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This study explores the effects of metacognitive and cognitive prompting on the scientific inquiry practices of students with various levels of initial metacognition. Two junior high school classes participated in this study. One class, the experimental group ($n = 26$), which received an inquiry-based curriculum with a combination of cognitive and metacognitive prompts, was compared to the other class, the comparison group ($n = 25$), which received only cognitive prompts in the same curriculum. Data sources included a test of inquiry practices, a questionnaire of metacognition, and worksheets. The results showed that the mixed cognitive and metacognitive prompts had significant impacts on the students' inquiry practices, especially their planning and analyzing abilities. Furthermore, the mixed prompts appeared to have a differential effect on those students with lower level metacognition, who showed significant improvement in their inquiry abilities. A combination of cognitive and metacognitive prompts during an inquiry cycle was found to promote students' inquiry practices.

Keywords: *Science practices; Inquiry; Metacognition; Technology-infused learning*

International science education reforms have stressed and continue to stress science as inquiry, inquiry-based learning, and practices and habits of mind associated with doing scientific inquiries (National Research Council [NRC], 2000, 2012). Recent meta-analyses and systematic reviews of research results related to inquiry appear

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to confirm earlier meta-analysis results which indicated the positive potential for student achievement (Minner, Levy, & Century, 2010). They have also found that explanation-driven inquiry contributes to students' knowledge of and about science as well as to their inquiry abilities (Lin et al., 2012). The 50-year history of science inquiry has some critical anchor points and a pattern of evolving applications. Very early in the promotion of science inquiry learning and teaching, Schwab (1962) stressed the need to engage students in scientific inquiry through the cycle of questioning, observing, data collecting, and transformation within an experimental context. Throughout the years, many curricula and instructional approaches have been developed to promote students' inquiry abilities, such as the Inquiry Training Model (Suchman, 1962), Predict—Observe—Explain (White & Gunstone, 1992), the Inquiry Cycle (White & Frederiksen, 1998), and the Investigation Web (Krajcik et al., 1998).

Previously, research indicated that inquiry-based curricula and instructional approaches can enhance students' understanding of content knowledge (Arnold, 2010; Ketpichainarong, Panijpan, & Ruenwongsa, 2010; Sandoval & Morrison, 2003) and their scientific inquiry abilities, such as data analysis, scientific reasoning, and general communication (Ebenezer, Kaya, & Ebenezer, 2011; Krajcik et al., 1998). However, other researchers have argued for the actual effects of inquiry-based instruction (Blank, 2000; Moscovici & Nelson, 1998; Roth, 1989). These researchers have stressed that the problem might be due to students' unused metacognition when they engage in inquiry-based learning.

Students' metacognition plays an important role in complex learning environments such as hypermedia or computer-based learning environments (CBLE). It requires learners to employ effective regulatory strategies to process information and solve problems (Azevedo, 2005, 2007; Azevedo & Hadwin, 2005; El Saadawi et al., 2010). Inquiry-based instruction involves multiple stages such as questioning, planning, analyzing, and interpreting. Students need to set different types of goals and perform different tasks in these stages. Moreover, inquiry-based learning also requires students to adjust their goals and strategies through a recursive process in these inquiry stages (Hsu, Wu, & Hwang, 2008; Krajcik, Blumenfeld, Marx, & Soloway, 2000; Reiser et al., 2001). These requirements during inquiry cause substantial challenges for students, and most inexperienced students find it a difficult task (Azevedo, Moos, Johnson, & Chauncey, 2010). Students' inquiry abilities and their conceptual understanding can be promoted more effectively if metacognitive strategies are added to the inquiry curricula to guide them in how to use metacognition during their inquiry (Quintana, Zhang, & Krajcik, 2005; White & Frederiksen, 1998; White, Shimoda, & Frederiksen, 1999). Therefore, metacognition is important for inquiry learning (Davis, 2003; Manlove, Lazonder, & de Jong, 2007; White & Frederiksen, 1998).

Berthold, Nückles, and Renkl, (2007) compared the effects of four conditions (i.e. cognitive prompts, metacognitive prompts, a combination of cognitive and metacognitive prompts, and no prompts) on writing, and found that only cognitive prompts or a combination of cognitive and metacognitive prompts fostered successful learning (Berthold et al., 2007). Yet, the effects of mixed prompts on inquiry abilities have not been investigated in depth, and especially, the effects of embedding such prompts within e-learning environments. A comparison study is needed to investigate if only cognitive or if mixed prompts can foster student inquiry practices effectively in e-learning environments. Therefore, we conducted a study to compare the effects of two types of prompts—cognitive and a combination of cognitive and metacognitive prompts—in an online inquiry-learning environment for student inquiry practice. We also compared the influence of instruction (a combination of cognitive and metacognitive scaffolding) on students with different levels of metacognition. The contributions of this study are that it develops a mixture of cognitive and metacognitive prompting for inquiry practices within an e-learning environment based on students' difficulties identified in the literature, and examines the effect of such prompting on student scientific inquiry practices.

Cognitive and Metacognitive Prompting for Inquiry-based Learning

Students sometimes enact inquiry practices as rote mechanical behaviors without knowing the meaning or function underlying each activity (Moscovici & Nelson, 1998). Such shallow understanding of scientific inquiry justified the recent inclusion of science and technology practices as a central focus of the next generation of science education standards in many countries such as Taiwan (Ministry of Education in Taiwan, 1999) and the USA (Next Generation Science Standards, NRC, 2012). Curriculum developers are encouraged to add metacognitive practices to promote students' inquiry abilities and make their cognitive understanding more effective (Quintana et al., 2005; White & Frederiksen, 1998; White et al., 1999).

