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Collaborative Discovery Learning Based on Computer Simulation

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论著选摘

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Abstract

A growing number of studies have focused on scientific discovery learning based on computer simulation. However, most previous individual discovery learning without considering the perspective of social interaction. This study implemented an experiment a graders to investigate the effects of peer collaboration and questioning-explanation prompt on simulation-based scientific disc In the result, peer collaboration had prominent effect on the discovery outcomes, intuitive understandings and variable control influence of the questioning-explanation prompt was less clear, hence need to be addressed in depth in future studies.

Keywords: Collaborative learning, discovery learning, simulation, peer learning

INTRODUCTION

The most recent developments in learning theory including social constructivism, situated learning and distributed cognition ha interpret learning as an active knowledge construction process occurring in social and authentic contexts. From these perspecti technologies should be harnessed as powerful mind tools to enhance generative understanding, higher order thinking, as well as interactions, rather than merely be added in classrooms as media for information transmission. Within the constructivist paradi number of studies have focused on scientific discovery learning based on computer simulation (van Joolingen and de Jong, 1997). dedicated to explore the processes and effectiveness of collaborative discovery learning in computer simulation environment.

Supporting scientific discovery learning in simulation environment

Since computer simulation has the capacity to provide learners with an exploratory learning environment, it has been regarded a tool for scientific discovery learning. Nevertheless, many studies designed to contrast the effectiveness of simulation-based d learning to some mode of traditional learning found little persuasive evidence in its favor (see Banggert-Drowns, Kulik, & Kuli & Andre, 1992). The question arises, why does simulation-based learning, involving learners in active inquiry, not improve lear more consistently? One explanation lies in the wide range of difficulties learners may encounter in coping with discovery learn De Jong and van Joolingen (1998) classified the problems that learners may encounter into four categories: (a) difficulties in hypotheses, (b) poorly designed experiments, (c) difficulties in data interpretation, and (d) problems regarding the regulation learning. Despite its potential in stimulating constructive learning activities, it seems that the simulation-based learning en guarantee effective learning without sufficient support ("scaffolding") for discovery learning activities. This conclusion ha supported by Lee's (1999) meta-analysis showing that hybrid simulation involving instructional elements is more effective than for new knowledge acquisition.

Studies have been conducted to help learners with particular strategies from specific aspects. For example, some researchers d supportive methods to help generate hypothesis in simulation-based discovery learning (Njoo & de Jong, 1993; Quinn & Alessi, 19 Glaser, 1990). Others have looked at the issues connected with experimental design (Leutner, 1993), planning (Tabaket al., 199 the phenomenon and predicting the result (de Jong, 1999), and access to an appropriate knowledge base (Lewis et al., 1993).

Until the recent times, most studies on supporting simulation-based discovery learning adopted the strategies-oriented solution examine the effect of specific strategies according to learners' difficulties in particular aspects. In his doctoral dissertat (2000) proposed a triple scheme of learning support design for simulation-based scientific discovery learning. It was hypothesi interrelated main conditions may determine the effectiveness of scientific discovery learning to a great extent. (1) *The meanir discovery processes*: Learners need to activate their prior knowledge and map the knowledge on to the problem being addressed to representing the problem and generating appropriate hypotheses and understandings. (2) *The systematicy and logicality of discov* Effective discovery learning involves proper scientific reasoning, the systematical manipulation of the variables and qualified designs. (3) *The reflective generalization* over the discovery processes, which means the self-monitoring of the discovery proce reflective abstraction and integration of the discovered rules and principles. According to the three hypothesized conditions, learning supports were designed and geared towards the three spheres: (a) *interpretative support* that helps learners with knowl activation and the generation of appropriate hypotheses and coherent understandings, (b) *experimental support* that scaffolds le systematic and logical design of scientific experiments, the prediction and observation of outcomes, and the drawing of reasona and (c) *reflective support* that increases learners' self-awareness of the thinking and understanding processes and prompts the abstraction and integration of their discoveries. Three experiments were implemented to investigate the internal conditions by effects of the three types of learning support. Overall, the results support the main hypotheses, showing that generative meani systematic and logical design of experiments, and the reflective generalization constitute three essential internal conditions discovery learning, hence learning supports geared to the three spheres should be taken into account when designing simulation- learning environment.

