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Effects of explicit and implicit prompts on students' inquiry practices in computer-supported learning environments in high school earth science

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ABSTRACT

The study explored how to best use scaffolds for supporting students' inquiry practices in computer-supported learning environments. We designed a series of inquiry units assisted with three versions of written inquiry prompts (generic and context-specific); that is, three scaffold-fading conditions: implicit, explicit, and fading. We then examined how the three scaffold-fading conditions influenced students' conceptual understanding, understanding of scientific inquiry, and inquiry abilities. Three grade-10 classes ($N = 105$) participated in this study; they were randomly assigned to and taught in the three conditions. Data-collection procedures included a pretest–posttest approach and in-depth observations of the target students. The findings showed that after these inquiry units, all of the students exhibited significant learning gains in conceptual knowledge and performed better inquiry abilities regardless of which condition was used. The explicit and fading conditions were more effective in enhancing students' understanding of scientific inquiry. The fading condition tended to better support the students' development of inquiry abilities and help transfer these abilities to a new setting involving an independent socioscientific task about where to build a dam. The results suggest that fading plays an essential role in enhancing the effectiveness of scaffolds.

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Inquiry practices; scaffolding; computer-supported learning; written prompts

Introduction

For developing learners' scientific literacy, the construct of scientific inquiry has been the advocated goal for science education in the past decades (Ministry of Education, 2001; National Research Council [NRC], 2000; NRC, 2012). The recent released *Next generation science standards* (Achieve, 2013) further emphasized the importance of the doing of science, i.e. *practices*, in science learning. Constrained by the disciplinary background knowledge and the knowledge of using innovative instruments, it is inconceivable for students to 'practice' science like scientists. The fast development of computer technology offers ample opportunities for students to practice scientific inquiry in

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school settings. Computer-based environments can be used to engage learners in scientific inquiry activities, such as using simulations to scale down the phenomena to be investigated, or providing software tools to help analyze or visualize data (Krajcik, Czerniak, & Czerniak, 2007; Van Joolingen, De Jong, & Dimitrakopoulou, 2007). It is generally believed that learning in computer-based inquiry environments can facilitate meaningful understanding. However, studies have found that without support, learners can feel overwhelmed by being simultaneously exposed to hypermedia and complicated inquiry processes (De Jong & Van Joolingen, 1998; Van Joolingen et al., 2007). Achieving effective inquiry learning in computer-based environments requires the provision of certain types of guidance and support, which is called scaffolds (De Jong, 2006; Quintana et al., 2004; Tabak, 2004; Van Joolingen, 1998).

Various types of scaffolds have been designed for assisting learners in computer-supported scientific investigations. However, there appears to be conflicting research findings about the effectiveness of these scaffolds. The research by Oliver and Hannafin (2001) showed that a framework for inquiry was found unproductive in supporting students' inquiry practices in an open-ended learning environment. Land and Hannafin (1997) also indicated that the designed computer-based scaffolds did not seem effective in student-generated, open-ended investigations. However, other studies believe that the designed scaffolds did provide an effective way to support students' learning of scientific inquiry (Davis & Miyake, 2004). The researchers proposed a scaffolding design framework for software to promote scientific inquiry (Quintana et al., 2004), and suggested how different forms of scaffolds can be employed for addressing diverse learning needs in a complex learning settings (Tabak, 2004). Indeed, for effectively supporting students' development of inquiry abilities, the types of scaffolds provided, the ways the scaffolds are provided, and the duration of instruction are all needed to be taken into account (Kim, Hannafin, & Bryan, 2007; McElhaney, Chang, Chiu, & Linn, 2014).

Our research was interested in the most effective way to use inquiry prompts for supporting students' inquiry practices in computer-supported learning environments. The study designed computer-supported inquiry learning units that used generic and context-specific inquiry prompts to guide student investigating activities. We examined the effects of three scaffold-fading conditions of inquiry prompts: implicit, explicit, and fading, on students' learning about conceptual knowledge and scientific inquiry, and discussed in which condition these prompts better support students' development and transfer of inquiry abilities.

Literature review

In science education, the term inquiry has diverse definitions and it implies several different meanings (Flick & Lederman, 2006). In this study, we view inquiry as students' engagement of scientist-like investigating activities as well as teachers' instructional strategies to promote students' development of inquiry abilities (Bybee, 2006; Hsu, Lai, & Hsu, 2015). This view suggests that students need to develop not only an understanding of scientific inquiry but also the abilities to do scientific inquiry (Bybee, 2006; McNeill, Lizotte, Krajcik, & Marx, 2006).

Scaffolds in computer-based inquiry environments

The idea of scaffolding was first introduced in the context of adult–child interactions in which the child is able to complete a challenging task only when the more-knowledgeable adult provides support and guidance (Lin et al., 2012; McNeill et al., 2006; Wood, Bruner, & Ross, 1976). The notion of scaffolding is considered a promising strategy in teaching scientific inquiry (McNeill et al., 2006; Stone, 1998), and it has been extensively adopted in the pedagogical design of technology-supported science teaching (Quintana et al., 2004).

Diverse computer-based scaffolds such as visualization tools (e.g. Songer, 2006), computer-based modeling tools (Fretz et al., 2002; White & Frederiksen, 1998), and electronic probes and sensors (e.g. Tinker & Krajcik, 2001) were developed for supporting different facets of inquiry processes. Quintana et al. (2004) proposed a design framework for software that suggests scaffolding guidelines and strategies based on three scientific inquiry components (sense making, process management, and articulation and reflection) and the obstacles that students might have when doing a particular inquiry step. In reference to this framework, the study selected and incorporated several visualization tools into the design of the inquiry units. More specifically, these visualization tools were organized in a way that made the disciplinary strategies explicit in the learner–tool interactions. Different types of representations offered by the visualization tools allowed students to manipulate the data, inspect it in multiple ways, and reveal its latent properties (Quintana et al., 2004). It is expected that through the interactions with these visualization tools, students can 'see' the phenomena, manipulate the factors involved in the phenomena, identify the trends underlying the data, reason the cause and effect relationships, and make meaning of the scientific concepts.

Context-specific versus generic inquiry scaffolds

Previous research has suggested that content knowledge and understanding of scientific inquiry were two major factors to influence their success at completing inquiry activities (Metz, 2000). Students' domain-specific knowledge was found to be closely related to their ability to evaluate data (Chinn & Brewer, 2001) and the ability to use evidence to substantiate scientific explanations (Bybee, 2006; McNeill et al., 2006). In addition to content knowledge, a good understanding of scientific inquiry is crucial for inquiry practices. If students do not comprehend the notion of scientific inquiry and underlying principles, they may not know, for instance, what counts as evidence and how to apply these inquiry steps and principles to a particular scientific practice (McNeill et al., 2006). We agree with previous researchers that for successful scientific inquiry practice, students need to use content knowledge in conjunction with understanding of scientific inquiry (McNeill & Krajcik, 2009). In other words, these two bodies of knowledge are both important. Having either content knowledge or understanding of scientific inquiry alone is not sufficient for successful scientific inquiry practice.

When scaffolding inquiry learning, the prompts that hint students about what content knowledge to apply in a context-specific task are referred to *context-specific scaffolds*, whereas the prompts that support students to apply general inquiry expertise across different science domains such as constructing explanations or making argumentations, are named *generic explanation/argumentation scaffolds* (McNeill & Krajcik, 2009). Focusing on individual inquiry phase, previous research findings showed that providing context-specific scaffolds appeared to be more effective in developing students' understanding of content knowledge, while providing generic explanation or argumentation scaffolds were more closely associated with students' development of explanatory or argumentative abilities (McNeill & Krajcik, 2009; McNeill et al., 2006). The study continued the research theme by applying the notion of context-specific and generic scaffolds in a complete inquiry process. Indeed, scientific inquiry is a recursive activity including multiple steps, including asking questions, planning and carrying out investigations, analyzing and interpreting data, constructing explanations, engaging in argument from evidence, and evaluating information (NRC, 2000). Therefore, rather than addressing simply one phase of scientific inquiry practice, we adopted both generic and context-specific inquiry scaffolds in the instructional design and investigated how the two types of scaffolds influenced students' performance on several successive phases of inquiry.

Although previous studies provided insightful suggestion that both types of support (context-specific and generic scaffolds) were critical in successful science learning, a significant issue about what type of support should fade or remain as constant support to promote greater science learning was raised and called for further investigation.

The issue of fading

Fading (i.e. de-scaffolding) is seen as a crucial characteristic of scaffolds (McNeill et al., 2006; Van de Pol, Volman, & Beishuizen, 2010). Since learning is a dynamic process, the support provided by scaffolds needs to be adjusted (increased or decreased) based on the learner's status regarding the learning task and the difficulties encountered. These notions can also be applied to students' learning in computer-supported inquiry environments. The changes in the demands of learning across a series of activities mean that the scaffolds also need to change. The most pressing consideration for teachers and researchers is to determine when to reduce or remove scaffolds so as to maximize the degree to which students become successful, independent, and self-regulated learners.

