

EXPLORING THE EFFECTS OF GUIDANCE IN A COMPUTER DETECTIVE GAME FOR SCIENCE EDUCATION

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Introduction

For more than half a century, education scholars have advocated that science education should not only ask students to memorize knowledge but also teach them how to think (Wong et al., 2001). At present, under the unceasing endeavors of science education organizations and scholars who have promoted various science education projects and experimental curricula (National Research Council, 2000; NGSS Lead States, 2013), the educational idea of teaching students to do science and learn science through scientific inquiry activities has gradually been incorporated in the national education standards of numerous countries (Department for Education, 2013; National Research Council, 2013). At the same time, inquiry-based learning has become a core teaching strategy in contemporary science education.

Many researchers have recommended that these inquiry-based curricula should give students experience in dealing with real-world problems (Fortus et al., 2005; Hsu et al., 2016). Abundant research has also verified that implementing such curricula can enhance students' scientific knowledge acquisition and scientific inquiry abilities, such as data analysis and scientific inference abilities (Ebenezer et al., 2011; Furtak et al., 2012; Ketpichainarong et al., 2010). However, some challenges could arise when attempting to develop meaningful real-world science problems or create real-world inquiry situations in conventional science classrooms. Fortunately, the advancement and popularization of computer technologies have made them a feasible tool for supporting inquiry-based curricula.

Computers can simulate the conventional equipment that students require to conduct science experiments; they can also be used to construct virtual worlds where students can explore the real-world problems that cannot be conducted in traditional classrooms (Quellmalz et al., 2009). Currently, teachers can allow students to sit in front of computers to engage in scientific exploration activities on their own. Furthermore, using computer simulations saves both time for learning and the cost of science equipment;



JOURNAL
OF BALTIC
SCIENCE
EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

Abstract. *This research aimed to develop a computer detective game for science education to provide students in experiencing real-world problem-solving after learning electricity-related knowledge, and to explore the effects of designing the guidance of process constraints and prompts into this game. To explore the effects of guidance, two different game tasks with and without the guidance of process constraints and prompts were integrated into this game. At the same time, to understand appropriate prompt guidance, two different versions of the first game task with and without real-time prompts were also designed. Two ninth-grade classes from a lower secondary school were randomly assigned to use different versions of game with different real-time guidance prompts. The research findings indicate that students had significantly better problem-solving performance in first game task with the guidance of process constraints and prompts than those in second game task without guidance. The results also indicate that the design of real-time prompts may not only enhance students' problem-solving performance and knowledge acquisition, but also lower students' cognitive load.*

Keywords: *inquiry guidance, learning game, physics education, science knowledge, science problem-solving.*

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it also resolves safety concerns for engaging in otherwise dangerous science activities (Hickey et al., 2003). Numerous studies have confirmed that computer simulations contribute to students' science learning (Rutten et al., 2012; Smetana & Bell, 2012).

Nevertheless, engaging in science activities in a computer environment has drawbacks, including common problems observed in many e-learning environments. As e-learners generally partake in self-directed learning without a teacher present (Kim et al., 2014), this kind of learning can be ineffective for those who lack learning motivation and the requisite abilities to engage in self-directed learning. Furthermore, science inquiry activities in computer environments are more complicated than ordinary e-learning activities, as they often require learners to solve complex science problems involving varied procedures, such as defining the problem, collecting data, analyzing data, and interpreting results (Zhang et al., 2015). Therefore, exploring science problems in a computer environment without teacher guidance is a considerable challenge for most students, mainly because of the lack of learning motivation and the cognitive complexity caused by the rich information (Azevedo et al., 2010; Scheiter & Gerjets, 2007; Zacharia & Olympiou, 2011).

In recent years, game-based digital learning has become a popular solution for the lack of motivation and guidance in e-learning environments. Well-designed digital games do not have the problem of users lacking motivation and abilities to engage in gaming, because game designers know how to use the game rules, non-player characters (NPC), or competition to attract and guide players engaging in a new game (Nicholson, 2015). In addition, digital games have been viewed as a good way to integrate real-world problems into learning for developing students' problem-solving and decision-making abilities (Gee, 2003; Turkay et al., 2014). Thus, properly using the characteristics of games may transform computer games into an ideal inquiry environment where students can engage in science problem-solving with high motivation and adequate support.