Contingency, fading, and transfer of responsibility are discerned as the three key characteristics of scaffolding, and are closely connected based on the last decade's scaffolding literature (van de Pol, Volman, & Benshuizen, 2010). This review found that scaffolding is effective for students' cognitive and metacognitive activities, with many of the studies proposing specific scaffolding means such as modeling or questioning. We regard questioning as prompting in an online inquiry-learning module, and reducing the prompting gradually from the beginning to the last phase of the module based on the two key characteristics of scaffolding: fading and transfer of responsibility. Since prompting is often referred to as scaffolding in the literature (Dinsmore, Alexander, & Loughlin, 2008), prompting is used as a general description of scaffolding in this paper.

Hannafin, Land, and Oliver (1999) further categorized scaffolding supports into four types: conceptual, metacognitive, procedural, and strategic. They believed that metacognitive scaffolding functions as a guide, reminding learners to reflect on their goals and to access and organize available resources to solve problems. Therefore, metacognitive scaffoldings have been used frequently to help students monitor, regulate, evaluate, and reflect on their learning processes (Conner, 2007; Davis, 2003). Prompts used as metacognitive scaffolding are usually presented as text to evoke student thinking about their learning (Davis, 2003; Manlove et al., 2007; White & Frederiksen, 1998). Recently, more researchers have been interested in examining the effects of metacognitive tools in CBLE (Azevedo, 2005, 2007;

Zimmerman & Tsikalas, 2005) and have found that there is potential to facilitate students' self-regulation (Zimmerman & Tsikalas, 2005). With reference to Zimmerman and Tsikalas's study (2005), we identified three types of mechanism used as metacognition tools in CBLE: immediate feedback, persistent display of task-related information, and collaborative workspaces. Immediate feedback associated with measurements in CBLE could prompt learners to monitor and evaluate their learning process. Persistent display of task-related information in CBLE would help students monitor their learning progress. Collaborative workspaces in CBLE could lead students to be aware of their learning status from others' perspectives. Through the Internet, feedback, text prompts, task-related information, and social interactions can be delivered and recorded. Within such e-learning environments, students' inquiry learning is supported and promoted.

We broadly consider that metacognitive prompts encourage students to monitor their inquiry-learning process, to identify productive moves and difficulties, and to take appropriate actions to reach their personal learning goals during inquiry. In contrast, the cognitive prompts were designed to decrease learning difficulties resulting from the students' lower levels of conceptual understanding, procedural knowledge, and strategies (Davis, 2003; Nuckles, Hubner, & Renkl, 2008). All of the prompts in the online module were offered in the form of questions and hints, which reminded the students to be constantly aware of their possible learning difficulties and to develop their metacognitive and inquiry abilities.

Since there is a recursive process whereby metacognitive processes are linked to cognitive strategies (Winne & Hadwin, 1998), metacognitive prompts may trigger students' inquiry performance, and cognitive prompts may evoke their metacognition. For instance, prompting students to reflect on why they set variables in a certain way (metacognitive prompts) could lead them to become aware of their weakness in the planning skill (metacognitive process) and then they may select different planning strategies (cognitive strategy). On the other hand, prompting students how to select variables for dependent and independent variables (cognitive prompt) could evoke their reflection on how they select variables (metacognitive process). Therefore, it is worth exploring individual students' reactions to metacognitive and cognitive prompts, and to recognize the possible features of a recursive process between prompts and cognitive practices as well as metacognition.

Method

A mixed-method design involving intact junior high school classes was used to investigate the development of students' scientific inquiry practices using two versions of the online inquiry-learning module, that is, one with only cognitive prompts and the other providing a combination of cognitive and metacognitive prompts. During this eight-hour course, students with different levels of initial metacognition were invited to complete the inquiry tasks embedded in SeasonSim (Hsu, 2008). Students' inquiry practices and metacognition were documented using tests, questionnaires, and worksheets. The research questions were:

(1) Is there any significant difference in the inquiry practices of the students using the two types of prompts, only cognitive prompts and a combination of cognitive and metacognitive prompts, in the online inquiry-learning environment?
(2) Is there any significant difference in the inquiry practices of the students with different initial levels of metacognition?

A total of 51 Grade 9 students from two intact junior high school classes in a suburban city in southern Taiwan participated in this study. Most of the students came from working-class families and received lecture-based instruction in class most of the time. One class was assigned as the experimental group (EG) and the other was the comparison group (CG). There were 26 students (10 males and 16 females) in the EG and 25 (14 males and 11 females) in the CG. The two groups were taught by the same teacher who had taught earth science in a senior high school for 21 years. He had a strong undergraduate background in earth science and was a doctoral student in a science education program.

Understanding the Seasons (Online Inquiry-Learning Module with Metacognitive Prompts)

In Taiwan, the topic of the seasons is typically covered in Grades 5, 6, 10, and 11 textbooks. Our previous studies had developed an online inquiry-learning module based on the guidelines of the Technology Enhanced Learning model for Grade 11 students (Hsu, 2008; Hsu et al., 2008). Since the target students in this study were junior high school students, the online inquiry-learning module developers (an earth science teacher and three science education professors) adjusted the contents and revised representations of the computer simulation, SeasonSim (see Figure 1). Students could change the variables in SeasonSim (including the variables influencing the seasons, such as latitude, longitude, the tilted angle of the earth's axis, and eccentricity) to explore how solar radiation changes the Earth's surface temperature, to test their hypotheses. Then, they could reconstruct or build a model to explain why the Earth undergoes seasonal changes.