The fading of scaffolds is seen a feasible approach to help learners internalize the strategies targeted by the scaffolds (Fischer, Kollar, Stegmann, & Wecker, 2013). Previous studies have found that scaffold fading better equipped students to write stronger explanations (McNeill et al., 2006), had positive effects on students' problem-solving skills (Leutner, 2000), and had significant positive effects on students' online search competence (Wecker, Kollar, Fischer, & Prechtl, 2010). Together with peer-monitoring, the fading of instructional scripts (as a kind of social-cognitive scaffolding) was also found to be helpful for students to develop robust argumentation strategy knowledge (Wecker & Fischer, 2011). The researchers attributed the effect to both an increase amount of self-regulated performance and peer-monitoring after fading the scripts. This study focused on the effect of generic and context-specific scaffolds on students' inquiry practice. Specifically, we were interested in knowing how fading might play a role in promoting students' learning transfer during a series of inquiry units. As context-specific scaffolds provide hints not only about the science content for the task but also how to apply that specific content knowledge in a particular inquiry phase (McNeill & Krajcik, 2009), we chose to fade context-specific scaffolds, instead of generic scaffolds, in order to enhance students' internalization of the ability to use content knowledge in conjunction with understanding of scientific inquiry.

In sum, the study aimed to contribute to the knowledge about how scaffolds can be better used to support students' inquiry practices in a computer-supported learning environment. We explored how different scaffold-fading conditions in terms of different combinations of generic and context-specific inquiry prompts might impact students' inquiry practices. The main research questions that guided this study were (1) how do different scaffold-fading conditions for a computer-supported learning environment influence students' conceptual understanding and understanding of scientific inquiry? (2) How do different scaffold-fading conditions for a computer-supported learning environment influence students' development and the transfer of inquiry abilities?

Method

This study had a mixed-methods quasi-experimental design. The research methods involved a pretest–posttest approach and in-depth observations of target students.

Participants

The host school was a middle-sized (a total of 48 classes) public senior high school located in a middle-class, suburban area in northern Taiwan. The participating teacher, Ms Wang, had 13 years of teaching experience, and she had previously completed a 21-hour workshop that focused on designing scientific inquiry activities and inquiry teaching strategies. Although Ms Wang was not involved in designing the learning units, she had experiences in teaching some of the units before this study. A total of 105 grade-10 students (aged 17 or 18) from 3 intact classes participated in this study; all were taught by Ms Wang in an earth-science laboratory. The three classes were randomly assigned to the explicit, implicit, and faded groups. The students were taught the same earth-science content using an inquiry module except for the worksheets with different versions of written prompts provided. The students worked in groups during the lessons, and each group was given a laptop for carrying out inquiry activities. As for the subject of earth science, there were two sessions per week (50 minutes per session); the series of inquiry units took about three months to complete.

After eliminating incomplete work samples due to student absences from the pretest and posttest, the final sample size of the study was 93, with a similar distribution across the 3 classes. The final groups analyzed comprised 31 students in the explicit group (12 males, 19 females), 32 in the implicit group (12 males, 20 females), and 30 in the faded group (9 males, 21 females). Since the participating students were not legal adults, we informed the students' guardians and obtained their informed consent before the students participated in this study.

Regarding data collection (see Figure 1), all three groups performed paper-and-pencil pretests and posttests of (1) the Conceptual Understanding Test (CUT) for the three inquiry units, (2) the Test of Understanding of Scientific Inquiry (TUSI), and (3) the Inquiry Practice Test (IPT). For exploring the students' learning transfer, we randomly selected two target groups in each scaffold-fading condition (with four students per

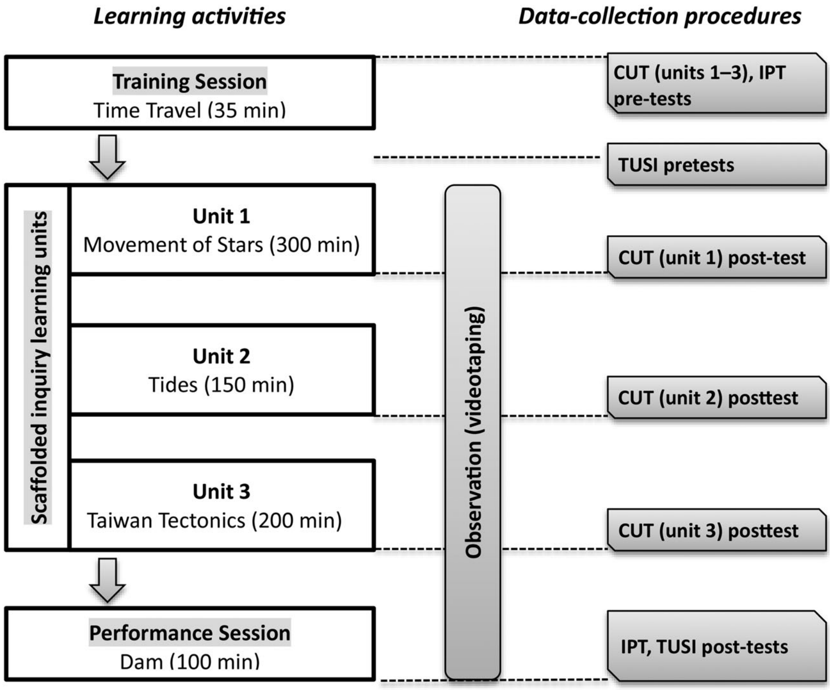

Figure 1. Study design: learning activities and data-collection procedures.

group), and observed, used videotaping, audiotaping, and screenshot-capturing software (Camtasia) to record their actions, interactions, and learning processes during the performance session.

Inquiry activities in computer-supported learning environments

A series of instructional units was developed to promote student inquiry learning, including a training session for conducting inquiry (*Time Travel*), three scaffolded inquiry learning units (*Movement of Stars*, *Tides*, and *Taiwan Tectonics*), and a performance session (*Dam*) with embedded assessments to measure the transfer of student inquiry abilities. To facilitate students' development of inquiry abilities, the idea of synergistic scaffolds (Tabak, 2004) was adopted to design inquiry learning activities. 'A system of scaffolds' (p. 318) were developed and simultaneously used for supporting students' inquiry practices. Specifically, three particular features were designed in this series of units: incorporating an inquiry teaching framework in the curriculum, using visualization tools in the learning process, and embedding written inquiry prompts. The learning activities with embedded scaffolds were presented in the worksheets, and relevant software was used for carrying out these activities.

Incorporating an inquiry teaching framework in the curriculum

Based on the National Science Education Standards (NRC, 2000) and Hsu (2008), the research team incorporated the following five essential scientific inquiry abilities into the module: questioning, planning, data collection and analysis, interpreting, and reviewing. Each learning unit incorporated all five inquiry abilities, with the exceptions that the *Movement of Stars* and *Taiwan Tectonics* units did not include planning ability, and the *Tides* unit did not include reviewing ability. When each unit began, the teacher introduced the interface of the software and briefly explained the learning task. The students then worked in groups to complete the scientific inquiry process by themselves.

Time Travel was a training session using a short film that provided the students with fundamental ideas about the whole process and each scientific inquiry step. During the succeeding scaffolded inquiry units (*Movement of Stars*, *Tides*, and *Taiwan Tectonics*), three different formats of inquiry prompts (i.e. explicit, implicit, or fading) were used to guide the students completing the inquiry tasks. In the final performance session, the students were required to complete the socioscientific (SSI) task: where to build a *Dam*. This task had embedded assessments that examined the extent to which the students were able to transfer their inquiry abilities into a new, complex, SSI setting. Table 1 provides a summary of the inquiry investigations involved in each learning unit.

Using visualization tools in the learning process

The interactive visualization tools (see Table 1 and Appendices 1, 2) supported students with topic-specific knowledge such as the movement of stars, tides, and plate tectonics. These tools assisted the students' explorations of real or simulated data. Through their interactions with the visualization tools, the students were expected to choose appropriate evidence for reasoning and identify the patterns in the data for constructing scientific explanations.

Embedding generic and context-specific inquiry prompts

This study adopted generic and context-specific inquiry prompts in the instructional design. The purposes of using these inquiry prompts were (1) prescribing specific sequences of inquiry activities, (2) evoking certain inquiry activities to be carried out, and (3) guiding inquiry tasks. For prescribing specific sequences of activities, we provided a generic inquiry map placed at the beginning of each activity worksheet (*generic inquiry prompts*). The map provided an overview of the inquiry process and presented an explanation for each step. For evoking certain activities to be carried out, we designed *context-specific inquiry prompts* and presented them in two forms. The first form was a flow chart juxtaposing to the generic inquiry map. The second form was offered in text boxes presented immediately before the corresponding activity. These prompts suggested context-specific enactments for the learning goal being considered at that time. They also supported students applying their understandings of inquiry to the specific context and referring the enactments to the generic inquiry map. For guiding inquiry tasks, we designed a series of *questions* to encourage group discussions and support them in completing the task collaboratively.