Nowadays, many science educators have also attempted to help students overcome challenges when performing scientific inquiries in a computer environment by providing appropriate guidance (Alfieri et al., 2011; Furtak et al., 2012). Different forms of guidance for scientific inquiry activities in a computer environment have been proposed, such as process constraints, prompts, or scaffolds (de Jong & Lazonder 2014). A number of empirical studies (D'Angelo et al., 2014; Kim & Pedersen, 2011; Olympiou et al., 2013) have proved that guidance can enhance students' learning effectiveness when learners are required to conduct scientific inquiry activities in a computer environment. However, research results showing the learning effects of applying such guidance into science computer games are few.

Accordingly, to address this research gap, this research developed a digital game entitled Science Detective Squad (SDS) to provide students with a real-world science problem-solving environment. Each participant plays the role of a science detective in this game to find the answers to the problem of the escalating electricity fees in a virtual family. Moreover, to explore the effects of using guidance in the science computer game, two game tasks with different situations and answers have been developed in this game. Only the first game task integrated the guidance of process constraints and prompts, as proposed by de Jong and Lazonder (2014), into the game mechanism to provide guidance for students, while the second game task did not include any design guidance.

The principle of process constraints involves restricting students' inquiry process. For example, guidance can structure the entire inquiry activity into a series of subtasks and lead students to complete the subtasks in order (de Jong & Lazonder, 2014). In this way, students can conduct the inquiry according to the proper inquiry process and explore in greater depth (Lazonder & Harmsen, 2016). The principle of prompts is to provide students with hints during the inquiry activities, and to remind learners what to do, instead of telling them how to do the inquiry tasks (de Jong & Lazonder, 2014). Therefore, this research divided the first SDS game task into four subtasks according to the general process of scientific inquiry. A NPC in SDS was created to lead students to perform each subtask in order. In addition, the game points were integrated with this guidance to restrict students' inquiry processes. Moreover, the NPC was designed to provide students with text-based hints about what to do before they executed each subtask, or to remind students what to do in that moment with real-time prompts during each subtask in the first game task.

However, because students are required to continually receive and collect a variety of information to solve the mystery task in SDS, providing them with real-time prompts during the task may increase their cognitive load or lower their pleasure in the game experience. Thus, the challenge remains of how to offer appropriate real-time prompts in a science computer game when relevant studies are extremely scarce. Therefore, this research developed two versions of the first SDS game task involving different real-time prompts (no real-time prompts and real-time prompts) to explore whether these variations affect student performance and perception in this game.



The Design of the Computer Detective Game

SDS is a single-player game that can be played individually through any web browser. To understand students' science problem-solving performance when providing guidance in the game, this game has two game tasks. The first one, referred to as task-1, provides guidance for players; the second one is task-2 without any guidance. The goal of each game task is to make each player play the role of a science detective to investigate why a virtual family's electricity prices rise suddenly in a specific scenario. The players can obtain game points when they conduct any behavior that facilitates the investigation or successfully solve each game task. Moreover, the amount of points awarded is related to time; for example, players who complete a game task faster earn more points. Thus, this game also provides a leaderboard that ranks the top 20 players according to scores. Therefore, the goals of each player are to complete each game task as fast as possible within a limited game time and to become a member of the high score list.

The game interface is shown in Figure 1. The upper area provides the game information, such as task time remaining, score, leaderboard, and personal records. This area also provides activation buttons linked to various game functions, such as calling the detective captain, the simulation tool, learning resources, and a notepad. The main area of the game interface displays various game scenes. This game is a third-person view game. For example, each player can see a virtual household with different spaces (e.g. living room, dining room, kitchen, bedroom, and balcony) and NPCs (e.g. father, mother, and children) when they start to investigate the game task. The bottom area provides real-time prompts in one version of game's task-1.

Figure 1
The interface of the SDS



This game designs a NPC, meaning the captain of the science detective squad, who explains the rules and each game task through texts. Each player can use the function of calling the detective captain to review the description of each game task and to report the investigation results when finishing the game task. The game's task-1 incorporates the guidance of process constraints, as proposed by de Jong and Lazonder (2014). To guide players to conduct the game task in the proper process and in depth, task-1 is divided into four subtasks according to the process of general inquiry: defining the problem, collecting data, analyzing data, and interpreting the results. The subtask of defining the problem asks students to preliminarily understand the task problem. The subtask of collecting data mainly asks students to collect information to solve the game task. In the subtask of analyzing data, students are asked to analyze information to solve the game task by using the simulation tool. In the subtask of interpreting the results, students need to consider and identify the cause of the task problem. Each player is asked to complete the four subtasks in order, and to provide the subtask investigation results to the captain after they have earned a certain number of game points in each subtask.



