发表评论

Supporting scientific discovery learning in a simulation environment

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论著选摘

Abstract Until recent times, most studies on supporting simulation-based scientific discovery learning adopted the *ad hoc* strate
approach. This paper makes a systematic analysis of the internal conditions of scientific discovery learning to propose a triple
learning support design that includes *interpretative support (IS)*, *experimental support (ES)*, and *reflective support (RS)*. The e
conducted with 78 students (aged from 12 to 13 years) to examine the effects of the IS and ES using a 2x2 between-subjects desig
results were: significant effects were observed for IS on the post-test of intuitive understanding, flexible application and kno
integration; no main effect was demonstrated for ES, and there was a marginally significant interactive effect for ES and IS on
understanding test. A process analysis showed that the successful learners had designed more well-controlled experiments than th
Learning support in a simulation environment should be directed toward the three perspectives to invite meaningful, systematic a
discovery learning.

Keywords: discovery learning, computer simulation, learning support, learning environment design

Introduction

In the past decade, the research on discovery learning has evolved from *concept discovery learning* towards more sophisticated ar
scientific discovery learning characterised by the need to design scientific experiments (van Joolingen & de Jong, 1997). Since
simulation has the capacity to provide learners with an exploratory learning environment, it has been regarded as a powerful too
discovery learning (SDL). A growing number of studies have focused on SDL through computer simulation within a constructivist pa
as was pointed out in the reviews by Lee (1999) and de Jong & van Joolingen (1998), a lot of research comparing the effects of s
learning to more traditional modes of learning finds little persuasive evidence in its favour. The question arises, why does sim
learning, that involves learners in active inquiry, not improve learning outcomes more consistently? One explanation lies in the
difficulties learners may have in dealing with discovery learning processes. De Jong & van Joolingen (1998) classified the diffi
learners may encounter into four categories:

- difficulties in generating and adapting hypotheses;
- poorly designed experiments;
- difficulties in data interpretation, and
- problems regarding the regulation of discovery learning.

Despite its potential in stimulating constructive learning activities, the simulation-based learning environment cannot guarante
learning without sufficient support (愖caffolding’) for discovery learning activities.

In order to promote effective discovery learning, a number of studies have been conducted to help learners with particular strat
specific aspects of the learning processes. For example, some researchers developed supportive methods to help generate hypothes
simulation-based discovery learning (Shute & Glaser, 1990; Njoo & de Jong, 1993; Quinn & Alessi, 1994). Others have looked at th
connected with experimental design (Leutner, 1993), planning (Tabak *et al*., 1996) and access to an appropriate knowledge base (L
1993). So far, most studies have adopted an *ad hoc* support strategies-oriented approach, intended to propose pieces of specific
according to learners’ difficulties in particular aspects and examine the effects of the proposed learning support. No study wa
made a systematic analysis of the internal conditions that determine the effectiveness of SDL and depict a proper scheme for sup
context.

Scientific discovery learning is a typical form of constructive learning based on problem solving activities involving the desig
implementation of scientific experiments. Scientific discovery is usually interpreted as the processes of mindful coordination b
hypothesised theories and evidence collected by experiments (Klahr & Dunbar, 1988; Kuhn *et al*., 1992). SDL is a knowledge constr
that is based on scientific discovery activities. Three main interlocked spheres exist in the processes of effective SDL (see Zh

- problem representation and hypothesis generation, which heavily relies on the activating and mapping of prior knowledge an making activities;

- testing hypotheses with valid experiments; and

- reflective abstraction and integration of the discovery experiences.

Taking all these perspectives into account, it is hypothesised that three interrelated conditions may determine the effectivenes great extent. These are:

- *The meaningfulness of discovery processes*: Learners need to activate their prior knowledge and map the knowledge onto the addressed to help representing the problem and generating appropriate hypotheses and understandings.

- *The systematicy and logicality of discovery activities*: Effective discovery learning involves proper scientific reasoning, manipulations of the variables, and qualified designs and implementations of experiments.

- *The reflective generalisation* over the discovery processes, which means the self-monitoring of the discovery processes and abstraction and integration of the discovered rules and principles.

The four categories of difficulties that learners may encounter during SDL, which have been summarised by de Jong & van Jooling all be attributed to the limitations in these three conditions. According to the three hypothesised conditions, three types of l can be designed and geared towards the three spheres:

- *interpretative support (IS)* that helps learners with knowledge access and activation, the generation of appropriate hypoth construction of coherent understandings;

- *experimental support (ES)* that scaffolds learners in the systematic and logical design of scientific experiments, the pred observation of outcomes, and the drawing of reasonable conclusions, and

- *reflective support (RS)* that increases learners’ self-awareness of the learning processes and prompts their reflective ab integration of their discoveries.