In order to investigate how fading might play a role in promoting students' 'transfer' of inquiry abilities in a new setting, we gradually faded context-specific prompts and compared its effect with the other two groups with constant support and without support. In other words, three scaffold-fading conditions (implicit, explicit, and fading; see Figure 2) were designed by different combinations of three components: *generic inquiry prompts*, *context-specific inquiry prompts*, and the *questions*. In general, all three conditions provided the same questions to guide inquiry tasks. The presentation of the

Table 1. Visualization tools and inquiry investigations in the units.

Unit	Visualization tool	Description of the visualization tool	Inquiry investigations in the unit
Movement of Stars	Stellarium (v. 8.2)	Stellarium is a free open-source planetarium that runs on a computer. It shows a realistic sky in 3D, like that seen with the naked eye, binoculars, or a telescope (http://www.stellarium.org/en/)	Students are required to use the information provided by Stellarium to explore the movements of the stars, and to discuss and summarize the factors that affect these movements
Tides	Taiwan-tides prediction software (Tide 2003) and the Tides Animation interactive software	Tide 2003 is free educational software that can predict tide heights and the times of high and low tides at specific dates and locations in Taiwan (http://content.edu.tw/senior/earth/tp_ml/tidal/menu-file/titaiwan.files/tideprog.htm) Tides Animation interactive software shows how the interactions among sun, moon, and earth cause tides (Appendix 1)	First, students are required to use Tides Animation interactive software to sum up and discuss the general principles that cause tides. Then, by means of Tide 2003 software, students identify the characteristics of the tide at genuine ports, and discuss and explain the effects of topography on tides
Taiwan Tectonics	Seismic Eruption	Seismic Eruption was created by Alan L. Jones, State University of New York at Binghamton. It is a program for visualizing seismicity and volcanic activity over space and time (http://bingweb.binghamton.edu/~ajones/#Computer%20Programs)	First, students are required to use Seismic Eruption to analyze and make sense of the earthquake data around Taiwan. Then, they diagnose the type of plate boundaries and explain the tectonic structure around Taiwan
Dam	Dam software	Dam is simulation learning software presenting a situational task in which students are asked to evaluate a potential dam location in the Jing-Si area, which is going to face a water-shortage problem in a few years. In order to solve this problem, students need to select an appropriate location to build a water reservoir for collecting surface water and stabilizing the water supply (Appendix 2)	Students are required to use Dam software to collect and analyze relevant information of the six potential dam locations. Then, based on the refined criteria and appropriate decision strategies, they decide the best dam location and explain the rationale behind their decisions

inquiry map (generic and context-specific inquiry prompts) and the text boxes for inquiry activities varied with the scaffold-fading condition. During the learning units, the teacher's instruction basically followed the prompts provided for each condition.

The implicit condition only embedded one component into the three inquiry units, which is a series of questions. The explicit condition embedded all the three components throughout the three units. In other words, the explicit condition provided consistently complete inquiry maps and text boxes with both generic and context-specific inquiry prompts, and a series of questions across all three inquiry units. To investigate how fading affected the students' learning transfer, the fading condition gradually faded context-specific inquiry prompts across the three units. In the first learning unit (*Movement of Stars*), all three components were included as in the explicit condition. In the second unit (*Tides*), the flow chart juxtaposed to the generic inquiry map and the term of the corresponding inquiry step in the textboxes were taken out. Therefore, in the second unit, students were required to relate their enactments to the corresponding

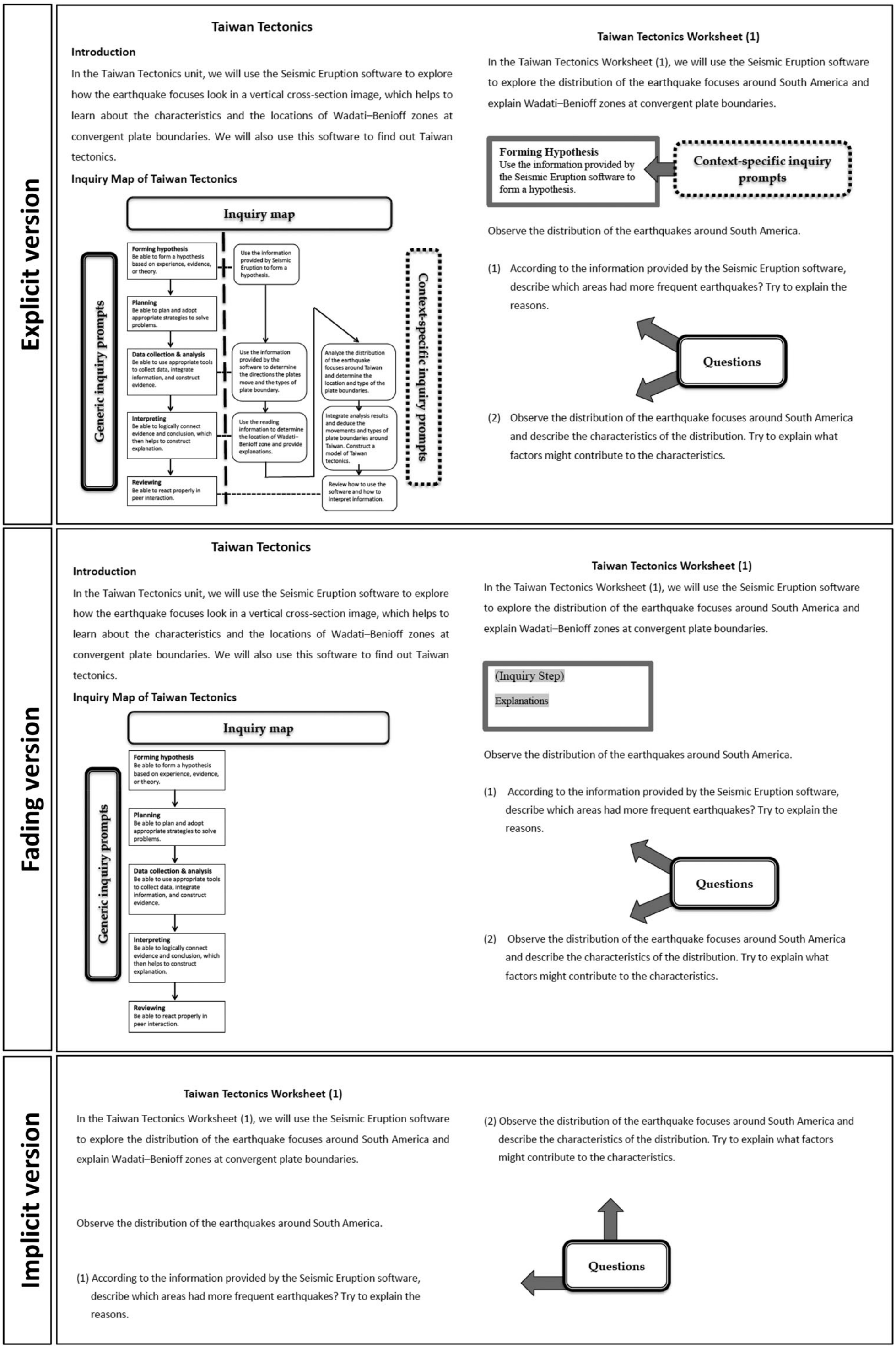

Figure 2. Design of the three scaffolding-fading conditions for the *Taiwan Tectonics* unit.

inquiry steps and to navigate themselves in the inquiry map. In the third unit (*Taiwan Tectonics*), the generic inquiry map was still kept but all the context-specific inquiry prompts faded. Therefore, the students were required not only to decide and explain what enactments they were going to take for each activity, but also to relate their enactments to corresponding inquiry steps and to navigate themselves in the inquiry map.

Instruments and analysis

Three paper-and-pencil tests on conceptual understanding, understanding of scientific inquiry and inquiry practice respectively, and embedded assessments in the performance session were employed to evaluate the students' learning in the computer-supported environment. A research team comprising two university science education professors, one science education graduate student, and five science teachers was engaged in developing and validating these test items.

Conceptual Understanding Test

The CUT was developed to measure students' conceptual knowledge about the movements of stars, tides, and plate tectonics. The CUT comprised 25 multiple-choice items (Appendix 3), and was pilot-tested with 107 grade-11 students. Analyses of the item responses revealed reasonable internal consistency (Cronbach's α was .71). The average item-discrimination and item-difficulty indexes were .40 and .62. A paired t-test was adopted to examine the pretest–posttest gains in each group on the CUT. An analysis of covariance (ANCOVA) was adopted to evaluate the main effect of the three scaffold-fading conditions on students' conceptual understanding, in which the covariate was the appropriate pretest scores, the independent variable was the three conditions, and the dependent variable was the posttest scores.