The role of collaboration in discovery learning and reasoning

In most studies, scientific discovery learning is regarded as an individual scientific reasoning process that involves the gene hypotheses and testing them against the collected evidence (Klahr and Dunbar, 1988). The perspective of social interaction has disregarded to some extent. Collaborative discovery is a common and growing practice in science, but has not yet been extensive (Okada & Simon, 1997). In a study, Li & Chen (2000) compared two modes of cooperatively using computers in primary geometry lea Cooperative Tool mode in which learners in small groups used Windows PBrush to explore the area of rectangles, and Cooperative learners used tutorial CAI program cooperatively to learn the same knowledge. In the results, Cooperative Tool mode brought on outcomes in reasoning ability, geometric knowledge, and learning motivation than Cooperative CAI. The outcomes seem to imply th combined with open technology tools have more potentials to promote explorative learning and higher-order thinking.

Among the few studies concerning collaborative reasoning or discovery, Gorman et al. (Gorman et al., 1984; Gorman, 1986) studie bias in group scientific discovery using a rule-discovery task - the "2-4-6 task". Subjects were instructed to follow either a strategy, a disconfirmatory strategy, or a combination of the two. In the result, groups outperformed individuals, and subjects disconfirmatory condition performed best, followed by those in the combined condition and the confirmatory condition respective (1992) studied the effect of group versus individual problem solving and the effect of entertaining multiple hypotheses versus hypothesis in the 2-4-6 task. The groups outperformed individuals, and in the multiple hypotheses condition groups used more di than individuals, which had improved their performance.

In an important study of collaborative discovery learning, Teasley (1995) investigated the role of verbal behavior in fourth gr peer collaborations in accomplishing the spaceship task. The subjects were assigned to one of the four conditions: Talk Alones problem alone while talking aloud; No-Talk Alones solved the problem alone without talking aloud; Talk Dyads solved the problem while talking to each other; No-Talk Dyads solved the problem with a partner without talking to each other. Talk Dyads performe by Talk Alones and No-Talk Alones, with No-Talk Dyads performing worst.

Pilkington & ParkerJones (1996) described a formative evaluation study in which medical students were recorded interacting with model of calcium balance. The role of dialogue interaction, between students and between experimenter and student, was investig potential source of learning support. Although all students demonstrated learning gains, these were greater amongst single stud with the experimenter than amongst students co-operating on tasks in pairs. Dialogue analysis revealed that experimenter-studen contained many more inquiries causing students to explain their reasoning, justify their conclusions, or state implications fro prompting of reflective activity seemed to result in a deeper understanding of the physiological model.

Okada & Simon (1997) explored the processes and effectiveness of Singles' and Pairs' discovery activities using protocol analys
Subjects who were undergraduate students were asked to discover molecular genetics laws in a computer micro-world. Compared wit
were more successful in discovering the correct rules, and participated more actively in explanatory activities (i.e. entertain
and considering alternative ideas and justifications). Explanatory activities were promotive for discovery only when the subjec
conducted crucial experiments. Explanatory activities were facilitated when paired subjects made requests of each other for exp

Discourse patterns for mediating collaborative learning

Collaborative learning context provides opportunities for learners to interact with one another in verbal and non-verbal, paral
It is the levels and patterns of interactions that determine the effectiveness of collaborative learning. In the studies of gro
Webb (1989) consistently found that giving elaborated explanations to others in the group is a strong predictor of achievement.

In a series of studies of peer learning, King (1999) developed a procedure called "Guided Peer Questioning", which is a questic
answering procedure designed to promote interaction and learning in small groups. This procedure is guided by structured questi
such as, "Why is …important?", "How is …similar to …", "What does … remind you of ? And why?". These open-ended question st
provided to members of the learning group, who then use the starters to guide them in generating their own specific questions r
material being studied. A series of studies (King, 1992, 1994; King & Rosenshine, 1993) revealed that when students were taught
other these thought-provoking questions during learning, their questions prompted high-level interaction and learning. Similarl
(1998) examined the effect of scaffolded explanation-based approach in collaborative discussion in classroom settings. During d
learners in experimental groups were given prompt cards to guide their questioning activity toward each other. This approach wa
great help in promoting learners' understanding of scientific knowledge. However, the learning tasks used in the above studies
knowledge acquisition in lecture or text-based context. Could such kind of reciprocal questioning and explanation approach faci
collaborative discovery learning based on computer simulation? No study so far has been found to address this question.