So far, most studies designed to support SDL focus on the impacts of certain specific support strategies, most of which are dire systematic, logical experiment and discovery activities (e.g. Rivers & Vockell, 1987; Njoo & de Jong, 1993; Tabak *et爐l.*, 1996). need to be carried out to examine the effects of the three types of learning support to propose a comprehensive scheme for learn design. Within the triple scheme of learning support design for simulation-based SDL, an experiment was set up to examine the ef Reflective Support (Zhang, 2000). The purpose of the present study was to make an experimental investigation on the effects of i and experimental support on simulation-based SDL. Based on the above theoretical analysis, it was expected that the experimental be able to enhance learners’ systematic and valid experimental activities and hence manifest prominent effects on the discovery underlying rules. The interpretative support should be able to increase the meaningfulness of the discovery processes and hence understanding, integration and flexible application of the discovered rules.

Methodology

The simulation learning environment

The topic chosen for the simulation was floating and sinking where the learners were required to explore the upthrust on objects water. Their task was to discover which one or more of three given factors (shape, mass and volume) were related to the size of a floating object. Learners often hold misconceptions about this phenomenon, assuming that the size of the upthrust depends on t volume of the object. Actually, the upthrust equals the weight of the object when it is floating because these two forces (weigh are balanced whilst the object remains stationary. The size of the upthrust depends only on the mass of the object. This topic i core issues in secondary science learning and has the structure of a scientific discovery task.

The simulation adopted paired-instance design that requires learners to construct a pair of experiments at a time, so that they the outcomes of two instances conveniently. For example, in order to examine the effect of the volume of object, learners can dr 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 keep their mas and vary the volumes (see Fig. 1). Then they can click the 傲UN’ button to see whether the upthrusts will be different or not. learners, a data sheet was provided on screen to record and display the value of the input and output variables in each pair of permanent button 惭ain Steps’ was prepared to remind learners of the main steps in an experiment, which involve selecting and c deciding their values, running the experiments, observing outcomes, and clicking the 懼EW’ button to start another trial.

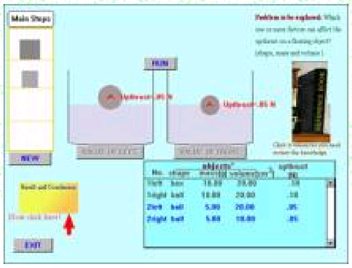

Fig. 1. Interface of the simulation

The learning environment contained two kinds of learning support: experimental support and interpretative support.

Experimental Support (ES). The ES included four specific treatments in order to help learners conduct systematic and valid exper
treatments were: explanations about scientific experimental design: in the introductory phase of the simulation, the programme g
general explanations about scientific experimental design (particularly about 憊arying one thing at a time '); identification of
of each trial (before designing each pair of experiments, learners were required to identify their objectives by ticking the var
wanted to examine; predictions and comparison (learners were required to predict which of the two specified objects would have a
before running the experiments, and to check their predictions against the outcomes after the experiments); finally, conclusions
discovery against an experiment structure table showing the comparisons of the input and output variables between the two object
experiments. Learners could access the last three supports by clicking a button (e.g. the 慠esult and Conclusion ' button in Fig

Interpretative Support (IS). The IS, which was intended to support learners to conduct meaningful discovery learning and generat
understandings, consisted of three measures: (a) Activating prior knowledge: A multiple-choice question was offered in the intro
of the simulation programme to activate learners ' prior knowledge about balanced forces, which asked for an object *floating* in
force or forces are acting on it? ' (b) General analysis of the problem: a multiple-choice question requiring students to select
that are relevant to upthrust (without feedback) was presented prior to the discovery processes in order to prompt the students
general analysis of the factor(s) that are relevant to the size of the upthrust on a floating object; (c) Access to knowledge ba
learners access to the relevant knowledge during the discovery learning processes by providing a permanent button, *reference boo*
contained the descriptions of the concepts of weight, balanced forces, motion, as well as the basic meaning of upthrust.

The simulation programme was written in such a way that it registered learners ' manipulations during the learning processes and
for each student.

Research design

In order to investigate the effects of ES and IS, a 2 (ES/no ES) by 2 (IS/no IS) between-subjects design was used to compare fou
basically the same simulation environment: ES but no IS, IS but no ES, ES & IS, and no support. Logfiles were used to analyse ho
proceeded in using the ES and IS.