A synthesis of the literature related to inquiry teaching identified four common stages or practices including questioning, planning, analyzing, and interpreting (Ebenezer et al., 2011; Krajcik et al., 1998; White & Frederiksen, 1998). We incorporated these four stages into an inquiry-based online module that allows students to move forward and backward to double-check their thinking and solutions at different inquiry stages. We embedded 10 metacognitive prompts (MP) and 7 cognitive prompts (CP) into the online module to help the students develop their inquiry practices and to address the complexity of online learning and individual learning obstacles. This online inquiry-learning module with questions regarding the learning tasks, prompts (CP and MP), and SeasonSim included three components: a training task (guiding students to become familiar with the interface of SeasonSim and the learning platform), a structured inquiry (prompting students regarding what to do in the inquiry process), and a guided inquiry (allowing students to plan their own

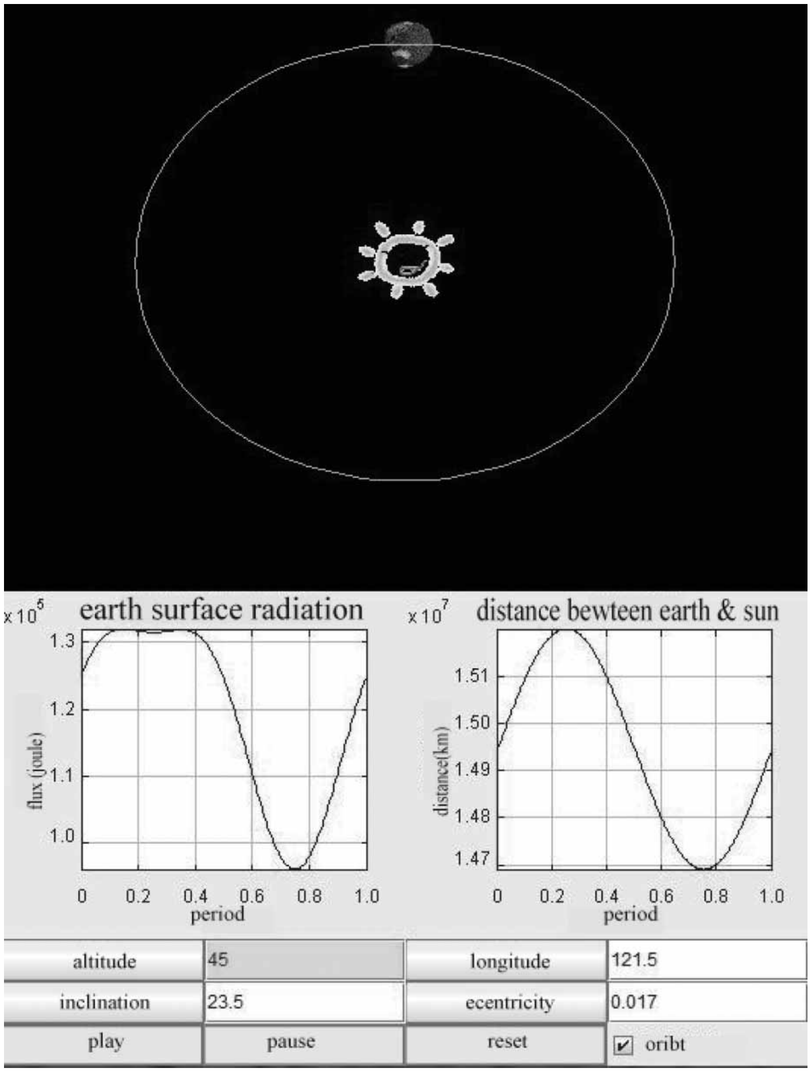

Figure 1. Screen shot from SeasonSim (one period on Earth is about 12 months)

investigation for given research questions or situations within the constraints of the platform). In the training task, the students were required to describe the relationship between the sun–earth distance and solar radiation at different latitudes after the teacher showed them how to manipulate SeasonSim. In the structured inquiry, prompts and examples were given in online worksheets to facilitate completion of the learning tasks in each inquiry stage (questioning, planning, analyzing data, and interpreting). These text prompts were designed based on the literature review, which pointed out students' difficulties in the different inquiry stages (see Table 1). Many researchers, as previously mentioned, have indicated students' cognitive and metacognitive problems as two major difficulties that would inhibit their employment of metacognitive strategies during the learning process. Extensive CPs and MPs in the form of hints or questions carrying key information were used to facilitate the students' inquiry. These CPs were designed to encourage the students to use cognitive strategies when they encountered cognitive problems (e.g. 'Did you find out the trend of solar radiation received by the Earth?') after they completed the worksheets used in one inquiry stage. The MPs (e.g. 'How will you make sure the variables you choose are correct?') were used to help the students use their metacognitive strategies (e.g. monitoring and evaluating) when they faced problems in a certain inquiry stage. The details of the CPs and MPs in the online inquiry-learning module and the complete instructional framework are shown in Table 1. All the metacognitive prompts were designed in text form to promote the students' monitoring or evaluation of their inquiry learning.

Finally, the guided inquiry was focused on refining inquiry practices, but decreased the prompts as the inquiry activities progressed. For example, the students were required to explore a research question ('How does the tilted angle of the earth's axis affect the seasons?') without further prompts. They needed to plan their own investigation with SeasonSim, analyze the simulated data, and interpret their findings. After a student finished the inquiry tasks, peer reviews from at least three classmates evaluated his/her worksheets in the stages of planning, analyzing, and interpreting. Each student received and used a rubric with explicit criteria that we developed and modified from previous research literature (AAAS, 1993; National Research Council, 1996, 2000; White & Frederiksen, 1998, 2005) to help them evaluate their classmates' inquiry practices. Peer review encouraged the students to critique their peers' work and to receive critiques and feedback from their peers about their own work, which are central emphases of the next-generation science education standards in the USA (NRC, 2012).

In the EG, the students received the online inquiry-learning module, which included both CPs and MPs. The CG received the CP-only version of the online inquiry-learning module, which deleted all MPs. It should be noted that the EG and CG received the same content and the same assignments. Both groups had equal opportunities and instructional time to achieve their learning goals.

Instruments

Both the Inquiry Practices Test (pretest and posttest) and the Questionnaire of Metacognition (pretest only) were used to evaluate how all students performed the inquiry practices during the seasons module. A research team that included three university science education professors, two science education graduate students, and two science teachers was engaged in developing and validating the test items.