The Purpose of the Present Study

While collaborative discovery learning with simulation is an important topic, relatively few experimental studies have been con
it. Among the few relevant studies, what researchers are interested is not how students deal with discovery learning collaborat
mainly human's scientific discovery as a topic in psychology of science (Okada & Simon, 1997; Gorman, 1986; Freedman, 1992). Ve
have been conducted to explore collaborative discovery learning among young learners in schools. Could collaboration function a
learning support to facilitate learners' discovery processes based on computer simulation? How will reciprocal questioning and
activities promote discovery learning? This study aims at answering these questions through an experiment. Peer learning approa
adopted among collaborative subjects. Explanatory prompt cards will be used to guide learners' questioning and explanation acti
effects and the processes will be evaluated to reveal the influence of the treatments.

METHOD

The Simulation Learning Environment

The domain chosen for the simulation was floating and sinking, where the subjects were required to explore the upthrust on obje sinking in water. This topic is one of the core issues in secondary science learning and encompasses the representative variabl scientific discovery tasks. In this study, learners' task was to discover which one or more of three given factors (shape, mas object) were related to the size of the upthrust on an object. For floating objects, the upthrust equals to its weight and the pair of balanced forces, which make an object stay still in water. So the mass of object is the only influential factor to the under this circumstance. For objects submerged in water, as can be predicted based on Archimedes's law, the size of the upthrus on the volume of the object, because the volume of object determines the volume of the excluded water, which influences the siz upthrust in turn. Learners often hold misconceptions about this phenomenon, e.g. assuming that the size of the upthrust depends volume of the floating object.

The simulation started with floating objects determined by the default parameters (volumes, masses) in the program. No delibera was offered to guide the subjects to take both floating and sinking circumstances into account when conducting experiments with

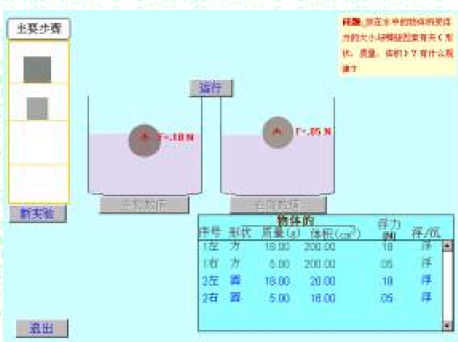

Figure 1. Interface of the simulation software

The simulation adopted paired-instance design that requires learners to construct a pair of experiments at a time, so that t contrast the outcomes of two instances conveniently. For example, in order to examine the effect of the volume of object, a lea two objects of the same shape (e.g. ball) to the top of the left and right container, set the values on the left and right to k the same, and vary the volumes to be different. Then he/she can click the "RUN" button to see whether the upthrusts will be d in result. For all the students, a data sheet was provided on screen to record and display the value of the input and output va pair of experiments. In addition, a permanent button "Main Steps" was prepared to remind learners of the main steps in an exp simulation program was written in such a way that it registered learners' manipulations during the learning processes and wrot each subject.

Research design

In order to investigate the effects of peer collaboration and questioning-explanation prompt on simulation-based discovery lear
(pair/single) 5 2 (with/without explanatory prompt) 5 2 (floating/sinking) mixed design was adopted to compare the learning eff
subjects under four conditions: Prompt Pairs, No-Prompt Pairs, Prompt Singles, and No-Prompt Singles. The effectiveness in disc
underpinning rules for floating and sinking objects was contrasted by including floating/sinking as a within-subjects factor. C
influence of learners' pre-existing physics performance, the achievements on the most recent final physics exam was collected a
covariate when conducting ANOVAs. Log-files were used to analyze how learners designed simulated experiments and made the disco

Subjects

Subjects were 44 eighth grade students from a junior high school in Beijing. The students ranged in age from 13 to 15, with an
13.88. Twenty-one were boys and twenty-three were girls. The subjects were randomly distributed into four groups: Prompt Pairs
Prompt Pairs (n=12), Prompt Singles (n=10), and No-Prompt Singles (n=10). The overall evaluation of the subjects provided by th
teacher indicated no significant difference among the four groups in respects of their physics knowledge and experience with co

Assessments

The effectiveness of the discovery learning was assessed from the following perspectives:

Discovered rules. The subjects were required to summarize their discovery when they finished the experiment. A full score of 3
subject had clearly stated the exact rules for floating and sinking objects. A score of 2 indicated that the subject had made a
description (i.e. "Mass and volume is relevant to the size of upthrust.") without considering the differences between floating
objects. Score 1 was given when only one of the related factors (volume or mass) was mentioned. Score 0 meant that a subject ha
thoroughly wrong or irrelevant conclusion.