Subjects

Subjects were 78 boys from Year 8 (age range from 12 to 13 years) of a suburban boys comprehensive school in Manchester. They we
distributed in four groups: ES but no IS (n = 20), IS but no ES (n = 20), ES & IS (n = 20), and no support (n = 18). A pre-test
significant difference among the four groups in their topic knowledge, background knowledge, or experience with computers.

Tests

In order to gauge the effects of the learning supports on various aspects and levels of learning outcomes, four aspects of the c
discovery learning were assessed in the post-test.

Principle knowledge. This was assessed by seven multiple-choice items. One item focused on the general principle about the facto
affect the upthrust on the object floating in water. The others concerned specific principles underpinning the phenomenon.

Intuitive understanding. Five multiple-choice questions were designed to measure learners ' intuitive understanding, which is re
important goal in SDL (de Jong *et al*., 1999; Swaak & de Jong, 2001), especially when conceptual change is desired. Using picture
showed pairs of objects with different combinations of shapes, masses, and volumes and asked learners to predict how their upthr
compare in size.

Flexible Application. Eight multiple-choice items were written to determine how well learners could transfer the knowledge to ne
(e.g. the upthrust on a boat floating in a lake). These questions were more flexible, requiring the adaptation and integration o
knowledge. Flexible application is one of the crucial objectives of constructive learning, however, it seldom appears in studies

Integration of knowledge. Two types of items were developed to assess associations between the discovered rule and learners ' pr
especially the key concept of balanced forces. The first type took the form of 慳ssociation-rating ' questions that are one of t
formats in concept map tests (Ruiz-Primo & Shavelson, 1996). Learners were required to indicate whether each of the concepts was
their understanding about upthrust or not, and to give a brief justification if they responded with 憏es ' . Two concepts includi
慴alanced forces ' were set as target items, and three other concepts were included as filler items. Both learners ' ticking and
were used to decide the associations in their knowledge. The second type of item involved four 慽nstance-clustering ' tasks (sim
al., 1981). A picture showing a beach ball floating in a swimming pool was set as the prototype instance. The other four instanc
displayed to ask the learners to identify if each of the instances was similar to the prototype instance and explain why they th
knowledge association was inferred according to whether they clustered the instances on the basis of the deep structures (force
merely in term of their surface features (e.g. moving or stationary, being in water or on a desk). Since the test of knowledge i
relative new in format, reliability analysis was conducted particularly for this test, which revealed an acceptable internal con
coefficient (α = 0.69).

Three items in each of the first two categories (principle knowledge and intuitive understanding) of the post-test were used in
examine learners ' prior topic knowledge about upthrust. The pre-test also encompassed the items about relevant background knowl
experience of using computers.

Procedure

After a pilot study in a second school, the pre-test was administered to all students in written format one week before the form
The study took place in a computer laboratory equipped with 20 networked Pentium computers. The students were required to accomp
following tasks individually:

- *Warm-up*. Students worked with a tutorial version of the simulation programme. Two researchers were present to answer their
the programme. This stage lasted approximately 10 minutes.

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

- *Exploration*. Students were reminded that their task was to discover the rule on the basis of sufficient evidence through s
experiments.

The post-test, also in written format, was administered immediately after the completion of the exploration. A total of 30 minut
for the post-test.

Results

Comparison between the pre-test and post-test results

Table 1. Achievement on topic knowledge

Condition		Pre-test *m*	*s.d.*	Post-test *m*	*s.d.*	Effect size
ES	IS	1.90	2.10	7.20	2.46	2.32
	no IS	2.47	2.18	6.47	2.70	1.64
No ES	IS	2.89	2.08	6.44	2.79	1.46
	no IS	2.94	2.14	5.76	2.73	1.16
Total		2.53	2.12	6.50	2.66	1.66

As has been mentioned in the method section, the pre-test examined learners' prior topic knowledge about upthrust using the six
from the post-tests of principle knowledge and intuitive understanding. The mean scores of the four groups of learners on the pr
post-test are presented in Table 1.

The repeated measures MANOVA, using the ES and IS as between-subjects factors, indicated a significant improvement on the post-te
($F_{1,68} = 88.41$, $p < 0.001$). There was also a marg-inally significant interaction between the tests and ES, $F_{1,68} = 3.07$, $p = 0.08$
with the ES made a greater improvement compared to those without the ES.