Inquiry Practices Test. The Inquiry Practices Test (IPT) was designed to assess the students' inquiry practices given contextual problems. Test items were open-ended questions, which were modified from a set of mealworm questions (Lawson &

Table 1. Possible learning difficulties and corresponding prompting across the stages of inquiry and inquiry-based learning

Inquiry tasks		Cognitive prompts		Metacognitive prompts	
		Problems they might face	Prompts we offered	Problems they might face	Prompts we offered
Inquiry-learning module (training task, structured inquiry, and guided inquiry)	Questioning	Students' questions were too simple to be researched (Krajcik et al., 1998; Quintana et al., 2005) or students may abandon their questions if the results did not support their hypotheses (Dreher, 1995)	Prompt students to relate their predictions to the research questions or with their experience as well as to describe the reason	Questions posted by students might not be meaningful (Hoffman, 1999; Quintana et al., 2005)	Use driving questions to develop criteria for judging the quality of a given question
	Planning	Students had problems relating experiments to their research questions (Schauble, Glaser, Raghavan, & Reiner, 1991) or designing experiments without structure (Manlove et al., 2007)	Prompt students to distinguish control variable and manipulated variables for the research question	Students did not know how to collect data that were relevant to their research question or did not think about the quality of the data (Quintana et al., 2005; Wallace, Kupperman, Krajcik, & Soloway, 2000)	Prompt students to think about the reasons for selecting certain variables for their plan of data collection
	Analyzing	Their results were not related to research questions or could not be used to answer questions (Krajcik & Czerniak, 2007)	Guide students to recognize the patterns of data and the relationship between the patterns and the research question	Students' analytical abilities were not good enough (White & Frederiksen, 1998)	Prompt students to reflect on their analysis process and develop awareness of its quality and present students' learning progress to encourage them to notice their learning problems

	Interpreting	Students were unable to answer the research questions due to a lack of ability associating events, reasons, and scientific theories (Krajcik & Czerniak, 2007)	Guide students to apply their knowledge when seeking patterns and interpreting data	Students always reason intuitively and ignore the relationship between claims and warrants; besides, they have difficulty knowing how their wrong assumptions lead to wrong conclusions (Rickey & Stacy, 2000)	Ask students to think about why a certain conception could be used to help them reason and connect claims to evidence
Peer assessment				If students did not understand the criteria of inquiry, they could not learn the meaning of the inquiry (Quintana et al., 2005; White & Frederiksen, 1998)	Give students criteria for peer reviews to help them understand the meaning of inquiry and be aware of their lack of inquiry practice

Wollman, 1976), and two sets of the rusty motorcycle's exhaust pipe and river pollution questions. Items were selected to measure the students' questioning (3 items), planning (3 items), analyzing (3 items), and interpreting (3 items). The IPT was validated by two science education professors and one physics professor; the inter-rater reliability reached 0.95 (Spearman's rho). The IPT took approximately 40 minutes to complete. The scoring rubric is shown in Table 2. The students' pretest and posttest scores did not fit the assumption of normal distribution for inference statistics; therefore, we used non-parametric statistics for further statistical analysis. In the pretest, the range of students' inquiry scores was from 1 to 22, while the range of posttest scores was from 1 to 24.

Questionnaire of Metacognition. The Questionnaire of Metacognition (QM) was designed to assess the students' metacognition knowledge and experience based on a review of the literature (Brown, 1987; Flavell, 1987); it included 5 subscales of metacognitive knowledge and experience with metacognitive practices (i.e. planning, monitoring, regulation, and evaluation). The first part of the questionnaire contained four open-ended questions developed to detect the students' metacognitive knowledge and understanding of person, task, and strategy. Students' responses were scored according to the number of suitable strategies and reasonable answers provided. The answers of protocols of STID13, STID03 and STID02 to the question, 'What effective strategies do you use to facilitate your academic performance during learning science? and Why?' are shown below. The students' answers were scored as 3 points if they proposed more than one strategy with proper reasons for why they applied these strategies in science learning (e.g. STID13's protocol); 2 points if they reported one clear strategy with a proper reason for applying this strategy (e.g. STID18's protocol); 1 point when they only reported one specific and clear strategy without any reason (e.g. STID03's protocol); and 0 points when their answers were unclear or they reported any unsuitable strategy (e.g. STID02's protocol).

> *STID13 : I ask as many questions as I can in science class or discuss with my classmates because these ways help me gain more knowledge and learn more thinking skills from others.* **(3 points)**
> *STID18 : I ask myself questions whenever I cannot understand what the teachers say.* **(2 points)**
> *STID03: Make notes in the class.* **(1 points)**
> *STID02: My imagination. It can help me know which one is correct.* **(0 points)**

The inter-rater reliability was 0.85 (Spearman's rho). The second part of the questionnaire measured students' self-reporting of their experience with metacognitive practices using 32 self-report Likert-type items with a 5-point response scale from 'totally agree' to 'totally disagree'. The four metacognitive practices were planning (8 items), monitoring (10 items), regulation (5 items), and evaluation (9 items) (see Appendix I for sample items).