Test of Understanding of Scientific Inquiry

The TUSI pretest and posttest comprised seven and six matching items, respectively. The TUSI pretest presented several sets of episodes in a scenario pertaining to the training session (*Time Travel*); each episode was designed to illustrate one of the scientific inquiry steps in order to allow the students to identify the inquiry step for each episode (Appendix 3). Similarly, the TUSI posttest was a worksheet designed for a complete inquiry process that involved observing the weather on the school campus. The students were asked to identify the scientific inquiry step according to what they were required to do in each research step.

The TUSI generated ordinal data. Therefore, Kruskal–Wallis one-way analysis of variance (nonparametric) was adopted to examine whether the understandings of scientific inquiry differed between the three groups before the module, and whether different scaffold-fading condition affected the students' understanding of scientific inquiry.

Inquiry Practice Test

The IPT, which was developed to measure student inquiry abilities, includes three items on questioning, four on planning, four on analysis, and six on explaining. These items were presented in four sets of scenarios: a motorcycle's rusty exhaust pipe, tides, movements of stars, and plate tectonics. Students needed to integrate relevant conceptual knowledge with scientific inquiry abilities to answer the items. The IPT was pilot-tested by the same group of grade-11 students ($N = 107$) who completed the CUT. The IPT answers of the students were scored using a rubric (Appendix 4) adopted from Hsu, Chang, Fang, and Wu (2015) and Hsu, Lai, et al. (2015) and other researchers (McNeill & Krajcik, 2008; McNeill et al., 2006; Wu & Hsieh, 2006). This scoring rubric included four categories (questioning, planning, analyzing, and explaining), and each contained one or two subcategories that scored the students' responses on six levels (from 0 to 5). The interrater agreement for the IPT was 85%, and the interrater reliability reached .90 (Spearman's $\rho = .90$, $p < .01$). A paired t-test was adopted to examine the pretest–posttest gains in each group on the IPT. ANCOVA was again adopted to evaluate the main effect of the three scaffold-fading conditions.

Embedded assessments of the transfer of scientific inquiry abilities

For evaluating the students' inquiry practices in the performance session, we videotaped the target students' usage of the software and group conversations. The analysis involved three steps: (1) transcribing all of the videotapes, (2) segmenting them into episodes based on what inquiry skill or inquiry activity the students performed, and (3) scoring each episode using the rubric presented in Appendix 5. This scoring rubric included three categories (planning, analyzing, and explaining), and each contained one to three subcategories that scored the responses on three levels (from 0 to 2).

Taking two episodes that identified as demonstrating the P2 skill (be able to adjust investigating methods and processes during scientific investigations) as an example. Group IV2 (implicit version group 2) only considered the variables that they had been used before, so this episode was scored as 1. Group FV2 (faded version group 2) first used their previous variables (locations of landslides, geology map, and contour map) to eliminate some locations. They then included new information (ecology and historical heritage), revised their plan, and added more variables. Therefore, the episode performed by FV2 was scored as 2. Appendix 5 provides example episodes for each dimension of the inquiry skills. The interrater agreement for the video inquiry events analysis was 85%, and the interrater reliability reached .90 (Spearman's $\rho = .90$, $p < .01$).

Findings

The findings can be divided into three parts: conceptual understanding, understanding of scientific inquiry, and inquiry abilities.

Conceptual understanding

Paired t-test results of pretest–posttest changes on the CUT revealed that there were statistically significant improvements in the students' conceptual understanding about of the earth-science contents in all three scaffold-fading conditions, with moderate to high effect sizes (Table 2). However, the ANCOVA results indicated that there was no significant main effect on students' CUT posttest scores among the three different conditions, $F(2, 90) = 2.88$, $p = .061$, when the CUT pretest scores were used as the covariate. This finding suggests that the use of inquiry prompts with different designs did not influence students' conceptual understanding of the earth-science contents.

Understanding of scientific inquiry

The Kruskal–Wallis analysis results for the TUSI pretest of the whole-group students revealed no significant differences among the three groups (EV = 43.86, IV = 49.34, and FV = 47.88; $\chi^2 = 0.90$, $p = .64$). This indicated that the three groups had similar understanding of scientific inquiry before the inquiry learning. The Kruskal–Wallis analysis results for the TUSI posttest (EV = 50.95, IV = 37.22, and FV = 53.43) indicated that after the inquiry units the understanding of scientific inquiry differed significantly between the three groups ($\chi^2 = 10.48$, $p = .005$). The mean scores indicated that the FV and EV groups had a better understanding of scientific inquiry than the IV group. This implies that compared to the implicit condition, explicit and fading conditions were more effective in enhancing students' understanding of scientific inquiry.

Scientific inquiry abilities

The paired *t*-test results indicated that the students in the three conditions performed significant learning gains on the IPT after the units (Table 3). According to the ANCOVA results, there was no statistically significant main effect among the three conditions' IPT results, $F(2, 90) = 0.04$, $p = .96$. However, the mean scores showed a trend that the faded group ($M = 18.14$) performed slightly better than the implicit ($M = 17.96$) and explicit ($M = 17.87$) groups. Also, the faded group had the largest effect size among the three conditions.

Regarding the students' inquiry practices in the *Dam* unit, we analyzed the quality of each inquiry event. One of the six target groups, EV1 (explicit version group 1), was excluded from the analysis of the *Dam* performance session because the students did not follow the instructions for using the software – they had registered with a preowned username, so their plans and conclusions were contaminated with the learning results of other students. Therefore, five target groups (EV2, IV1, IV2, FV1, and FV2) were used in the following analysis of inquiry practices. Figure 3 illustrates the target groups' total scores and their separate scores for each inquiry ability. The two fading groups' scores were higher than the explicit and implicit groups, and FV2 was the highest. We found that the FV2 students repeated the steps of data analysis–prediction–testing prediction several times before they made their final decision. In other words, they not only performed these abilities frequently but also performed them well.

Table 2. Students' performance gains on the CUT.

Group[a]	Test	Mean	SD	t	p	ES[b]
EV ($n = 31$)	Pretest	60.78	14.65	7.97*	<.001	1.74
	Posttest	77.78	9.75			
IV ($n = 32$)	Pretest	61.18	10.54	9.46*	<.001	1.35
	Posttest	77.88	12.27			
FV ($n = 30$)	Pretest	66.06	12.32	3.75*	<.001	0.74
	Posttest	74.86	11.90			

[a]EV, explicit version; IV, implicit version; FV, faded version.
[b]Effect size (ES) was calculated by dividing the difference between the pretest and posttest mean scores by the pretest SD. The magnitude of the effect size was quantified as follows: (a) small, 0.2–0.5 SDs; (b) moderate, 0.5–0.8 SDs; and (c) large, >0.8 SDs (Sheskin, 2004).
*$p < .001$.

Table 3. Students' performance on the IPT.

Group	Test	Mean	SD	t	p	ES[a]
EV ($n = 31$)	Pretest	12.93	3.95	6.37*	<.001	0.96
	Posttest	17.67	4.96			
IV ($n = 32$)	Pretest	13.08	3.99	6.30*	<.001	0.99
	Posttest	17.89	4.86			
FV ($n = 30$)	Pretest	13.69	4.36	5.68*	<.001	1.16
	Posttest	18.42	4.08			

[a]Effect sizes calculated and defined as in Table 2.
*$p < .001$.

In an attempt to look closely into how the students in the three conditions performed inquiry abilities during the *Dam* unit, the qualitative data for representative groups EV2, IV2, and FV2 were presented. We used a flowchart of the inquiry steps and selected conversations to illustrate each group's inquiry performance.

EV2: Compared to IV2 and FV2, the EV2 flowchart (Figure 4) consisted of fewer inquiry steps because these students did not revise their predictions repeatedly. They seemed to spend longer time considering what kind of information they needed to purchase and analyzing these data. They eliminated locations #3 and #5 after the first analysis; then they compared and tested locations #1 and #2 but found they had limited information to make any further decision. Therefore, they included more information, analyzed it, and chose location #2. Although they did not use inquiry abilities frequently (a total of 12 events), they had a relatively higher total score on the quality because they were able to perform these limited inquiry abilities well.

IV2: Figure 5 summarizes the IV2's decision-making process. Video analyses showed that immediately after the instruction, the students bought six pieces of information for examining the six dam locations. They considered one criterion at a time in a sequential order. Once the location was eliminated, they did not consider it again. The following transcription of an ongoing conversation shows part of the deliberations and decision-making process within the IV2 group (the second number indicates a specific student).

