ISC_{game}	1.79 (0.41)	0.32	0.73	0.11†	
$ISC_{game\text{-}agent}$	1.67 (0.68)				
Nature					
ISC_{info}	0.50 (0.52)				
ISC_{game}	0.63 (0.49)	0.42	0.66	0.13†	
$ISC_{game\text{-}agent}$	0.67 (0.48)				
Urban Development					
ISC_{info}	2.42 (1.24)				
ISC_{game}	3.54 (1.10)	4.09	0.02*	0.40‡	ISC_{game} >ISC_{info} *
$ISC_{game\text{-}agent}$	3.50 (1.24)				
Policy					
ISC_{info}	0.08 (0.28)				ISC_{game} >ISC_{info} **
ISC_{game}	0.17 (0.38)	17.87	0.00**	0.84‡	$ISC_{game\text{-}agent}$>ISC_{info} **
$ISC_{game\text{-}agent}$	0.94 (0.63)				$ISC_{game\text{-}agent}$>ISC_{game} **

* p<0.05, ** p<0.01, Effect size: ‡large, †small

The results in Table 6 reveal that there were significant differences in the categories of urban development (p = 0.02), and policy ($p < 0.01$) across conditions but no significant difference was found in other categories. Post-hoc Scheffe test revealed that in the category of urban development, ISC_{game} outperformed ISC_{info}. And in the category of policy, $ISC_{game\text{-}agent}$ outperformed ISC_{game} as well as ISC_{info}. This indicates that the provision of agent support was effective in guiding students to explore a less explored category like the "policy" category.

Students' Performance in Pre-post Implementation Test

We conducted a pre-post implementation test design in order to explore the influence of interventions on students' future performance. As shown in Table 7, the results of the ANCOVA showed that there were statistically significant differences in the adjusted posttest mean vectors among the three groups (F (2, 51) = 3.71, p = 0.03, f = 0.41, large effect size).

Table 7: Descriptive Statistics for the Adjusted Post-Test SCT Scores for the Different ISCgroups

Treatment	Adjusted posttest scores	*ANCOVA* *F*	*p*	*f*	Post hoc
ISC_{info}	37.00 (11.31)	3.71	0.03^{*}	$0.41^{‡}$	$ISC_{info} > ISC_{game}^{**}$
ISC_{game}	26.78 (10.50)				$ISC_{game\text{-}agent} > ISC_{game}^{**}$
$ISC_{game\text{-}agent}$	33.31 (10.64)				

* $p < 0.05$, Effect size: ‡ large (close to 0.4)

Post-hoc multiple comparisons reveals that the ISC_{info} condition outperformed the ISC_{game} condition (p=0.01) and $ISC_{game\text{-}agent}$ outperformed the ISC_{game} condition (p=0.06). The result appears to be contrary to the results observed in the main task.

Discussions

Game-based learning environment can improve students' in the area of idea generation and brainstorming

In this work, we designed an educational game to support idea generation and conducted an empirical study to investigate the utility of various designs. The major finding of this study was that game-based learning environment can improve students' idea generation function. In particular, the performance in ISCgame-agent group was better than the other two groups. As mentioned above, recent theoretical and empirical evidences suggest that group interaction and competition is beneficial in the generation of new ideas. Therefore, it is reasonable to see that game competition can engage students more in their brainstorming activity and also encouraged students to think more diversely.

The peer-like intelligent agent can improve students' divergent thinking ability

By analyzing the number of valid ideas and categorical coverage among generated ideas, we found that adding a peer-like agent to the game environment is helpful in guiding students to visit unexplored categories during idea generation. Positive empirical supports were also found from the analysis of the experimental results. As shown previously, in comparing the coverage rates in idea categories, the peer-like intelligent agent was able to help students explore rarely visited categories, such as the "policy" category.