The reliability for each subscale ranged from 0.71 to 0.83, and the total questionnaire's reliability was 0.90. We judged these levels of reliability to be acceptable. The questionnaire was reviewed by two science education professors. Their evaluations

Table 2. Scoring rubrics for inquiry abilities

Inquiry ability	Score	Description
Questioning		
Q1. Posing a testable question	2	Posing a testable question that is relevant to a scenario and involves relationships between variables
	1	Posing a testable and descriptive question that is relevant to a scenario
	0	Posing a question that is untestable or irrelevant to a scenario
Q2. Recognizing key variables of a question	2	Recognizing key variables of a question and indicating relationships between the variables
	1	Recognizing key variables of a question, but no relationships identified
	0	Cannot recognize variables of a question
Planning		
P1. Designing an experiment with relevant variables	2	Designing an experiment that can verify all relationships between the key variables
	1	Designing an experiment that can verify a few relationships between the key variables
	0	Cannot design an experiment or designs an experiment that cannot verify any relationships
P2. Designing feasible experimental procedures	2	Designing feasible experimental procedures that can answer the research question
	1	Designing feasible experimental procedures, but the procedures cannot answer the research question
	0	Designing experimental procedures that are not feasible
Analyzing		
A1. Identifying the patterns of data	2	Identifying important patterns of data
	1	Identifying a pattern of data
	0	Cannot identify any pattern of data
Interpreting		
I1. Addressing reason by data	2	Identifying variables and describing causal relationships between them
	1	Identifying variables without a description of relationships between them
	0	Identifying irrelevant variables or wrong relationships
I2. Concluding results from evidence and reasoning, then constructing and modifying the scientific reasons	2	Constructing a model to interpret results and comparing the effects of two variables
	1	Constructing a model to interpret results, but cannot compare the effects of two variables
	0	Identifying the effect of one variable or constructing a model that cannot interpret results
I3. Identifying and analyzing the alternative or making a correct prediction	2	Applying the model to make a correct prediction and providing reasons
	1	Applying the model to make a correct prediction, but cannot provide any reason
	0	Cannot apply the model to make a prediction

supported a claim for content validity of the questionnaire. We used the total score of the QM (including 32 Likert-type questions and 4 open-ended questions with a maximum total score of 180) as an indicator of student metacognition. Students' QM scores ranged from 45 to 165.

Data Collection and Data Analysis

It took 8.5 hours to administer the pretests and posttest and to complete the online inquiry-learning module. We collected multiple sources and types of data for documenting and analyzing student performance and development of inquiry practices. In addition to the students' pretest and posttest scores, we collected results from their worksheets and their online actions during the inquiry activities through the screen-recording software Camtasia Studio® from TechSmith (http://www.techsmith.com/camtasia.html).

In order to examine the overall effect of the online inquiry-learning module and the impact of metacognitive prompts on student inquiry practices, we collected data from two sources: the IPT and the online worksheets. A scoring rubric was developed to score student inquiry practices of questioning, planning, analyzing, and interpreting that ranged from 0 to 2 points (see Table 1). The online worksheets in the training task (7 units of learning activities), structured inquiry (8 units), and guided inquiry (8 units) were designed to engage the students in inquiry-based learning. The learning activities of the training task included two analyzing and five interpreting units. Eight units (1 questioning, 2 planning, 1 analyzing and 4 interpreting) were designed as structured inquiry. In the guided inquiry, 8 units (1 questioning, 1 planning, 2 analyzing and 4 interpreting) were used to involve the students in inquiry-based learning. The inter-rater reliability of the worksheets was 0.86.

Since all the data did not satisfy the assumptions of ANCOVA (the independence, normality, and homogeneity of the variances of the residuals; see Appendix II), we decided to use non-parametric statistics. In order to compare the effect of prompting on student inquiry for the EG and CG, we used the Mann–Whitney *U* test to compare the gain scores between the pre- and post-Inquiry Practice Test of these two groups. Also, we attempted to investigate the students' inquiry practice during online learning through comparing the coded scores of the online worksheets of the EG and CG using the Mann–Whitney *U* test.

Furthermore, since initial metacognition was found to influence students' inquiry performance, we divided the students from both groups into three subgroups based on their QM total pretest scores: high-metacognition (HM: the top 27%), medium-metacognition (MM: the medium 46%), and low-metacognition (LM: the bottom 27%). The numbers of students in the HM, MM and LM subgroups are 13 (5 in EG and 8 in CG), 24 (13 in EG and 11 in CG) and 14 (8 in EG and 6 in CG), respectively. Descriptive statistics for the subgroups and the whole group are shown in Table 3. We utilized the Kruskal–Wallis *H* test to explore the instructional effects on inquiry performance (worksheet scores) for groups of student with different initial levels of metacognition (HM, MM, and LM) within the EG and CG.

Table 3. Descriptive statistics (means and standard deviations) of students' metacognition

	HM (top 27%)			MM (medium 46%)			LM (bottom 27%)		
Group	*N*	*M*	SD	*N*	*M*	SD	*N*	*M*	SD
Experimental	5	142.38	10.01	13	118.50	2.95	8	90.75	24.48
Comparison	8	146.00	9.13	11	117.33	9.64	6	93.38	5.85
Total	13	144.19	9.45	14	117.95	6.79	14	92.06	17.25

Note: HM, high-level metacognitive group; MM, medium-level metacognitive group; LM, low-level metacognitive group.

Results

In this section, we first report the results of the comparisons of the student inquiry practices of the two versions of the online inquiry-learning modules (EG and CG) from the analysis of the IPT and worksheet scores. Then, we report the development of student inquiry practices influenced by the students' initial metacognition levels (HM, MM, and LM subgroups) within the online inquiry-learning modules (EG and CG).

Effect of Prompting on Student Inquiry Practices

The results of the comparisons of the student inquiry practices of the two versions of the online inquiry-learning modules (EG and CG) from the analysis of the IPT and worksheet scores using the Mann–Whitney *U* test are summarized in Tables 4 and 5. Table 4 presents the descriptive statistics of the students' gain scores and the results of the Mann–Whitney *U* test for each inquiry practice, and the overall IPT scores before and after the online inquiry-learning modules. Significant effects were

Table 4. Mann–Whitney *U* test summary of gain scores on the inquiry practice test for the CG and EG