Task-1 also incorporates the guidance of prompts, as proposed by de Jong and Lazonder (2014). Based on the suggestion of de Jong and Lazonder, the guidance provided in this game reminds players of what to do, instead of telling them how to do it. The captain prompts players what they can carry out some actions instead of performing specific action for completing the subtask by text-based hints. For example, before executing the subtask of defining the problem, the captain will prompt players to collect information from the family members or the house to gain a preliminary understanding of the detective case, instead of telling players to collect information from specific family members.

Moreover, to understand the effects of real-time prompts, in one version of task-1, the captain provides real-time text prompts to the player during task-1 execution. This guidance provides timely reminders to players regarding what they can do during each subtask of task-1. For example, the captain will provide real-time prompts reminding players to collect information from the household appliances in each game scene during the subtask of collecting data (see the bottom area in Figure 1). This guidance also provides timely and encouraging messages or useful information to players. For instance, if the player completes an action by freely choosing the preset text-information menus (see the main area in Figure 1) to collect useful information from the family members in the subtask of defining the problem, the real-time prompt will mention that the player has found a piece of valuable information for the subtask, and remind the player to use the notepad function to record this information. Another example is when players click the household appliances; the real-time prompt notifies them that they found useful information, and timely provides some electricity knowledge, such as introducing the electricity consumption information of the appliance, even though each player can search the learning contents in the game function of learning resources.

After players complete task-1, task-2 begins. Task-2 does not have any restrictions of procedure and game points and does not provide any prompts. Thus, players can use their own investigation procedure, and report the investigation results to the captain at any time after completing the task.

Task-1 and task-2 have different problem situations and answers relating to the escalating electricity fees in a virtual family. The problem situation of task-1 is related to the use of new electrical appliances, while task-2 is about the changing behaviors of using appliances in daily life. Finally, students must identify the correct answers through multiple-choice type questions when reporting their investigation results in each game task. No matter whether task-1 or task-2, the player can collect information from the virtual family members, such as finding out the ordinary electricity usage behaviors of the family or collecting statistical data concerning their recent electricity expenses. The player also can collect information regarding the electric power data from the appliances within the virtual family, and use the simulation tool provided by the game (see Figure 2) to analyze the collected information to estimate the electricity expenses of different appliances. In other words, players also can explore the relations of appliance's electric power and time on electricity expenditures through changing variables and observing the effects in the simulation tool. Furthermore, the game offers learning materials related to electricity as a reference for each player, as well as a notepad function for players to record the key points of their investigation.

Figure 2
The simulation tool in SDS

The screenshot shows a user interface for a simulation tool. It is divided into several sections:

- Analysis and Research Information (分析研究資訊):** A list of collected appliances including: 客廳冷氣機 (Living Room Air Conditioner), 電視機 (TV), 美術燈 (Art Light), 烤箱 (Oven), 微波爐 (Microwave), 電冰箱 (Refrigerator), 筆記型電腦 (Laptop), 主臥室檯燈 (Master Bedroom Table Lamp), 小孩房冷氣機 (Child's Room Air Conditioner), and 洗水機 (Washing Machine).
- Simulation Process:**
 - Select one collected appliance:** A button to choose an appliance from the list.
 - Electric power of the selected appliance:** Displays details for the selected appliance: 大銀牌冷氣 (Da Yin Pai Air Conditioner), 額定電壓: 220V(伏特) (Rated Voltage: 220V), 額定功率: 1300W (Rated Power: 1300W).
 - Start simulation:** A button to begin the simulation.
 - Select simulation time:** A field to input the usage time, currently set to 4 hours.
- Simulation Results (模擬耗電情形):**
 - 電費計算說明 (Electricity Calculation Explanation):** 電費 = 電器耗電度數 × 1度電的費用 (Electricity Fee = Appliance electricity consumption degree × 1 degree electricity fee). (1度電 = 1000瓦的電器使用1小時 = 1千五小時).
 - 模擬結果 (Simulation Result):**
 - 此電器的電功率 = 1300瓦 = 1.3千瓦 (This appliance's electric power = 1300W = 1.3kW).
 - 此電器使用4小時耗電量 = 1.3千瓦 × 4小時 = 5.20千度 = 5.20度 (This appliance uses 4 hours, electricity consumption = 1.3kW × 4h = 5.20kWh = 5.20 degrees).
 - 假設每1度電3元, 此電器每天花費 = 5.20(度) × 3(元/度) = 15.60(元) (Assuming 3 yuan per 1 degree, this appliance costs 15.60 yuan per day).
 - 每個月耗電468.00元 (Monthly electricity consumption 468.00 yuan).
- Simulation Evidence (研究證據):** A table showing the results for various appliances.