The effects of the ES and IS on the post-test

Table 2 shows the means and standard deviations of different groups on the four categories of the post-test.

Table 2 The means and standard deviations of four types of post-tests

Condition		Principle knowledge *m*	*s.d.*	Intuitive understanding *m*	*s.d.*	Flexible application *m*	*s.d.*	Integratio knowledge *m*	*s.d.*
ES	IS	4.00	2.70	6.80	1.77	4.50	1.47	4.75	3.19
	no IS	2.60	2.41	4.90	2.38	3.50	1.64	2.40	1.96
No ES	IS	3.75	2.65	5.70	2.27	4.85	1.36	4.58	
	no IS	3.50	2.43	5.56	2.61	3.56	2.06	3.11	2.08
Total		3.72	2.51	5.74	2.33	4.12	1.77	3.71	2.72

Principle knowledge. Students with the ES scored a little higher on the principle knowledge test than those without the ES, and existed for IS (see Table 2). However, there was no significant main effect or interaction for ES or IS.

Table 3 ANOVA of ES and IS on intuitive understanding test

Source of variance	*SS*	d.f.	*F*	*Sig.*
ES	1.18	1	0.23	0.63
IS	21.30	1	4.13	0.04
ES x IS	14.99	1	2.91	0.09
Residual	381.64	74		

Intuitive understanding. Table 3 shows the result of the ANOVA for this test. There was a significant main effect with IS (p < 0 groups with the IS outperformed those who didn抰 receive this support (see Table 2). There was a marginally significant interact and ES (p = 0.09). IS indicates a significant effect among the students with the ES ($F_{1,75}$ = 7.08, p = 0.01), whilst no such eff among the no ES groups (p > 0.10) (see Fig. 2).

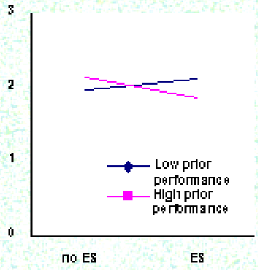

Fig. 3. The interaction of ES and prior science performance level on Index II

Flexible application. The fourth column in Table 2 gives the achievements of the groups on this test. A two-way ANOVA showed a ve main effect for IS, $F_{1,74}$ = 8.85, p < 0.01, which was in favour of the role of the IS. There was no significant effect concernin interaction between ES and IS (p > 0.10)

The integration of knowledge. For the items in this category, a full score of 2 was given when students' judgement and justific item were both clearly in favour of the knowledge association. A score of 1 indicated that the student had made a correct judgem only a vague justification. The maximum score was 12. As anticipated, IS indicated a quite significant positive main effect on t integration test (see Table 2), $F_{1,73}$ = 10.79, p < 0.01. Again, no significant effect was found for ES or the interaction betwee

($p > 0.10$).

Process analysis

Using the data provided by the logfiles, an analysis was made to see how the students had interacted with the simulation environ
they had used the supports.

Number of experiments and time on exploration. A maximum time of 35爁inutes and a minimum number of five pairs of experiments ha
the exploration session. On average students conducted 10.83 (*s.d.* = 5.63) pairs of valid experiments. The students who receive
performed significantly fewer experiments than those without the ES, $F_{1,73} = 20.91$, $p < 0.01$. There was no significant differenc
($p > 0.10$). The average time spent on the exploration was 23.26 (*s.d.* = 6.93) minutes. Significant main effects were found regar
on the time spent on exploration ($F_{1,74} = 10.42$, $p < 0.01$ for ES and $F_{1,74} = 3.47$, $p < 0.10$ for (IS). However, there was no signi
correlation between the post-test scores and the time on exploration or the number of experiments ($p > 0.10$). All the trends rep
observed when the ANOVAs were performed using the time and the number of experiments as covariates. So it can be inferred that th
and IS on the post-tests cannot be ascribed to the differences in time and number of the experiments performed by the individual

Frequencies of using the supports. The use of the noncompulsory supports was analysed. The mean frequency of using the 慠*eferenc*
component of the IS) was 1.63, and the mean time spent on it was 80 seconds. Students chose to summarise their discovery (a comp
in 78.64% of their experiments. There was no significant correlation between the post-test scores and the frequencies of using t
($p > 0.10$).

Evaluation of learners’ experiments. Using the data collected in the logfiles, an analysis was made to see how the students had
experiments. 慍hange one thing at a time’ is an important principle in scientific experiment. Unfortunately, learners often var
in one experiment (Glaser *et al.*, 1992; de Jong & van Joolingen, 1998). Focusing on the principle of variable control in scienti
three indices were adopted to evaluate the learners’ experiment designs.