		CG ($n = 25$)		EG ($n = 26$)					
		Mean	SD	Mean	SD	Gain scores mean of CG	Gain scores mean of EG	*Z*	*p*
Question	Pretest	2.48	1.83	4.08	1.44	0.60	0.15	1.13	0.260
	Posttest	3.08	1.26	4.23	1.39				
Plan	Pretest	2.72	1.86	3.23	2.01	−0.16	1.85	3.24	0.001
	Posttest	2.56	1.96	5.08	1.41				
Analyze	Pretest	3.00	1.68	2.62	1.55	0.24	1.15	1.97	0.049
	Posttest	3.24	1.62	3.77	1.68				
Interpret	Pretest	2.16	1.38	2.92	2.15	0.40	0.31	0.91	0.363
	Posttest	2.56	1.45	3.23	1.53				
Total	Pretest	10.36	5.11	12.85	4.99	1.08	3.46	1.34	0.179
	Posttest	11.44	4.09	16.31	4.34				

Table 5. Mann–Whitney *U* test summary of scores on the worksheets for the CG and EG

	CG ($n = 25$)		EG ($n = 26$)			
	Mean	*SD*	Mean	*SD*	*Z*	*p*
Question	1.56	1.26	3.00	1.06	3.76	<0.001
Plan	1.04	0.84	1.96	0.20	4.51	<0.001
Analyze	4.92	1.98	9.58	2.44	5.55	<0.001
Interpret	4.04	2.48	7.73	3.11	4.04	<0.001
Total	11.56	2.87	22.27	4.78	6.15	<0.001

found for the planning scores ($Z = 3.24$, $p = 0.001$) and the analyzing scores ($Z = 1.97$, $p = 0.049$) of the two groups. The results revealed that the online learning module with mixed prompting helped the students to learn inquiry practices more effectively, especially in terms of their planning and analyzing practices.

Table 5 shows the descriptive statistics of the students' scores on the worksheets and the results of the Mann–Whitney *U* test for the two versions of the online inquiry-learning modules. According to Table 5, significant differences were revealed not only in the overall inquiry practices ($Z = 6.15$, $p < 0.001$) but also in questioning ($Z = 3.76$, $p < 0.001$), planning ($Z = 4.51$, $p < 0.001$), analyzing ($Z = 5.55$, $p < 0.001$), and interpreting ($Z = 4.04$, $p < 0.001$). The results indicated that the EG had better inquiry performance on the worksheets than the CG. Therefore, the results revealed that mixed metacognitive and cognitive prompting helped the students to learn inquiry practices more effectively than only cognitive prompting.

The improvements and higher performance of the EG appear to be attributed to the design of the metacognitive prompts embedded in the online learning module. Three major features of the metacognitive prompting were used to facilitate the students' inquiry practices in this study. First, the metacognitive prompts reminded the students to examine the difficulties they were facing, and encouraged them to address these difficulties, which otherwise they would probably have ignored. Second, the metacognitive prompts engaged the students in self-monitoring and self-regulating their learning when they were made aware of their difficulties or the weakness of their strategies. Third, the metacognitive prompts aligned with the cognitive prompts facilitated the students' acquisition of the inquiry practices necessary to reach their learning goal. Therefore, the EG students benefited from the metacognitive prompting as they gained inquiry practice when compared with the CG students.

Influence of Students' Metacognition on Their Inquiry Practices

Table 6 shows the descriptive statistics of the students' worksheet scores and a summary of the Kruskal–Wallis *H* test results for groups of students within the EG and CG with different initial levels of metacognition. Significant metacognition effects were found for analyzing practice ($\chi^2 = 6.74$, $p < 0.03$) in the CG. *Post hoc*

Table 6. Kruskal–Wallis *H* test summary of inquiry practice scores on the worksheets for the HM, MM, and LM groups

		HM		MM		LM				
Group		Mean	SD	Mean	SD	Mean	SD	χ^2	*p*	*Post hoc*
Comparison ($n = 25$)	Question	1.50	1.64	1.36	1.03	1.88	1.36	0.73	0.696	
	Plan	1.17	0.75	1.00	0.89	1.00	0.93	0.16	0.921	
	Analyze	6.67	1.37	4.45	2.11	4.25	1.49	6.74	0.034	H>L, M>L
	Interpret	4.00	1.79	4.27	3.10	3.75	2.19	0.08	0.963	
	Total	13.33	1.03	11.09	2.63	10.88	3.76	3.18	0.204	
Experimental ($n = 26$)	Question	3.13	1.46	2.85	0.90	3.20	0.84	1.52	0.468	
	Plan	1.88	0.35	2.00	0.00	2.00	0.00	2.25	0.325	
	Analyze	9.50	1.93	9.62	3.15	9.60	0.89	0.47	0.792	
	Interpret	8.75	3.77	7.69	2.81	6.20	2.59	1.12	0.571	
	Total	23.25	4.77	22.15	5.57	21.00	2.45	0.67	0.717	

Note: HM, high-level metacognitive group; MM, medium-level metacognitive group; LM, low-level metacognitive group.

Table 7. Kruskal–Wallis *H* test summary of students' gain scores on the inquiry practices test for the HM, MM, and LM groups

		HM		MM		LM			
Group	Progressive score	Mean	SD	Mean	SD	Mean	SD	χ^2	*p*
Comparison ($n = 25$)	Question	−0.25	1.49	1.00	1.61	1.00	1.10	3.52	0.172
	Plan	−0.25	1.75	−0.36	1.36	0.33	0.52	1.74	0.419
	Analyze	0.88	2.10	−0.09	2.26	0.00	2.28	0.37	0.833
	Interpret	1.25	1.49	0.00	2.24	0.00	1.67	1.73	0.422
	Total	1.63	5.18	0.55	5.61	1.33	4.23	0.003	0.998
Experimental ($n = 26$)	Question	−0.40	2.88	0.46	1.05	0.00	1.51	2.34	0.311
	Plan	1.80	2.95	1.85	2.44	1.88	2.53	0.006	0.997
	Analyze	1.00	2.24	1.23	1.64	1.13	1.46	0.69	0.710
	Interpret	−0.20	2.28	0.77	2.52	−0.13	1.96	0.46	0.795
	Total	2.20	3.90	4.31	4.50	2.88	4.39	0.82	0.665