Intuitive understanding. Nine multiple-choice questions were designed to measure learners' intuitive understanding, which is r
important goal in scientific discovery learning (see de Jong et al., 1999). Each item depicted a pair of objects with different
shapes, masses, and volumes. Learners were asked to predict how the upthrusts would compare in size. Four of the items were rel
upthrusts on floating objects and five were geared to upthrusts on sinking ones.

Variable control skills. Variable control ("Change one thing at a time") is an important principle in scientific experiment.
learners are often found to vary many variables in one experiment (Glaser et al., 1992; Lin & Lehman, 1999). This test included
evaluate learners' variable control strategies in scientific experiment by providing the cases of experiment designs (either w
or with flaws) for learners to make critical evaluations and justifications. Similar methods have been frequently used in the r

variable control skills (see Ross, 1988).

Evaluation of learners' experiments. Surrounding the principle of variable control, we evaluated learners' experiments conducte learning process, which had been recorded in their log-files. In specific, we evaluated how learners had made ***focused examinat*** variables under floating and sinking conditions. We identified a pair of experiments as having undergone a "focused examinatio variable (shape, mass or volume) if that variable was the only variable that was varied in that pair of experiments. For each v score of 2 was given when it had been examined by at least two pairs of experiments at different levels of the controlled varia is shown in Appendix). Score 1 indicated that the variable had been examined by only one pair of experiments or by more than on experiments but at constant levels of controlled variables. Sequentially, score 0 meant that no experiment had been focused on all. Average scores across the three variables were used to evaluate learners' focused examinations under floating and sinking respectively. This index reflects the distribution of well-controlled experiments across the features and conditions, hence ind logical and systematic searches in the experiment space during discovery processes.

Procedure

The study took place in a computer laboratory equipped with 50 networked Pentium II computers. The subjects were required to ac following tasks in pairs or individually:

1. *Warm-up.* Subjects worked with a tutorial version of the simulation program. Three experimenter was present to answer their regarding the program. This stage lasted approximately 10 minutes.

2. *Problem presentation.* The subjects were asked to explore which one or more of the factors among shape, mass and volume influ upthrust on an object either floating or sinking in water. A brief description of the problem was available on the top-right co screen throughout the discovery process.

3. *Exploration.* All subjects were reminded that their task was to discover the rules on the basis of sufficient evidence throug experiments. Subjects in pairs were required to accomplish the task collaboratively and were told that they were to be evaluate For the Prompt Pairs and Prompt Singles, explanatory prompt cards were put in front of their monitors, reminding them the quest ask their partners or ask themselves during the exploration processes. These questions included: (1) what's the objective of th (2) How should the experiment be designed to achieve this objective? (3) What does this experiment mean? (4) How can the experi this conclusion? (5) I think the result doesn't support this conclusion, because… (6) I think this is not the exactly right co because… The subjects were required to summarize their discovery at the end of this stage.

4. *Posttest.* The posttests of intuitive understanding and variable control skills were administered immediately after the comp exploration in written format. A total of 30 minutes was allotted for this session.

RESULTS

Evaluation of the rules discovered by different groups

Table 1. The discovery outcomes of different groups

Groups	M	SD
Prompt Pairs	1.500	.905
No-Prompt Pairs	1.667	.492
Prompt Singles	1.200	1.033
No-Prompt Singles	1.400	.843
Total	1.455	.820

Table 1 shows the evaluation results of the discovered rules of different groups. There were relatively few students who had c the exact rules for floating and sinking objects. The univariate ANOVA using collaboration and explanatory prompt as fixed fact learners' recent physics scores as covariate indicated that collaboration had significant main effect on the discovery outcome p=.021). Pairs have discovered the underpinning principles more successfully. A clear interaction was observed between collabor covariate (F(1, 36)=5.410, p=.026). In order to make clear the pattern of the interaction, we aggregated the subjects into two to the median of their physics scores. Simple effect analysis revealed that collaboration had significant positive effect among achievement learners (F(1, 41)=6.07, p=.018), whilst had no significant influence to higher achievement learners. The overall a prompted learners displayed to be lower than learners without prompts. However no significant main effect or interaction was ob explanatory prompt (p>.10) in the statistic analysis.