電器名稱 (Appliance name)	電功率 (Electric power)	每天使用時間 (Use time)	顯示使用度數 (electricity charge)	每月費用 (Monthly fee)	每個月費用 (Monthly fee)
客廳冷氣機 (Living Room Air Conditioner)	1300瓦 (1300W)	1小時 (1h)	1.3度 (1.3 kWh)	3.9元 (3.9 yuan)	11.7元 (11.7 yuan)
電視機 (TV)	1300瓦 (1300W)	2小時 (2h)	2.6度 (2.6 kWh)	7.8元 (7.8 yuan)	23.4元 (23.4 yuan)
烤箱 (Oven)	1300瓦 (1300W)	3小時 (3h)	3.9度 (3.9 kWh)	11.7元 (11.7 yuan)	35.1元 (35.1 yuan)
- Simulation Evidence (Simulation evidences):** A label pointing to the table above.
- Simulation result: electricity charge:** A label pointing to the calculation and result section.
- Set simulation result as the evidences:** A button to save the results.
- Return to the game:** A button to go back to the main game.

Research Focus

The primary research questions of this research were, as follows:

- Does integrating the guidance of process constraints and prompts into the SDS affect students' problem-solving performance?
- Does providing real-time prompt guidance in SDS affect students' problem-solving performance, science knowledge acquisition, participation perception, and cognitive load?

Research Methodology

General Background

To explore the effects of guidance in the self-developed computer game, this research conducted an experiment using a two-group pre-test post-test quasi-experimental design. Participants were randomly assigned to an experimental group (playing the SDS with real-time prompts in task-1) or a control group (playing the SDS without real-time prompts in task-1). Participants' science knowledge acquisition was assessed before and after the experiment, and their problem-solving performance, participation perception, and cognitive load were also evaluated after the experiment. The research participants, procedures, and instruments are detailed, as follows.

Participants

This research selected two ninth grade classes from a lower secondary school in Kaohsiung City, Taiwan, as the participants. The two classes ($n = 58$) were randomly assigned to use different versions of SDS with different real-time guidance prompts in task-1. After eliminating the students who were unable to complete the pre-test, post-test, or the SDS game, the study sample included 50 students. One class with 24 students (10 males and 14 females) used the SDS without real-time prompts in task-1, while the other class with 26 students (11 males and 15 females) used the SDS providing the real-time prompts in task-1. In order to give students experience in dealing with real-world problems after learning the science knowledge, all the research participants had learned electricity-related knowledge in the semester prior to the one in which this experiment was conducted.

Procedures

The experiment was conducted over three weeks in April 2017, encompassing six class periods (lasting 45 min each) in the participants' science and living technology course. The experimental procedure comprised three steps. Before playing the SDS game, all the students took pre-test, including a self-developed electricity knowledge test. After completing the pre-test, the students were instructed to operate a computer by themselves to engage in the SDS game. Students were required to participate in task-1 first, and then task-2. When all students had completed the SDS game, they were asked to perform post-test of the same electricity knowledge test, and to complete the cognitive load scale and participation perception scale, as developed by this research.

Instruments

Electricity Knowledge Test

This research developed an electricity knowledge test to explore whether playing the SDS game with different real-time prompt guidance affects the enhancement of students' science knowledge. The questions in this test focused on the learning concepts used in the SDS game, including electric power, the correlation between electric power and energy, and the calculation of electricity expenses. The test consisted of 20 multiple-choice questions, such as "Assuming 1 kWh of electricity costs NT\$5, what electricity expenses would be generated by using an 800W oven for 2 hours?" and "How much electric power does a microwave use that consumes 24,000 J of electricity for 30 sec of operation?" Each question had four answer choices. The total score of this test is 100, and the questions were examined by two junior high school teachers to ensure the content validity. Kuder-Richardson reliability was .79.