Note: HM, high-level metacognitive group; MM, medium-level metacognitive group; LM, low-level metacognitive group.

comparisons of means for the analyzing practice showed that the HM ($M = 6.67$) and MM students ($M = 4.45$) in the CG were not significantly different, but both performed significantly ($p < 0.05$) better than the LM students ($M = 4.25$). These findings (i.e. regarding the significant difference in the CG but no significant differences in the EG) taken in the context of the EG significantly outperforming the CG on the worksheets (Table 5) might be attributed to the metacognitive prompting that the EG students received. The metacognitive prompts may have assisted the LM students to monitor and regulate their learning processes and strategies, which helped them to learn more inquiry practices while staying with their more metacognitive peers. These promptings mediated the lack of self-monitoring and self-regulating abilities of these students, thereby leveling the learning opportunities and reducing the initial metacognition's effect within the EG. The embedded metacognitive promptings apparently provided the LM students with a chance to carefully examine their own inquiry processes and to apply or develop their inquiry practices.

Table 7 presents the gain scores from the pretest to the posttest of the inquiry practices test (IPT) and a summary of the Kruskal–Wallis *H* test results for the groups with different levels of initial metacognition. The results show that there is no significant metacognitive effect on the progressive scores of the IPT. The possible reason could be that the students may not have applied their metacognition when answering the IPT since a pencil-and-paper test may not evoke students' recursive processes among the components (e.g. controlling, monitoring, and cognitive evaluation) of the self-regulation.

Discussion

Metacognitive prompting is frequently used to remediate learners' metacognition (Pifarre & Cobos, 2010; White & Frederiksen, 1998, 2005; Zimmerman, 2002) and/or inquiry practices (Quintana et al., 2005). This study examined how cognitive and metacognitive prompting can facilitate students' inquiry practices. A few findings shed light on how the students developed their inquiry practices and metacognition in the online learning module, which provided prompting based on their learning difficulties experienced in the inquiry settings as indicated in the research literature.

In this study, we found that the mixture of cognitive and metacognitive prompting appeared to enhance the IPT performance, especially in terms of planning and analyzing (see Table 4), and had significant positive effects on the scores of all inquiry subscales coded from the worksheets (see Table 5). The HM and MM students in the CG performed significantly better than the LM students in the analysis practice, but there were no significant differences in the EG (see Table 6). Most importantly, this instructional approach leveled the learning opportunities and helped the LM students to overcome their initial lack of self-management and develop their inquiry practices by prompting them to monitor their inquiry processes and recognize the learning goals. These findings echo a meta-analysis of 33 empirical studies in student SRL within computer-based learning environments (CBLEs; Winters, Greene, & Costich, 2008). The different learner and task characteristics (including the types of SRL supports) affect the quality of students' SRL as they learn with CBLEs.

Compared with the literature, we tried to deepen the understanding of and support for these findings. Many research studies have indicated that MPs not only improve students' metacognition but also have positive impacts on students' learning outcomes (e.g. reading comprehension, mathematics ability, inquiry ability); some researchers have emphasized that students possess weak inquiry ability due to their lack of metacognitive ability (Beeth, 1998; Berthold et al., 2007; Blank, 2000; Cuevas, Fiore, Bowers, & Salas, 2004; Quintana et al., 2005; White & Frederiksen, 1998). Our findings confirm that the students' metacognition influenced their inquiry practices in the CG with only cognitive prompting, which echoes the above literature. This means that HM students performed better inquiry practices than LM students when they experienced an online inquiry-learning module without metacognitive prompting. In the EG that embedded a mixture of CPs and MPs in the online inquiry-learning module, we found that the LM students developed metacognition and inquiry practices effectively when compared with the HM and MM students. There was no significant difference in the inquiry practices of the HM, MM, and LM students, thereby closing the performance gap that initially existed. This finding is supported by previous findings on the differential effects of the MP curriculum, which benefits students with lower metacognitive abilities the most (Berthold et al., 2007; White & Frederiksen, 1998). However, it might remain a possibility that there was a bias in grouping the students according to their initial level of metacognition based on their scores of the QM which was a self-reported instrument. Some students' responses on the QM might have been limited because of their vague memory of their cognitive process or confusion between their actual status and expected status in learning science.

Based on these results, we summarize three characteristics of the effective metacognitive prompts we designed in the e-learning environment for improving inquiry practices. First, metacognitive prompts in the online inquiry-learning module serve as immediate feedback associated with the cognitive problems. The metacognitive prompts pop up automatically right after students accomplish all cognitive problems in one inquiry stage in order to provide timely support for their reflection on and evaluation of their inquiry practices. Second, persistent display of a rubric with explicit criteria helps students to monitor their inquiry progress and recheck their goal for each inquiry stage. Third, a workspace of peer reviews helps students to recognize if they need to seek resources or assistance from peers and/or teachers.

There are, however, three limitations of this research which need further consideration. First, the QM might be unable to precisely assess students' metacognition because it is a self-report instrument. It is suggested that multiple data should be used to decide student metacognition levels such as think-aloud and computer log files. Second, the findings showed that there was no significant improvement in questioning and interpreting. In the question stage, we proposed a research question for students to judge whether it was a good question rather than asking them to generate their own question. This might limit students' questioning performance on the IPT. Future work needs to consider how to deliver rich contexts with hypermedia and prompts to help students generate their own research questions. Additionally, the students' interpreting ability did not show significant improvement even though we used cognitive prompts for evoking prior knowledge and metacognitive prompts for thinking about why a certain conception could be used to reason and connect claims to evidence. We think that interpreting is not easy to learn partly because it is a higher level thinking skill and partly because students face cognitive overload when trying to interpret several causes with complex relationships of cause and effect about seasons. In this study, we did decompose complex relationships of cause and effect into several simplified learning tasks to reduce the students' cognitive load, but perhaps some of the students lacked the appropriate prior knowledge and so failed to develop their interpreting ability. We would suggest that future studies first detect students' prior knowledge as a basis for decomposing complex learning tasks. Third, this study only examined the net effect of the prompts on inquiry practices. Sometimes, prompts elicit both cognitive and metacognitive learning actions, and thereby improve the effects (Berthold et al., 2007). It might be a good direction to investigate how students react to metacognitive and cognitive prompts and compare the pattern differences in the reactions of students with different initial levels of metacognition.