Students get higher learning outcome in ISC_{info} group and $ISC_{game\text{-}agent}$ group

Although the competitive game-based design was shown to be more effective than the information-sharing support in the main brainstorming task, its effect seemed to be less clear or somewhat at the opposite in conception learning. The students who worked with the game-based system without intelligent agent support appeared to be the least successful group among the three in the transfer test. This may implicate that although game competition contributes positively to productive divergent thinking, participants' dispositions to explore and to think diversely may just be temporary (i.e., during the time when the game rules are available). Therefore, when the game environment was removed, the thinking disposition did not persist or transfer to the subsequent test in which they were asked to work individually without any support.

A common concern with educational games is the risk of students' 'gaming the system' instead of focusing on the content. In our design, this phenomenon was alleviated because of the form of the game, where the students usually concentrated on writing down their thoughts to the given open-ended question. Nevertheless, it is difficult to eliminate the attitude of "gaming" in the system totally. For the ISC_{game} group, we think that the students may lose their gaming strategies and their motivation for divergent thinking when the game context was suddenly removed in the transfer test.

Another alternative explanation for this contradiction is that the post-experiment test reflected their understanding of the domain knowledge rather than their ability in divergent thinking. In the ISC_{game} and $ISC_{game-agent}$ groups, students have a limited view of nine ideas at maximum because we wanted to make them focus on extension of a few ideas in their limited working memory. In contrast, in the ISC_{info} *group*, students could review all ideas appearing in the information window at any time. In the information sharing and the gaming with agent conditions, more cues related to the domain knowledge of earth science (and thus the transfer task) were exchanged and made available. These cues may have helped participants generate more ideas in the transfer task.

When combing the results from the main task and the post-experiment task, we may conclude that gaming with agent was the best design among the three conditions because it supported students in generating the most ideas with superior efficiency in the main task.

Conclusion and Future Work

In this work, we proposed to incorporate game competition and peer-like agent to design a brainstorming-support system for creativity learning. We also conducted an experiment that compared three different types of brainstorming-support systems by experimental manipulation (i.e., ISC_{info}, ISC_{game}, and $ISC_{game-agent}$ conditions). The results show that the game-based brainstorming system with intelligent agent support outperforms the other types of systems. With the support of peer-like agent, the game's competitive environment can help users to concentrate on brainstorming tasks and aid them them in thinking from different viewpoints. It is suggested that the game-based brainstorming system with intelligent agent support is the most applicable, especially if we would like to use this system for students to broaden their ideas and views.

From our experimental results, it is not clear about the effects of reducing cognitive load in the working memory on divergent thinking and learning outcome. The ISC_{info} groups had the information-sharing window to review all ideas. The students in these groups performed better in the transfer test maybe due to the fact that they have chances to accumulate more knowledge after repeatedly browsing this information. Nevertheless, the thinking ability of a person may be difficult to change simply by playing this game a single time. It is worthy to conduct a sequence of experiments on the same students with different topics to observe the change of their paradigm-modifying thinking habits.

At this time, we did not have the comparison between individual and group brainstorming in our experiments. The group brainstorming activity is suitable for the people from different fields because their diverse perspectives may stimulate each others. However, the participants of this experiment are homogenous in their age, education, and living environment. In addition, we should conduct more qualitative analysis to evaluate this system for examining the quality of ideas because the psychometric approach is not enough to measure creativity. It would be worthwhile to conduct pedagogical learning activities on more subjects and then observe the long-term effect of creativity learning.

Note that in the current work, the baseline employed for comparison is the information-sharing condition, which can be viewed as a standard setting for typical group brainstorming. However, social psychological research has suggested that brainstorming groups may suffer from process losses due to various structural or socio-affective factors, such as production blocking due to turn-taking, social loafing and evaluation apprehension (Mullen, Johnson, & Salas, 1991). Generating ideas individually without information sharing and then pooling everyone's ideas collectively may actually lead to the best overall outcome. It might be noteworthy to further investigate whether game competition and agent support may compensate for process losses in brainstorming groups using the experimental technique of nominal brainstorming (Mullen et al., 1991).

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