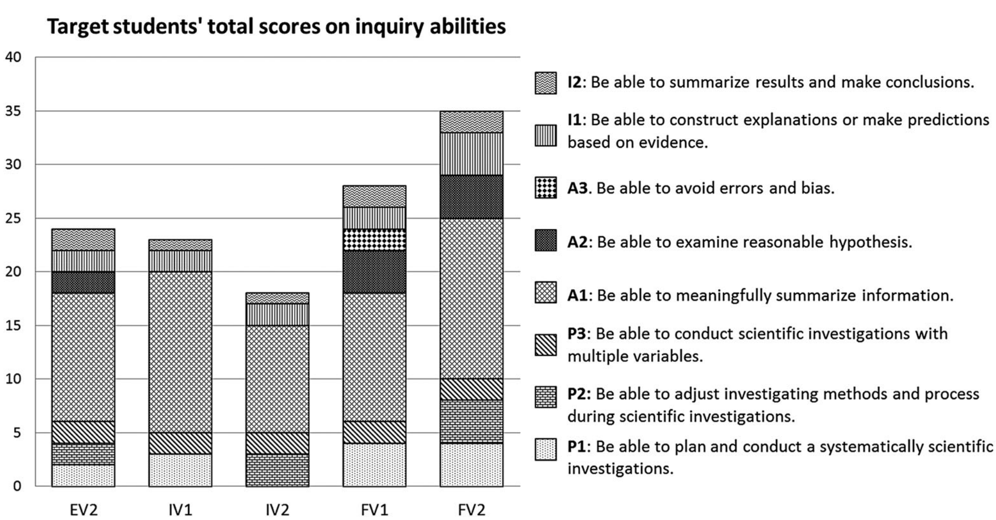

Figure 3. Scores in the target groups for the inquiry abilities in the *Dam* performance session.

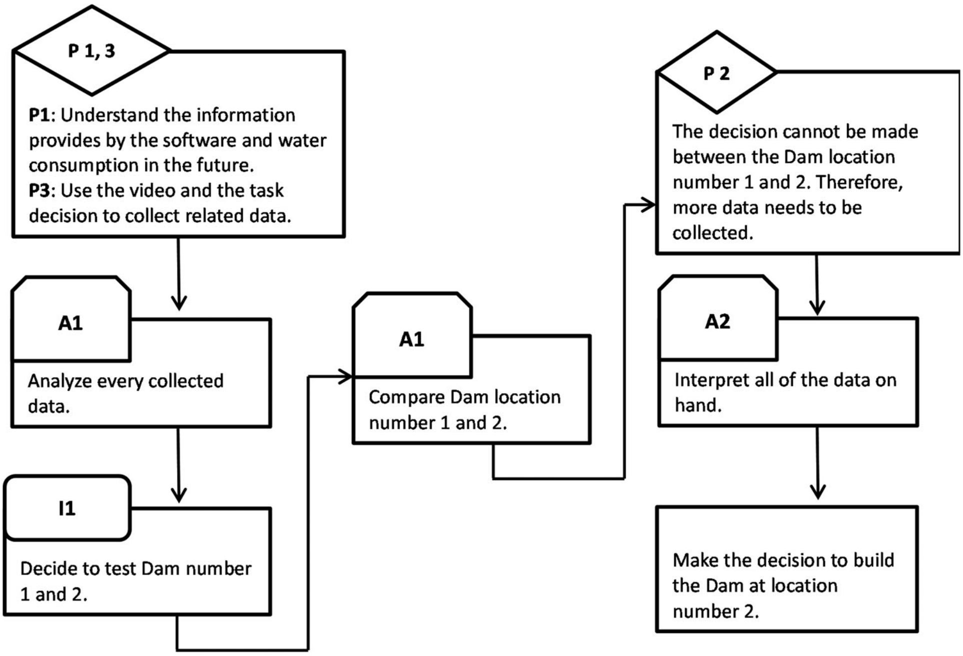

Figure 4. A flowchart of EV2's scientific inquiry steps during the *Dam* unit (P1: Be able to plan and conduct a systematically scientific investigations. P2: Be able to adjust investigating methods and process during scientific investigations. P3: Be able to conduct scientific investigations with multiple variables. A1: Be able to meaningfully summarize information. A2: Be able to examine reasonable hypothesis. I1: Be able to construct explanations or make predictions based on evidence).

IV21: Look! There will be more landslides in these two locations, so we don't want these two locations [#5 and #6].

IV22: You have to consider which location has a higher elevation.

IV21: OK! These places are higher [points to locations #5 and #6]; so if landslides happen, there must be some serious effects.

IV23: So, we can only consider locations #1, #2, #3, and #4.

… (Considering the distribution of faults)

IV21: Look! A fault passed through location number #3.

IV22: Therefore, we cannot choose #3.

IV24: Only #1, #2, and #4 are left.

… (Considering human settlements)

IV21: There are many human settlements at #4.

IV23: Then, don't choose #4, but #1 is OK!

IV22: Why not #4?

IV23: Because we don't have to spend a lot of money for compensation.

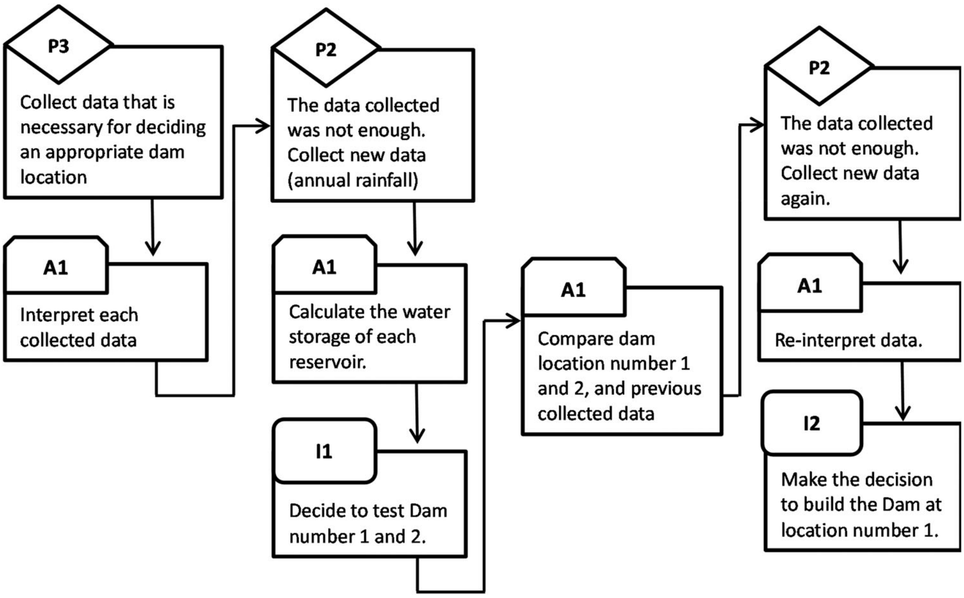

Figure 5. A flowchart of IV2's scientific inquiry steps during the *Dam* unit. (P2: Be able to adjust investigating methods and process during scientific investigations. P3: Be able to conduct scientific investigations with multiple variables. A1: Be able to meaningfully summarize information. I1: Be able to construct explanations or make predictions based on evidence. I2: Be able to summarize results and make conclusions).

It seemed that the IV2 students used a more arbitrary, serial approach to make a decision. They did not include multiple factors for consideration and discussion, nor did they evaluate the pros and cons of each dam location at the same time to avoid biases. In addition, they did not have a priority in considering the individual factors. All of these actions contributed to their lowest total score (18) among the five target groups.

FV2: The flowchart for FV2 (Figure 6) reveals that before these students made their decision, they analyzed the information very carefully and revised their plans several times. These students first considered the water usage in the area. Next, they used the software to explore the six dam locations, and discussed what information is essential to consider a dam location. Then, they drafted a plan on the worksheets that listed the step-wise procedures they were going to use: (1) observe the environment of each dam location, (2) rivers and rainfalls, (3) faults, (4) human settlements, (5) rare species, (6) the first test, (7) the second test, and (8) analysis and make a decision.

Essentially, the FV2 students did not eliminate any location based simply on one single piece of information. They, in contrast to the other groups, were able to integrate new and old information in order to make a better decision about the complex SSI issue. The following transcript of their conversation illustrated this process.

… (During the first analysis)

FV21: So definitely not #3 [from the fault's distribution].

FV22: No, not #3?