Cognitive Load Scale

With reference to Hong et al. (2017), this research developed a cognitive load scale comprised of eight items on a 5-point Likert scale to understand whether providing real-time prompts in SDS affects students' cognitive load. Sample questions in the scale include: "Task-1 in SDS was difficult for me, because there was too much information related to the task." and "I tended to lose my attention while playing the SDS." Cronbach's α for this scale was 0.93.

Participation Perception Scale

A scale comprising 11 items rated on a 5-point Likert scale was developed in this research to evaluate whether providing real-time prompts in SDS affects students' perceptions of pleasure and learning. Of the 11 items, 6 assessed the pleasure perceptions by using questions, such as "I think the SDS game is fun" and "I would like to play similar games in the future". The remaining 5 items tested learning perceptions by using questions, such as "I learned about electricity through this game" and "I think this game is beneficial for science knowledge acquisition." Cronbach's α values for the overall scale, pleasure perception, and learning perception were .91, .84, and .90, respectively.

Data Analysis

To explore the guidance effects of the process constraints and prompts on students' problem-solving performance in the computer detective game, this research used paired sample *t*-test to analyze the differences of all students' problem-solving performance between task-1 and task-2, because each student first played the task-1 with guidance and then played the task-2 without any guidance. Moreover, because one group of students participated in the game version with real-time prompts in task-1 and the others played the game without real-time prompts in task-1, the two groups' problem-solving performance, participation perceptions, and cognitive load were compared by using independent *t*-test to explore the guidance effects of real-time prompts. A one-way analysis of covariance (ANCOVA) was also used to evaluate whether students' enhancement of science knowledge was different between the two groups who accepted different real-time prompts in task-1.

Research Results

Analysis of Students' Problem-Solving Performance

To explore the effects of integrating guidance into the science computer game, this study analyzed students' problem-solving performance in SDS. If we only analyze whether each student could correctly identify the cause of each task problem through the multiple-choice question when reporting their task investigation results in SDS, 50% of the students ($n = 50$) correctly found the right answer in task-1 with the guidance of process constraints and prompts, while 36% of students successfully found the correct answer in task-2 without any guidance. However, students could select the right answer by guessing. In order to accurately analyze participants' problem-solving performance in each game task, each student's problem-solving performance was calculated by a scoring rubric, as shown as Table 1. The total score that each student obtained in a task was added (for a maximum possible score of 8 points) and adopted as that student's overall score of problem-solving performance in that task.

Table 1
Scoring rubrics for problem-solving performance

Problem-solving behavior	Score	Description
Defining the problem	2	When reporting the task investigation results, students correctly identified the task problem through a multiple-choice question.
	0	Students incorrectly identified the task problem.



Problem-solving behavior	Score	Description
Collecting data	2	Students collected all the key information for solving the game task (i.e. the key information in task-1 comprised the electricity expense figure and information about the air conditioner and electric water heater; task-2 consisted of the electricity expense figures for the past 2 years, and information concerning the air conditioner, electric water heater, and oven).
	0	Students did not collect all the key information for solving the game task.
Analyzing data	2	Students simulated all key information for solving the game task by using the simulation tool.
	0	Students did not simulate all key information for solving the game task by using the simulation tool.
Interpreting results	2	When reporting the task investigation results, students correctly identified the cause of the task problem through a multiple-choice question.
	0	When reporting the task investigation results, students incorrectly identified the cause of the task problem through a multiple-choice question.

Based on the scoring rubric, whole students ($n = 50$) who received the guidance of process constraints and prompts in task-1 received an average score of 5.68 ($SD = 2.26$) for overall problem-solving performance, while students received an average score of 4.20 ($SD = 2.29$) for overall problem-solving performance when they participated in task-2 without any guidance. As all students first played task-1, followed by task-2, paired sample t -test was conducted to explore the guidance effects of the process constraints and prompts on students' overall problem-solving performance between task-1 and task-2. The result of this test was $t(49)=3.60$, $p < .05$, suggesting that student's scores for overall problem-solving performance in task-1 were significantly higher than those in the task-2. The findings imply that integrating the guidance of process constraints and prompts into the game mechanism may be useful for enhancing students' problem-solving performance in a computer detective game for science education.