Index I: The percent of well-controlled experiments. As has been mentioned in the methodology section, this simulation used pair
design that required learners to conduct a pair of experiments at a time, so that they could contrast the outcomes of two instan
indicates the percentage of the well-controlled experiments in which one and only one factor (shape, mass, or volume) was differ
left and right side instances (see Fig. 1 as an example).

Index II: Average number of variables varied in each pair of experiments. This is a looser criterion displaying how many variabl
mass and volume were varied in each pair of experiments on average.

Index III: Focused examination of the three variables. A pair of experiments were identified as having undergone a 慺ocused exam
certain variable if that variable was the only variable varied in that pair of experiments. For each variable, a full score of 2
it had been examined by at least two pairs of experiments at different levels of the controlled variables. Score 1 indicated tha
had been examined by only one pair of experiments or by more than one pair of experiments but at the constant levels of controll
Sequentially, score 0 meant that no experiment had been focused on this variable at all. An average score across the three varia
the final analyses. Among the three indices, Index III is the strictest in that it was the only index that indicated the distrib
controlled experiments across the three variables.

In comparing the experimental quality of the ES to the no-ES groups, no significant difference was found in the *T*-tests using ES
variable ($p > 0.05$). In order to analyse the effect of ES among high and low level students, the students’ scores in a recent e
science class were collected. The top and bottom 25 students were sorted out and formed the high and low science achievement gro
gives the evaluation of their experiments. ANOVAs of the three indices, using ES and science achievement level as independent va
displayed a significant interaction on Index II ($F_{1,44}$=4.48, p<0.05) (Fig. 3). Simple effect analysis demonstrated that ES had a
significant effect among the high science achievement students ($F_{1,45} = 4.07$, $p = 0.05$). Those with the ES varied much fewer var
pair experiments, whilst no significant effect was found among the low science achievement students. ES and science achievement
significant effect on Index I and III.

Table 4. The indices evaluating learners’ experiments

Groups		Index I *m*(%)	*s.d.*	Index II *m*	*s.d.*	Index III *m*	*s.d.*
ES	High	36.80	0.23	1.86	0.39	0.71	0.54
	Low	34.00	0.12	2.12	0.21	0.61	0.24
No ES	High	28.30					

		0.15	2.15	0.33	0.70	0.25
Low	33.33	0.20	1.97	0.41	0.70	0.26
Total	33.53	0.18	2.01	0.36	0.68	0.36

Table 5. Differences between groups on three indices

Groups	Index I m(%)	s.d.	Index II m	s.d.	Index III m	s.d.
Success (n = 44)	36.44	0.19	1.94	0.40	0.76	0.41
Failure (n = 32)	26.03	0.15	2.06	0.31	0.59	0.36
Significance	$T(75) = 2.54$ $p = 0.01$		$T(74) = -1.45$ $p = 0.15$		$T(75) = 1.86$ $p = 0.07$	

Note: 2 students were excluded because they didn抉 respond to this item.

In order to explore the relation-ship between the quality of experi-ments and the result of learning, the students were put in t
ding to whether they had discovered the correct rule by the end of the experiment. This could be identified by their responses t
items in the principle knowledge test. Table 5 gives the evaluation of the experiments conducted by the successful and failure g
successful group exceeded the failure group on all the three indices, with significant or marginally significant differences on
($p = 0.01$) and Index III ($p < 0.10$).

Comparing the post-tests and the experiment design, the score of the principle knowledge test was significantly correlated to I
$r = 0.24$, $p < 0.05$) and Index II (Pearson $r = -.25$, $p < 0.05$). There was also a marginally significant correlation between the p
knowledge test and Index III (Pearson $r = -.20$, $p < 0.10$).

Discussion

This study examined the effects of experimental support and interpretative support in simulation-based SDL. As was demonstrated
and post-test scores, learners of the four groups all benefited significantly from the simulation-based learning processes. As f
effects of the treatments are concerned, there was no significant effect for ES or IS on the post-test of principle knowledge. T
consistent with the opinion that a formalised knowledge test is not a sensitive indicator of the effect of simulation-based lear
al., 1999). The IS manifested prominent main effects on the tests of intuitive understanding, flexible application and knowledge
The expected interactive effect between IS and ES was observable on the intuitive understanding test. It seems that the IS can f
intuitive understanding when the ES is also available. This is congruent with Okada & Simon (1997)抯 statement that students nee
actively in both crucial experiments and explanatory activities in order to discover the right mechanism.