Conclusion

In this study, we found that the mixture of cognitive and metacognitive prompting appeared to enhance the IPT performance, especially in planning and analyzing (see Table 4), and had significant positive effects on the scores of all inquiry subscales coded from the worksheets (see Table 5). Most importantly, this instructional approach leveled the learning opportunities and helped the LM students to develop their inquiry practices by prompting them to monitor their inquiry process and recognize the learning goals. Therefore, we suggest that future research needs to address how to prompt students at both the metacognitive and cognitive levels across different inquiry stages and to develop a system of prompts for inquiry-based learning from a holistic viewpoint. The results of this study provide a basis for further research and development focused on developing practices central to scientific inquiry where 'scientists determine what needs to be measured; observe phenomena; plan experiments, programs of observation, and methods of data collection; build instruments; engage in disciplined fieldwork; and identify sources of uncertainty' (NRC, 2012, p. 45).

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Appendix I

Sample items of the metacognition questionnaire

Subscale (number of items)	Sample items
Self-planning (8)	I could make a learning plan to meet the learning goals according to my abilities
Self-monitoring (10)	I would clarify why I am encountering a learning problem and then try to resolve it
Self-regulation (5)	I would adjust the learning plan when it is ineffective for me to reach the learning goals
Self-evaluation (9)	I would recheck the correctness of my answer after finishing the assignment

Appendix II-A

Results of examining the assumptions of ANCOVA (Gain scores of the two groups in the IPT)

Testing normality using the Shapiro–Wilk test and testing the homogeneity of variances using the Levene test

		Group	Normality (p)	Homogeneity (p)
Pretest	Question	CG	0.057	0.134
		EG	0.068	
	Plan	CG	0.008	0.873
		EG	0.002	
	Analyze	CG	0.075	0.916
		EG	0.170	
	Interpret	CG	0.002	0.005
		EG	0.012	
	Total score	CG	0.980	0.803
		EG	0.223	
Posttest	Question	CG	0.048	0.679
		EG	0.003	
	Plan	CG	0.029	0.019
		EG	$p < .001$	
	Analyze	CG	0.008	0.859
		EG	0.031	
	Interpret	CG	0.056	0.573
		EG	0.057	
	Total score	CG	0.068	0.934
		EG	0.008	

Homogeneity of the variances of the residuals test.

Pretest group	SS	*df*	MS	*F*	*p*
Question	0.074	1	0.074	0.051	0.822
Plan	29.001	1	29.001	15.200	$p < .001$
Analyze	4.967	1	4.967	2.025	0.161
Interpret	0.402	1	0.402	0.181	0.672
Total	8.655	1	8.655	0.639	0.428

Appendix II-B

Results of examining the assumptions of ANCOVA (Gain scores in the IPT for different levels of metacognition)

The normality (Shapiro–Wilk test) and homogeneity of variances (Levene test)

			Normality (p)	Homogeneity (p)				Normality (p)	Homogeneity (p)
CG	pre-Q	HL	0.315	0.707	EG	pre-Q	HL	0.044	0.547
		ML	0.207				ML	0.043	
		LL	0.101				LL	0.801	
	pre-P	HL	0.239	0.839		pre-P	HL	0.685	0.994
		ML	0.128				ML	0.028	
		LL	0.070				LL	0.040	
	pre-A	HL	0.002	0.873		pre-A	HL	0.754	0.514
		ML	0.355				ML	0.129	
		LL	0.961				LL	0.156	
	pre-I	HL	0.197	0.903		pre-I	HL	0.899	0.992
		ML	0.051				ML	0.150	
		LL	0.093				LL	0.356	
	pre-T	HL	0.196	0.391		pre-T	HL	0.523	0.869
		ML	0.812				ML	0.968	
		LL	0.574				LL	0.174	
	pos-Q	HL	0.168	0.477		pos-Q	HL	0.777	0.338
		ML	0.377				ML	0.005	
		LL	0.006				LL	0.114	
	pos-P	HL	0.135	0.868		pos-P	HL	0.046	0.365
		ML	0.647				ML	0.001	
		LL	0.080				LL	0.002	
	pos-A	HL	0.156	0.132		pos-A	HL	0.314	0.579
		ML	0.846				ML	0.059	
		LL	0.014				LL	0.314	
	pso-I	HL	0.025	0.197		pso-I	HL	0.967	0.752
		ML	0.048				ML	0.012	
		LL	0.161				LL	0.521	
	pso-T	HL	0.197	0.023		pso-T	HL	0.050	0.680
		ML	0.643				ML	0.938	
		LL	0.535				LL	0.073	

Appendix II-C

Results of examining the assumptions of ANCOVA (Gain scores in the IPT for different levels of metacognition)

Homogeneity of the variances of the residuals test

	Pretest metacognitive group	SS	*df*	MS	*F*	*p*
CG	Question	0.027	2	0.013	0.010	0.990
	Plan	1.863	2	0.932	0.472	0.631
	Analyze	2.150	2	1.075	0.384	0.686
	Interpret	8.637	2	4.318	2.412	0.117
	Total	38.369	2	19.185	1.592	0.229
EG	Question	12.270	2	6.135	5.576	0.012
	Plan	2.189	2	1.094	0.474	0.629
	Analyze	3.629	2	1.814	0.729	0.495
	Interpret	1.237	2	0.618	0.254	0.778
	Total	19.337	2	9.668	0.740	0.490