At the same time, in order to understand which step of the problem-solving behaviors led to the significant difference, the problem-solving performance scores of each step scored according to a scoring rubric between task-1 and task-2 were analyzed separately. Table 2 presents the results, which show that students' performance of collecting data and analyzing data in task-1 scored significantly higher than those in task-2. In other words, the significant difference of the overall problem-solving performance between task-1 and task-2 could be attributed to students' better problem-solving performance of collecting and analyzing data in task-1.

Table 2

The results of paired t-test for the problem-solving performance between task-1 and task-2

	Task-1 ($n = 50$)		Task-2 ($n = 50$)		Paired t-test
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>t</i>
Problem-solving performance in defining the problem	1.92	.40	1.96	.28	$t(49) = -.573$
Problem-solving performance in collecting data	1.4	.93	.96	1.01	$t(49) = 2.29^*$
Problem-solving performance in analyzing data	1.36	.94	.56	.91	$t(49) = 4.67^*$
Problem-solving performance in interpreting results	1.00	1.01	.72	.97	$t(49) = 1.55$
Overall problem-solving performance	5.68	2.26	4.20	2.29	$t(49) = 3.60^*$

* $p < .05$

Moreover, in order to explore the effects of providing real-time prompts, students' problem-solving performance in task-1 was individually analyzed by independent t -test. Through the same standard of the scoring rubric, students' problem-solving performance scores of each step in task-1, which provided real-time prompts, were compared with those providing no real-time prompts. As shown in Table 3, student's scores of overall problem-solving performance in task-1 with real-time prompts are significantly higher than those without real-time prompts. Moreover, in addition to the performance of defining the problem, students' problem-solving performance scores



of each step in task-1 with real-time prompts are also all significantly higher than those without real-time prompts. This means that providing the guidance of real-time prompts may be helpful for enhancing students' problem-solving performance in a computer detective game for science education.

Table 3

The results of independent t-test for the problem-solving performance between two groups in task-1

	Real-time prompts group ($n = 26$)		No real-time prompts group ($n = 24$)		Independent t -test t
	M	SD	M	SD	
Problem-solving performance of defining the problem in task-1	2.00	.00	1.83	.56	$t(48) = 1.45$
Problem-solving performance of collecting data in task-1	1.69	.74	1.08	1.02	$t(49) = 2.41^*$
Problem-solving performance of analyzing data in task-1	1.69	.74	1.00	1.02	$t(49) = 2.73^*$
Problem-solving performance of interpreting results in task-1	1.46	.90	.50	.88	$t(49) = 3.76^*$
Overall problem-solving performance in task-1	6.85	1.29	4.42	2.43	$t(49) = 4.37^*$

* $p < .05$

Students' problem-solving performance in task-2 without the guidance of process constraints and prompts was also analyzed by independent t -test to understand whether the two groups' performances were different in task-2 after participating in task-1 with different real-time prompts. Based on the same standard of the scoring rubric, the two groups' problem-solving performance scores in task-2 were compared. As shown in Table 4, student's overall and each step problem-solving performance scores in task-2 are not significantly different between the two groups that were provided with different real-time prompts in task-1. This implies that students' problem-solving performances may be similar when the game task did not integrate guidance into the game mechanism, even though all students had accepted the guidance of process constraints and prompts in task-1 and some students had accepted the guidance of real-time prompts in task-1.

Table 4

The results of independent t-test for the problem-solving performance between two groups in task-2 without any guidance

	Real-time prompts group ($n = 26$)		No real-time prompts group ($n = 24$)		Independent t -test t
	M	SD	M	SD	
Problem-solving performance of defining the problem in task-2	2.00	.00	1.92	.41	$t(48) = 1.00$
Problem-solving performance of collecting data in task-2	1.00	.02	0.92	1.02	$t(49) = .29$
Problem-solving performance of analyzing data in task-2	.62	.94	.50	.88	$t(49) = .45$
Problem-solving performance of interpreting results in task-2	.62	.94	.83	1.01	$t(49) = -.79$
Overall problem-solving performance in task-2	4.23	2.29	4.17	2.35	$t(49) = .10$