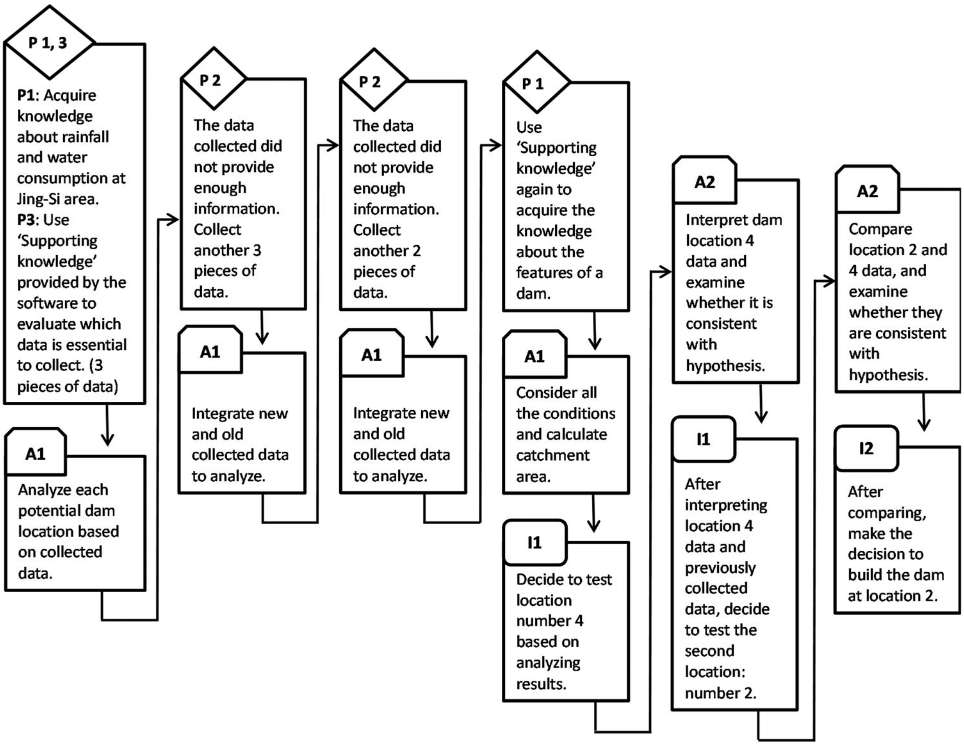

Figure 6. A flowchart of FV2's scientific inquiry steps during the *Dam* unit. (P1: Be able to plan and conduct a systematically scientific investigations. P2: Be able to adjust investigating methods and process during scientific investigations. P3: Be able to conduct scientific investigations with multiple variables. A1: Be able to meaningfully summarize information. A2: Be able to examine reasonable hypothesis. I1: Be able to construct explanations or make predictions based on evidence. I2: Be able to summarize results and make conclusions).

FV23: We should also look at landslides.

FV22: How about #2? I think both #2 and #4 are OK.

FV24: I would say #4.

FV22: But there are landslides above #4.

FV21: Then every location would have landslides!

FV22: How about we look at other factors as well?

FV24: We need geological maps.

FV23: We need contour map!

FV24: You do like contour map, don't you?

FV23: Of course you need contour map, as you can use the map to determine whether you need to consider landslides.

FV24: Agree!

The FV2 students were able to consider multiple factors at the same time. After they bought new information, they used both new and old information to evaluate the locations. This explains why the FV2 group had the highest total score (35) among the five target groups.

Discussion

This study incorporated different levels of scaffolds (in the form of three scaffold-fading conditions: implicit, explicit, and fading) into inquiry learning units and sought to best support students developing inquiry abilities in a computer-supported learning environment. The results suggest that a system of scaffolds designed in the learning units including visualization tools and various written inquiry prompts significantly improved the students' science learning regardless the conditions. A consistent presentation of generic inquiry prompts (in explicit and fading groups) helped students reinforce their understandings of scientific inquiry. In addition, fading context-specific inquiry prompts appeared to be a promising approach to enhance students' development of inquiry abilities and their applications of these abilities to a new setting.

The effects of the presentation of the generic and context-specific inquiry prompts on students' inquiry practices

The distinction between the explicit and implicit groups was the provision of inquiry prompts. Accordingly, a comparison between these two groups' results implied that showing inquiry prompts made students aware of the inquiry steps and thus helped strengthen students' understanding of the meanings of the inquiry steps. However, showing these prompts consistently did not seem to be helpful for students to internalize their understandings and improve inquiry abilities. A comparison between the explicit and fading groups highlights the significance of the ways the inquiry prompts were presented. Put differently, not only the provision of inquiry prompts was important for developing inquiry ability, how the inquiry prompts were presented (and faded) was indeed critical. McNeill et al. (2006) stated that 'by fading the scaffolds, we forced students to think about and apply what they had learned from the previous scaffolds to the current learning task' (p. 181). In our study, the students in the fading condition were forced to first, review the meanings and the process of inquiry steps and relate them to the current context when the context-specific prompts were partially faded. This partial fading might have directly reinforced their understanding of inquiry. Then, when all the context-specific prompts were faded, the students needed to figure out which inquiry step they were enacting and apply both of their content knowledge and understandings of this inquiry step into this context-specific task. We found that gradually fading context-specific inquiry prompts appeared to have the potential not only to promote the development of students' inquiry abilities but also help transfer these abilities to a new context. These results resonate the suggestion of Stone (1998) that students internalize the support structure during the scaffolding process, and eventually the scaffolding is no longer needed since they can provide their own internal supports and self-regulation. The faded scaffolding ensures that this transition occurs.

This study also aimed to determine if students can transfer and actually perform inquiry abilities in a new context. For this we designed a performance session, *Dam*, in which the students applied what they have learned about inquiry in previous units to determine the best location for building a dam. The students' performance in the fading condition seemed to imply that gradually fading context-specific inquiry prompts may have indirectly enhanced the students' appreciation of the purpose of various inquiry steps and their competence in transferring the inquiry abilities to a new setting (White & Schwarz, 1999). A deeper understanding of the meaning of the inquiry practice then led to a more sophisticated inquiry practices (Toth, Suthers, & Lesgold, 2002). This presupposition appears to support that the presence of strategic fading over time is essential when providing inquiry prompts. More specifically, fading written inquiry prompts avoids the problem of 'over-scripting' (Kollar, Fischer, & Slotta, 2007) and thus can lead to better internalization (Fischer et al., 2013). The process of forcing students to review, reflect, and apply what they have learned may actually be related to their metacognitive skills. The students needed not only to construct understanding, store this understanding in long-term memory, and recall what they had experienced, but also to reflect on their own learning process. In other words, the students were required 'to monitor and evaluate the process and product of inquiry in order to help themselves coordinate present action and to plan next steps' (Kyza, Constantinou, & Spanoudis, 2011, p. 2492).

The use of formative assessments in computer-supported learning environments

The study used two different approaches to examine students' scientific inquiry practice. One approach was to document changes using the pretest and posttest of IPT, and the other was a qualitative analysis of the students' inquiry practices in the *Dam* unit. The pretest and posttest results showed that although the faded group had higher mean scores, they did not outperform the other two groups significantly. However, the qualitative results from the video analysis of the *Dam* unit suggested that fading context-specific inquiry scaffolds appeared to enhance the students' inquiry practices. The discrepancy between the results of the two approaches for assessing inquiry practice raises a significant issue about how student inquiry practice can be better evaluated. It also implies the need and the strength of using multiple approaches to document complex performances, such as inquiry practice. Su, Lin, Tseng, and Lu (2011) argued that higher order thinking skills (e.g. inquiry processes and formulating scientific explanations) were actually difficult to evaluate with traditional paper-and-pencil tests; therefore, these tests alone may be insufficient for monitoring and assessing how well students are developing scientific inquiry abilities. The use of formative assessment, such as the *Dam* unit in the study, provides a context for students to apply and perform what inquiry abilities students have developed. The examination of students' inquiry practice throughout successive inquiry steps thus may help teachers observe more fine and subtle changes in their development of inquiry abilities.

Written inquiry prompts as complementary support in computer-supported learning environments

Fading and gradual transfer of responsibility and ownership are critical features during scaffolding (Van de Pol et al., 2010). However, when learning collaboratively in a computer-based learning environment, it can be difficult to determine when to fade or decrease scaffolds or to transfer the responsibility to students, since the teacher has to attend to 20–30 students with different learning status at the same time and to realize that each student's needs change over the duration of a lesson or unit of study. One size or type of support does not fit all students – or even an individual student – as they develop inquiry proficiencies. In other words, it is very challenging for a teacher to scaffold a group of students because each student has a different starting point and rate of learning. We believe that fading inquiry prompts in a series of learning units complements the support to computer-based and peer scaffolds in a computer-supported learning environment. Depending on the status of the students, teachers can decide to increase or decrease inquiry prompts during a series of lessons. This view is in accordance with the synergistic scaffolds that have been discussed and suggested in previous research (Hsu, Lai, et al., 2015; Kim et al., 2007; McNeill & Krajcik, 2009; Tabak, 2004). The notion of synergy involves adopting different forms of scaffolds to address the same learning need. Importantly, these scaffolds are intertwined and complement each other, which produce robust support (Tabak, 2004). For example, the use of the visualization tool with the assigned learning task alone in the current case might have been insufficient for helping students to develop inquiry abilities. The scaffolds that include a series of questions, inquiry maps, and context-specific prompts within the collaborative environments can serve as a synergistic scaffold to be adjusted according to the performance or response of individual student. Therefore, individualized student learning is facilitated through the joint contributions of the teacher, peers, and their mutual interactions with scaffolds as a complete system (Tabak, 2004).