The effects of collaboration and explanatory prompt on intuitive understanding test

Table 2 indicates the means and standard deviations of learners' intuitive understanding of the upthrusts on floating and sinki

Table 2. The means and standard deviations of intuitive understanding test

Groups	Floating		Sinking	
	M	SD	*M*	*SD*
Prompt Pairs	1.000	.603	2.000	1.045
No-Prompt Pairs	2.333	1.303	1.250	1.288
Prompt Singles	1.100	.738	1.500	.850
No-Prompt Singles	1.100	.994	2.100	.738
Total	1.409	1.085	1.705	1.047

The repeated measures MANOVA was implemented using collaboration and explanatory prompt as between-subjects factors, floating/s within-subjects factor, and learners' physics scores as covariate. There was a marginally significant main effect for collabor =3.047, p=.089), indicating that Pairs outperformed Singles on intuitive understanding test. A marginally significant interacti observed between collaboration and learners' physics achievements (F(1, 36)=3.303, p=.077). Simple effect analysis revealed th had significant positive effect to higher achievement learners (F(1, 41)=8.000, p=.007), whilst had no significant effect to lo ones (p>.10). No notable main effect or interaction was observed for explanatory prompt (p>.10).

Analysis of learners' variable control skills

Table 3. The means and standard deviations of learners' variable control skills

Groups	M	SD
Prompt Pairs	4.75	1.42
No-Prompt Pairs	4.83	1.03
Prompt Singles	3.30	2.06
No-Prompt Singles	4.40	1.58
Total	4.36	1.60

Table 3 shows the scores of variable control skills by different groups of learners. The ANOVA using collaboration and explanat fixed factors revealed that there was a significant main effect for collaboration (F(1, 40)=4.098, p=.050). Pairs demonstrated performance on variable control skills. Again, no notable main effect or interaction was observed for explanatory prompt (p>.10

Process analysis

Table 4. Learners' focused examination of upthrust during discovery processes

Groups	Focused investigation of floating objects		Focused investigation of sinking objects	
	M	SD	*M*	*SD*
Prompt Pairs	.67	.24	.06	.15

No-Prompt Pairs	.58	.32	.17	.19
Prompt Singles	.83	.33	.00	.00
No-Prompt Singles	.78	.19	.00	.00
Total	.71	.27	.06	.13

We evaluated learners' experiments conducted during discovery processes using the procedure described in the method section. T results concerning learners' focused examinations of the related factors under floating and sinking conditions were reported in repeated measures MANOVA using floating/sinking as within-subjects factor and collaboration and prompts as between-subjects fac that there was a significant main effect for the within-subjects factor, showing that learners had made more focused investigat the upthrust on floating objects (Sphericity Assumed F (1, 36)=64.342, p=.000). A marginally significant interaction was observ collaboration and floating/sinking condition (Sphericity Assumed F (1, 36)=3.293, p=.095) (Figure 2). Compared to single learne made more focused investigations on the upthrust of sinking objects, relatively fewer examinations for floating objects. Actual had ever made any focused experiment for sinking objects at all.

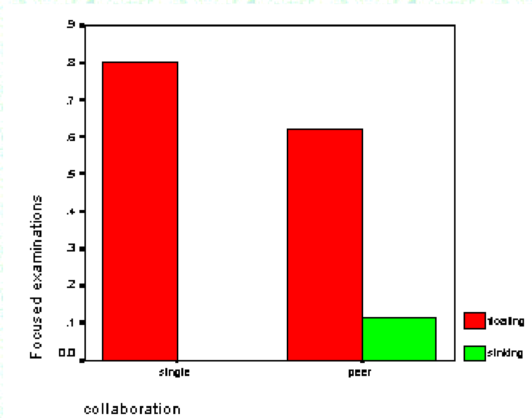

Figure 2. Focused examinations of floating/sinking objects made by pair and single learners

DISCUSSION

This study examined the effects of peer collaboration and questioning-explanation prompt on scientific discovery learning among students. We found that: (1) Peer collaboration had notable effect on the overall discovery outcomes and intuitive understandin the discoveries; (2) There were clear interactions between collaboration and learners' physics performance on the overall disco and intuitive understanding test but with different trends; (3) Collaboration had positive effects on learners' variable contro their focused design of experiments; (4) No significant main effect or interaction was revealed concerning explanatory prompt.