* $p < .05$

Analysis of Students' Science Knowledge Acquisition

To explore whether students' enhancement of science knowledge was different between the two groups who accepted different real-time prompts in task-1, this study adopted the student's group as an independent variable, the pre-test score of electricity knowledge test as a covariant, and the post-test score of this test as a dependent variable to perform ANCOVA. Before ANCOVA, the assumption of regression homogeneity was tested, $F(1, 46) = 3.91$, $p > .05$, and was not violated. The ANCOVA result was $F(1, 47) = 5.54$, $p < .05$, and $\eta^2 = .11$, indicating that, after the effect of the covariant was eliminated, students' post-test scores of electricity knowledge were significantly



different between the two groups who accepted different real-time prompts in task-1. Moreover, according to post hoc comparison using the least significant difference (LSD) method, the real-time prompt group obtained a significantly higher adjusted average score in the electricity knowledge post-test ($M = 75.64$) than the no prompt group ($M = 67.23$). In other words, providing students with more electricity knowledge through real-time prompts in SDS may be effective in helping them enhance their science knowledge.

Analysis of Students' Participation Perception

To clarify whether providing real-time prompts lowered students' participation perceptions in the game, this study adopted the student's group as an independent variable and the score of the participation perception scale as a dependent variable to perform independent t -test. The t -test result ($t(48) = .07, p > .05$) indicated that no significant differences existed between the real-time prompts ($M = 3.25, SD = .83$) and no real-time prompt ($M = 3.24, SD = .52$) groups in terms of pleasure perception. Regarding learning perception, the result of t -test was $t(48) = .80$ and $p > .05$, suggesting that significant differences did not exist between the real-time prompts ($M = 3.62, SD = .70$) and no real-time prompt ($M = 3.48, SD = .53$) groups. In other words, providing real-time prompts in SDS may not affect the students' perceptions of in-game fun and learning. Overall, all the students had a positive view of the pleasure and learning in the SDS game.

Analysis of Students' Cognitive Load

To understand whether providing excessive real-time prompts increased students' cognitive load, this study adopted the student's group as an independent variable and participants' scores on the cognitive load scale as a dependent variable to perform independent t -test. The results of t -test did not achieve significance ($t(48) = -1.80, p > .05$), indicating that significant differences did not exist between the real-time prompts ($M = 2.52, SD = .78$) and no real-time prompt ($M = 2.89, SD = .65$) groups regarding their overall perceptions of cognitive load in the game. Moreover, if only partial questions (item 3 and item 7) regarding students' perceptions toward task-1 on the cognitive load scale were analyzed, the results of t -test achieved significance ($t(48) = -2.27, p < .05$), while the real-time prompt group obtained a significantly lower average score ($M = 2.29, SD = .87$) than the no prompt group ($M = 2.83, SD = .82$). However, significant differences did not exist ($t(48) = -.51, p > .05$) between the real-time prompts ($M = 2.79, SD = 1.06$) and no real-time prompt ($M = 2.92, SD = .66$) groups regarding their partial perception questions (item 4 and item 8) of cognitive load toward task-2. In other words, providing real-time prompts in SDS may not increase students' cognitive load when participating in the game. Even providing real-time prompts may decrease students' cognitive load in SDS's task-1.

Discussion

This research aimed to develop a computer detective game for providing students with motivation and opportunity in experiencing real-world problem-solving after learning electricity-related knowledge. To explore the effects of applying guidance proposed by science educators in the science computer game, the guidance of process constraints and prompts, as proposed by de Jong and Lazonder (2014), were designed into the game's first task, while the second game task was without guidance. In addition, in order to explore how to offer appropriate real-time prompts in this detective game, the first game task was designed with and without real-time prompts.

The research findings indicate that, when students play the proposed SDS game alone, providing the guidance of process constraints and prompts may affect students' problem-solving performance. The experimental evidences reveal that fewer (only 36%) students correctly identified the right answer in task-2, while all students in task-1, which included the guidance of process constraints and prompts, exhibited significantly higher scores of overall problem-solving performance than those in task-2 without guidance. These results imply that the design of integrating guidance through process constraints and prompts in the game mechanism may be appropriate for guiding students to solve a real-world science problem in a computer detective game. This finding seems to support previous science educators' arguments, which indicate that unguided inquiry learning is challenging for most students (Alfieri et al., 2011; Azevedo et al., 2010). It also seems to support that providing the guidance of process constraints and prompts to students in computer scientific inquiry environments is useful to improve their performance (Hagemans et al., 2013; Manlove et al., 2006), even though the definition of problem-solving



performance in this study is different from the previous pure simulation-based scientific inquiry research, which only indicates the inquiry performance in simulation tools.