Conclusion

The effectiveness of the scaffolds for teaching and learning scientific inquiry involved many factors, including the types of scaffolds provided (generic or context-specific), the ways to provide these scaffolds (embedded in learning materials, visualization software, teacher, or peer), and the most effective way to provide that support over time (constant support or fading) (McNeill & Krajcik, 2009). For different purposes, teachers and educational researchers may design and select different types of scaffolds, provide them in different ways under different conditions. As Wu and Hsieh (2006) suggested that the scaffolds provided in computer-supported learning environments 'need to be distributed, integrated, and multiple, and can be provided by different agents in classrooms including teachers, representations, learning tools and instructional materials' (Wu & Puntambekar, 2012, p. 764).

This study has demonstrated that fading inquiry prompts together with visualization tools were potentially helpful for developing students' inquiry abilities. However, we acknowledged that individual student has distinct learning characteristics. Therefore, different scaffolding-fading conditions or different forms of scaffolds may have diverse impacts on individual student. How individual's learning characteristics may play a role when they encounter different types of scaffolds is worth exploring in future research. In the study, the students worked in groups during the inquiry learning units. Due to limited research resources and small sample size, the study did not examine the students' performances at group level. Future studies may further investigate how different scaffolding-fading conditions influence group students' inquiry performances or how collaborative learning may affect the effectiveness of individual's use of different types of scaffolds.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on Contributors

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Wei Hsiu Hsu is an experienced secondary earth science teacher.

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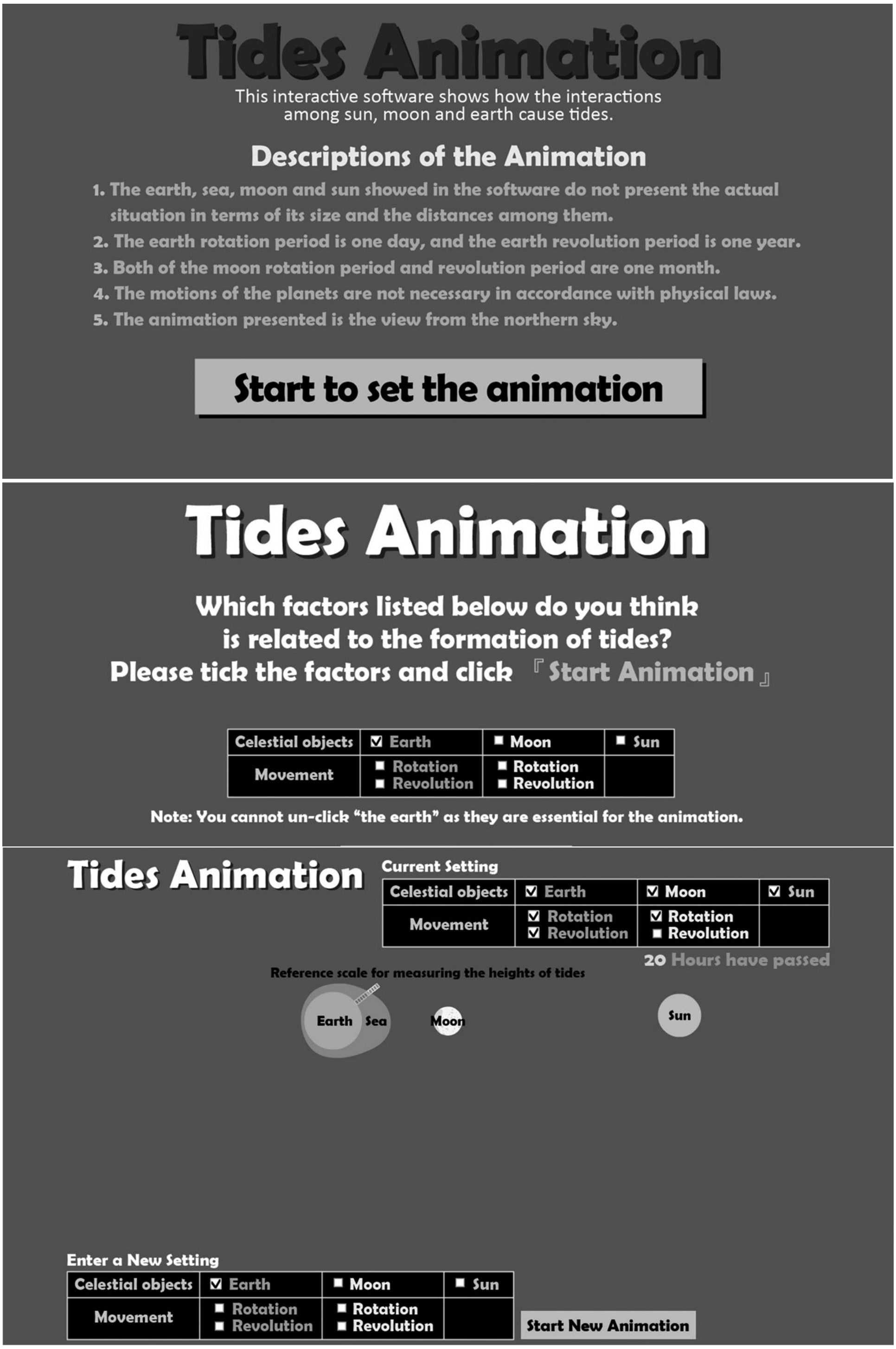
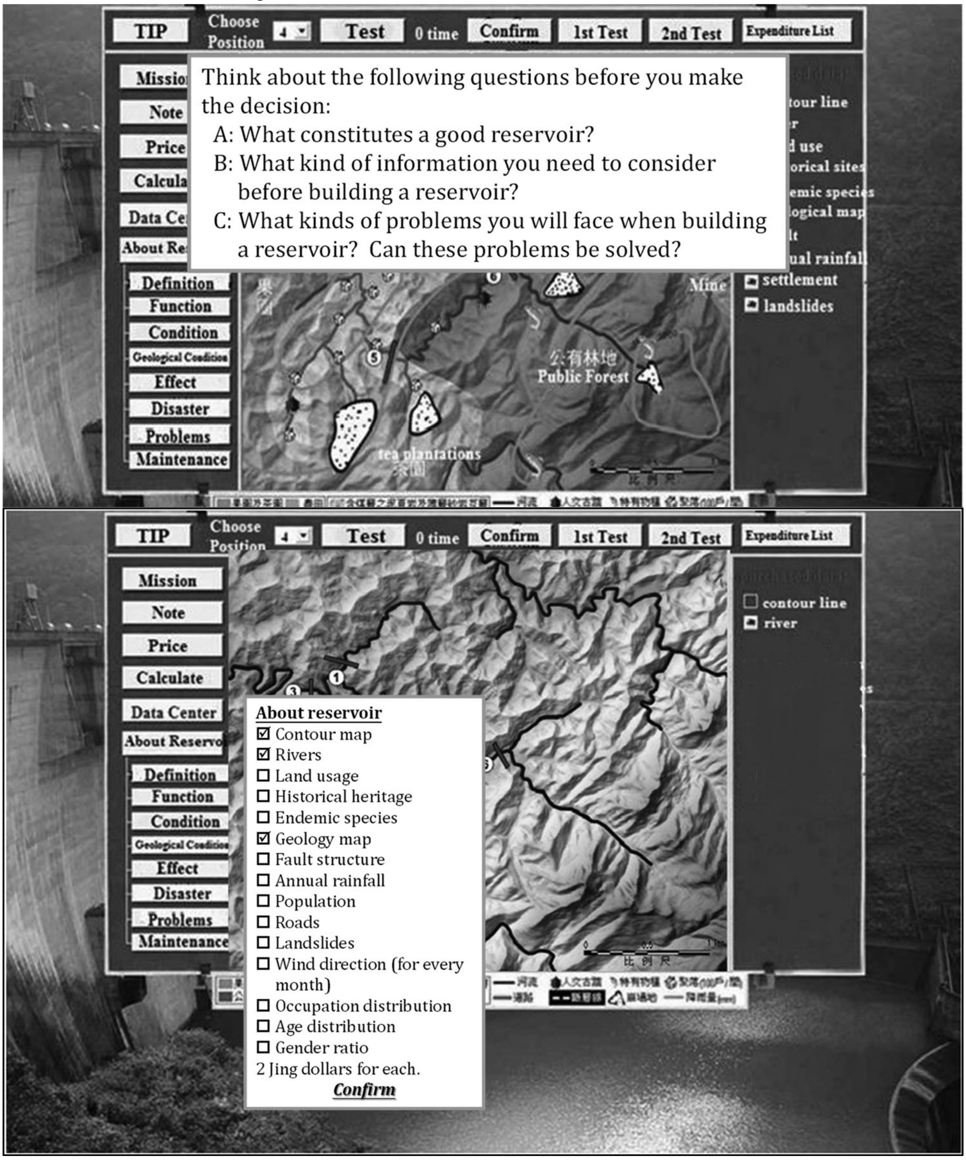
Appendix 1