Overall, the function of the IS has been demonstrated as highly significant in this study. The IS was designed to support discov
activating the relevant knowledge in the learners' memories, enhancing the problem representation and hypothesis generation bas
existing background knowledge, eliciting more explanation activities toward the experiments, and promoting the access of knowled
has been found to be helpful for learners to construct a more elaborate, coherent and deep understanding about the explored doma
the intuitive understanding test, the students who received the IS could come up with a more accurate insightful intuition in sp
situations. On the knowledge integration test, the IS groups exhibited more elaborate associations between their understanding o
their prior knowledge about balanced forces. When confronted with novel problem situations in the application test, these studen
generate more appropriate solutions by generalising and transforming the principle derived from their experiments. For instance,
explorations were focused on the upthrust of objects floating in water. One of the questions in the flexible application test as

are placed in two beakers half full of two kinds of liquids: water and oil, and they are both floating. How will the upthrusts c
compare?’ It was more likely for students in IS groups to generalise their discovery to this situation because they could assim
new instance of the more fundamental conception, balanced forces.

All these results support one of the major assumptions in the study: the integrative meaning-making perspective plays a critical
process, and hence it should be one of the key targets for instructional support. As Ausubel *et al*. (1978; p. 519–564) argued,
discovery learning depends on the meaningfulness of the discovery experience. SDL does not end with the discovery of one or two
but is intended to incorporate the findings into learners’ profound, elaborate, and coherent knowledge structures, and help lea
their own 慽deas’ on the scientific phenomena. To a large extent, these learning outcomes will rely on learners’ explanatory a
interpretative meaning-making activities. Apart from the access and activation of relevant knowledge which has already been addr
studies (Leutner, 1993; de Jong *et al*., 1999), instructional support in this sphere needs to do more to foster learners’ explan
interpretative activities, such as representing the problem in relation to the relevant knowledge, explaining the experimental o
their fundamental knowledge, and synthesising their discovery and generating a integrative understanding.

The overall effect of the ES was not so clear as that of the IS. An effect was only observed in the comparison of the post-test
test, and also somewhat in the interaction with IS on the intuitive understanding test. As can be seen from the process analysis
outperformed the no-ES groups on two of the three indices evaluating their experiments, but with no significant difference being
in this study included a number of elements such as of the explanation about experiment design (especially 慥arying one thing at
prompts about identifying the objective of each experiment, predicting and observing outcomes, and summarising their discoveries
treatments were still not supportive enough to improve the learners’ experimental activities or learning outcomes. This result
Rivers & Vockell (1987)抯 finding that providing learners with general experimentation hints before their exploration could prom
experimentation abilities, as well as Swaak *et al*. (1998)抯 conclusion that the experimental support in the form of assignments
on SDL. One possible explanation is that the students in the present study were 12–13-year-olds, whilst most of the other studi
were performed among college or high school students. In an earlier survey conducted in UK, Archenhold *et al*. (1988) documented
difficult for 13-year-olds to control the variables properly during the investigation process. A relevant result in the present
interaction between ES and science achievement level on Index II, which implies that learners with high science achievement coul
from the ES. Another possible reason is that selecting the supports and answering the questions during the learning processes mi
distracted learners from their investigation and therefore cancelled the effect of the ES.

However, the importance of qualified experimental activities was verified from another aspect by the analysis of the relationshi
quality of experiment and the discovery result. Learners who had discovered the right rule surpassed the failing learners on all
indices of experiment design. There was also a clear correlation between the indices and the principle knowledge test. As is emp
researchers in this field, the perspective of scientific reasoning and experimental activities does count a lot in SDL process.
discovery learning depends heavily on learners’ reasoning and experiment activities such as generation and adaptation of hypoth
and focused manipulation of input variables, prediction and observation of outcomes, and drawing conclusions from experiments. T
inefficiencies in the above activities can hamper successful discovery.

Conclusion

In conclusion, this study proposed a triple scheme of learning support design for simulation-based SDL and examined the effects
experimental and interpretative support. The overall results support the importance of the meaningfulness and the logicality of
processes, and imply that learning support, either bedded within simulation software or provided by a human tutor in classroom e
should be directed toward these perspectives to invite meaningful and systematic discovery learning. However, it is important to
are many uncertain problems behind the triple learning support scheme for simulation-based discovery learning. More repetitive e
the three types of learning support are needed. Especially, future research needs to re-design the treatments in the ES and re-e
effect on simulation-based discovery learning among learners with different capabilities.

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