In terms of the research question, meaning whether providing real-time prompts is appropriate, the research findings indicate that designing real-time prompts into the game may enhance students' problem-solving performance and science knowledge, and could not affect students' cognitive load and participation perceptions. The experimental evidences reveal that students in task-1 with the additional guidance of real-time prompts exhibited significantly higher scores of overall problem-solving performance and electricity knowledge than those in task-1 without real-time prompts. The statistical evidences also show that the two group who accepted different real-time prompts in task-1 had no significant differences in their scale scores of pleasure, learning, and cognitive load perceptions toward the SDS game, and even the group who accepted real-time prompts in task-1 exhibited significantly lower scores regarding their cognitive load perceptions toward task-1 than those who accepted no real-time prompts in task-1. These results imply that the design of providing the guidance of real-time prompts in this detective game may be appropriate for helping students improve their problem-solving ability and knowledge acquisition, while decreasing their cognitive load. These results seem to support that, the provision of guidance to students facilitates their learning in computer scientific inquiry environments (Alfieri et al., 2011; Eckhardt et al., 2013; Olympiou et al., 2013). It also seems to support previous research findings, which indicate that students attain superior scientific inquiry effectiveness with lower cognitive load in simulation-based scientific inquiry environments (Eckhardt et al., 2013). Moreover, this finding seems to support previous research results again, which indicate that providing guidance to students in computer scientific inquiry environments is useful to improve their performance.

The research findings also indicate that students' better overall problem-solving performance when accepting game tasks with additional guidance could be the result of their superior performances in the problem-solving behaviors of collecting and analyzing data. The experimental evidences reveal that students in task-1 with the guidance of process constraints and prompts exhibited significantly higher problem-solving performance scores of collecting and analyzing data than those in task-2 without guidance. Students' problem-solving performance scores of collecting and analyzing data in task-1 with additional real-time prompts are also significantly higher than those without real-time prompts. These results imply that the design of providing additional guidance in this detective game may be helpful for first enhancing students' performance of collecting and analyzing data, and then, promoting their overall problem-solving performance. It also seems to support Tsai's (2017) research findings, which indicate that the performance of analyzing data is a critical factor regarding whether students can complete an inquiry task in a game.

Conclusions and Implications

In summary, this research develops a computer detective game to provide students in experiencing real-world problem-solving after learning electricity-related knowledge, and finds that integrating the guidance of process constraints and prompts into the game have effects on enhancing students' problem-solving performance and knowledge acquisition. The evaluation of this game indicates that students have significantly better problem-solving performance in the game task with the guidance of process constraints and prompts than those in the game task without guidance. It also indicates that the design of real-time prompts may not only enhance students' problem-solving performance and knowledge acquisition but may also lower students' perceptions of cognitive load.

However, the research experiments should be improved in some aspects. Future studies should adopt more participants to verify the findings of this study and evaluate students' cognitive load with more appropriate timing. Paying more attention to analyzing students' inquiry behaviors in the SDS's simulation tool should also be conducted in the future. Moreover, the digital game developed in this research still requires improvement in some aspects. In addition to the guidance of process constraints and prompts, other forms of guidance, such as metacognitive prompts or another scaffolding design, can be incorporated in this game to further determine whether other guidance designs can more effectively improve students' problem-solving performance.



Acknowledgements

This research received financial support from the Ministry of Science and Technology of Taiwan under contract numbers MOST 104-2511-S-415-010-MY2, MOST 106-2511-S-415-005, MOST 107-2511-H-415-008-MY2, and MOST 109-2511-H-415-008-MY3.

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Received: April 05, 2020

Accepted: July 26, 2020

Cite as: Tsai, F.-H., & Hsu, I.-Y. (2020). Exploring the effects of guidance in a computer detective game for science education. *Journal of Baltic Science Education*, 19(4), 647-658. <https://doi.org/10.33225/jbse/20.19.647>

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