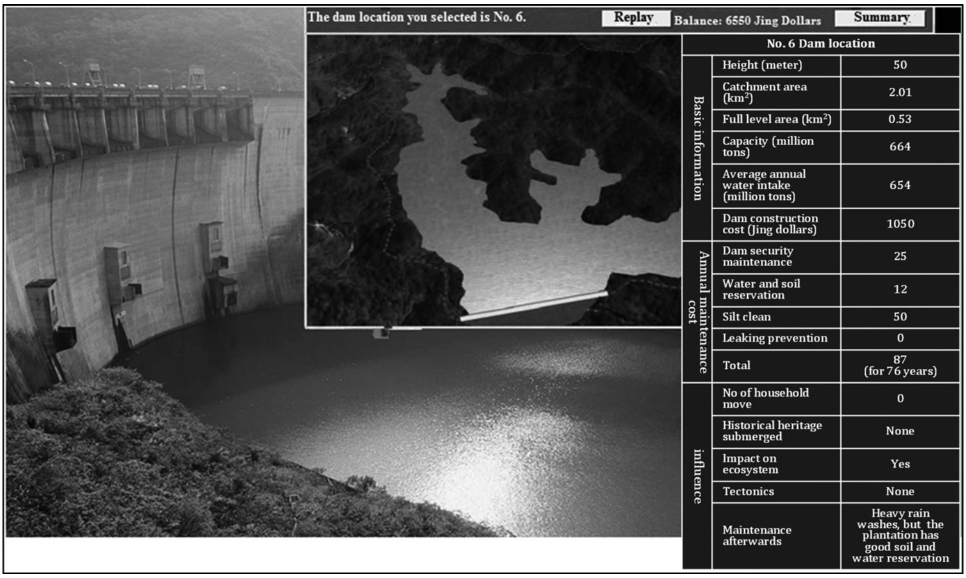
Screenshots from the Tides Animation Interactive Software



Appendix 2

Screenshots from the Jing-Si Reservoir Software





Appendix 3

Sample items for CUT, TUSI, IPT, and interview questions

Sample multiple-choice item for the CUT:

1. ( ) At 9:00 pm on 18th April, Mary saw ‘the Dipper’ in the Northern sky. If she would like to see ‘the Dipper’ in the same point of the sky, and at the same location, when should she be here again?
(A) 9:00 pm
(B) 8:00 pm
(C) 7:00 pm
(D) 6:00 pm

Sample item for the TUSI:

The following events A to G (A to C were listed) describe the scientific inquiry steps that the scientists experienced in the video. Please match each event with a corresponding scientific inquiry step.

A. Holmes found that the landforms in the area of Barberton were layered. He believed that the formation of the layered landforms should take a very long time. Therefore, he proposed that the Earth was much older than the statement in the Bible that it was formed at 4004 A.C.
B. James Hutton found nonconformities between rocks and believed that they would have been formed a very long time ago. Therefore, he proposed that the Earth was much older than the statement in the Bible that it was formed at 4004 A.C.
C. Lord Kelvin calculated the age of Earth by measuring thermal gradients in a mine and arrived at an estimate of 100 million years old.

Sample item for the IPT:

David lives in the Jing-mei area of Taipei city. He left his scooter outdoors and found that the exhaust pipe was rusted. One day, he went to visit his aunt around the Port of Keelung. He found that his aunt’s scooter exhaust pipe was even more seriously rusted than his, even though the two scooters were bought at the same time.

1. From the above information, what do you think is the reason(s) that caused the exhaust pipe to be rusted?
2. In your opinion, what are the factors that differentiated the levels of rust in these two areas (Jin-mei and Keelung)?

Appendix 4

Scoring rubric for the IPT.

Scientific inquiry ability	Scientific inquiry ability index	Items (n)	Score	Explanation
Questioning	Provides problem-related variables	2	0	Does not provide variables that relate to the problem
			1	Provides related variables; score is given for each variable
	Provides appropriate and testable research questions	1	0	Research questions provided are not based on scientific principles or not testable
			1	Research questions provided are based on scientific principles and testable; however, the description of the question is incorrect
			2	Research questions provided are based on scientific principles and testable; the description of the question is also correct
Planning	Distinguishes variables that relate to the research question	2	0	Provides incorrect variable(s)
			1	Provides one of the three correct variables
			2	Provides two of the three correct variables
			3	Provides all three correct variables
			4	Provides all three correct variables and two control variables
	Provides research steps based on the research question	2	0	Does not explain how to control variables
			1	Correctly explains the steps that relate to one of the three variables (control, independent, or dependent)
			2	Correctly explains the steps that relate to two of the three variables (control, independent, or dependent)
			3	Correctly explains the steps that relate to two of the three variables; correctly explains which variable is controlled and how to correctly and quantitatively manipulate independent variables
			4	Correctly explains the steps that relate to all three variables; correctly explains which variable is controlled, how to manipulate independent variables, and correctly record dependent variables
			5	Correctly explains the steps that relate to all three variables; correctly explains which variable is controlled, how to correctly and quantitatively manipulate independent variables, and correctly record dependent variables
Data collection and analysis	Analyzes and summarizes the information	5	0	Unable to summarize the information
			1	Be aware of and classifies the differences from the data
			2	Explains the patterns from the data
			3	Explains the patterns and finds the periods from the data
			4	Explains the patterns and the periods quantitatively
			5	Explains the patterns and the periods quantitatively; compares the patterns and periods between two different locations
	Selects appropriate information	2	0	Information selected is irrelevant to the summary
			1	Selects only one variable to summarize the data
			2	Selects one key variable to summarize the data
			3	Selects more than two variables to summarize the data
			4	Selects more than two variables including the key variables to summarize the data
			5	Selects all the variables to summarize the data
Interpreting	Reasons based on the evidence and makes a conclusion	3	0	Provides incorrect conclusion
			1	Provides incomplete conclusion
			2	Provides complete conclusion
			3	Makes logical reasoning between the evidence and conclusion

Appendix 5

Scoring rubric for the student inquiry ability performance in the *Dam* unit.

Dimensions of scientific inquiry	Scientific inquiry ability index	Score	Descriptions of example events
Planning Be able to use appropriate strategy based on the problem, exploit resources, and plan to solve problems	P1. Be able to plan and conduct a systematically scientific investigations (be able to clarify questions, methods, operation, and variables)	1	*IV1*: For a better evaluation of the potential dam location, the group double-checked the explanations of the task to ensure the future water supply. However, the group underestimated the water supply for each potential water reservoir due to misreading the information (44 million tons read as 4.4 thousand tons)
		2	*FV2*: From the information center, this group learned the essential factors for building a dam; and the group was able to select appropriate factors to evaluate the dam's location
	P2. Be able to adjust investigating methods and process during scientific investigations	1	*IV2*: The group only considered the variables that they had used before
		2	*FV2*: The group first used their previous variables (landslides, geology map, and contour map) to eliminate some locations. Then, they included new information (ecology, historical heritage), revised their plan, and added additional variables
	P3. Be able to conduct scientific investigations with multiple variables	1	Did not happen
		2	*EV2*: Through the information provided by the software (the geology map of each dam location and the calculation of the water storage of a reservoir), the group realized that in order to calculate the water storage of each reservoir, they needed to consider both the contour map and average annual rainfall

(*Continued*)

Continued.

Dimensions of scientific inquiry	Scientific inquiry ability index	Score	Descriptions of example events
Data collection and analysis Be able to use appropriate instruments to collect data, arrange data, and develop evidence	A1. Be able to meaningfully summarize information	1	*FV1*: The group was able to use the geology map as a reference to determine potential good dam locations. However, they did not realize that sandstone was not a safe geological condition for building a dam
		2	*FV2*: The group was able to determine to what extent the landslides influenced the reservoir by integrating the contour map and landslides information. Locations #5 and #6 had landslides upstream, so they had large amounts of sediment
	A2. Be able to examine reasonable hypothesis.	1	Did not happen
		2	*FV2*: After testing location #4, the group adopted testing results to examine their previous hypothesis. For example, they expected to spend fewer funds and have smaller amounts of sediment. However, they found the water storage capacity was smaller than they expected, so they decided to test the location again to verify their hypothesis
	A3. Be able to avoid errors and bias	1	Did not happen
		2	*FV2*: According to the factors being considered, the group constructed a scoring table for the six dam locations. These locations, therefore, were examined under the same conditions at the same time
Interpreting Be able to construct valid argument between evidence and conclusion. Through logical thinking, deduce the relationship between evidence and conclusion or develop an explanatory model	I1. Be able to construct explanations or make predictions based on evidence	1	Did not happen
		2	*EV2*: After examining the geology map, landslides, inhabitants, and ecology, locations #1 and #2 were selected for building a water reservoir
	I2. Be able to summarize results and make conclusions	1	*IV1*: The group eliminated the locations one by one simply based on one variable. The information was not integrated. Also, once the location was eliminated, they would not consider that location again. For example: landslide → eliminate #5 and #6; faults → eliminate #1 and #3; inhabitants → eliminate #4, so #2 was selected as the most appropriate location to build a dam
		2	*FV2*: After examining the test results of locations #2 and #4 and the historical heritage and ecology information, the group selected location #2