The effect of peer collaboration on simulation-based discovery learning

The positive effects of peer collaboration on scientific discovery learning were clearly observed on the overall discovery outco intuitive understanding test, as well as the variable control skill test. Pairs had discovered the rules more successfully, and insightful intuitive understandings on the relationships between the investigated factors and the size of upthrust under floati conditions. Hence they could more successfully predict the comparison of the upthrusts on each pair of objects depicted in the understanding test. These results support the consistent findings that collaborative learners outperformed single learners in a discovery learning or reasoning tasks (Okada & Simon, 1997; Teasley, 1995). It was revealed by Okada & Simon (1997)'s protocol important reason why Pairs performed better than Singles is because Pairs participated in explanatory activities such as entert hypotheses, talking about alternative ideas, and considering justification more often than Singles. It is not because Pairs sim great a chance as Singles of getting the right hypothesis, even without active interaction.

Clear interactions were found between collaboration and learners' physics performance on the overall discovery outcomes and int understanding test, however with different patterns. On the evaluation of the discovered rules, collaboration had significant p to lower achievement learners, whilst had no significant influence to higher achievement ones. On the intuitive understanding t involved more complex cognitive tasks, collaboration demonstrated significant positive effect to higher achievement learners, b significant effect to lower achievement ones. The peer collaboration might be helpful to both low and high achievement learners effectiveness among low and high achievement learners may manifest in different levels and aspects of learning.

As far as the discovery process is concerned, in this study, collaboration manifested a positive effect on learners' variable c scientific experiments. Also the index of focused examinations of the related features used in this study reflected the distrib learners' focused experiments across the features and conditions, hence indicated learners' systematic searches in the experime discovery learning processes. The interaction between collaboration and experiment condition (floating/sinking) manifested that more focused experiments for upthrusts on sinking objects. Since the default values of the volumes and masses of the objects in software determine a density (mass/volume) lower than that of water, the simulation starts with objects floating in water. No d instruction was offered to guide the subjects to change the comparisons of masses and volumes to make objects submerge in water floating and sinking conditions into account. In the result, the subjects conducted significantly more focused examinations for objects than sinking ones. Pairs made more focused experiments for upthrusts on sinking objects, whilst Singles made no focused sinking objects at all. The result implies that peer collaboration can help learners make more systematic searches in the exper design more crucial and informative experiments during scientific discovery learning. This disagrees with Okada & Simon (1997)' there was no significant difference between Pairs and Singles on the informativeness and systematicy of experiments conducted d processes.

The influence of the questioning-explanation prompts

The explanatory prompts used to elicit reciprocal questioning and explanation activities manifested no significant effect in th is inconsistent with Okada & Simon (1997)'s conclusion that explanatory activities facilitated by peers' requests had importan the effect of discovery, Coleman (1998)'s report about the effect of scaffolded explanation-based approach, as well as King's s that "Guided Peer Questioning" could help learners in acquiring and understanding knowledge (King, 1992, 1994; King & Rosenshin present study, the treatments concerning questioning-explanatory prompt included the use of prompt cards reminding the question request each other or ask themselves, and the special instruction to Prompt Pairs and Prompt Singles asking them to give attent questions on the prompt cards. However, there was no particular procedure to train and coach these subjects in asking the quest corresponding responses, as had been done in King et al. 's researches. These treatments might not have guaranteed the subjects learners from a middle school, to follow the explanatory prompt and perform intensive questioning-explanation activities. This most important reasons why explanatory prompt didn't display any expected significant effect in this study. For Chinese student used to the ways of reciprocal activities in regular classroom settings, they might need particularly more guiding and coaching explanation activities. More powerful and clear guidance should be adopted in the future studies to investigate the effect of r questioning-explanation activities as well as its interaction with the mode of collaboration in scientific discovery learning.

CONCLUSION

Nowadays, a growing number of studies have focused on scientific discovery learning based on computer simulation. However, most studies in this field focus on individual discovery learning without considering the perspective of social interaction. This st scientific discovery learning with collaborative learning and made a preliminary experiment in the context of secondary science collaboration was found to have prominent effect on the processes and outcomes of discovery learning. It can help learners make searches in the experiment space and design more crucial and informative experiments during scientific discovery learning. The questioning-explanation prompt was less clear, hence need to be addressed in depth in future studies.

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Appendix: Focused examination of volume: An example that was given full score

No.	Shape	Mass (g)	Volume (cm3)	Upthrust (N)
1 left	Ball	18.00	30.00	0.18
1 right	Ball	18.00	20.00	0.18
…				
3 left	Box	5.00	10.00	0.05
3 right	Box	5.00	400.00	0.05

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