
**International Journal of Contemporary Educational Research (IJCER)**

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**To cite this article:**

Wu, H. L., Weng, H. L., & She, H. C. (2016). Effects of scaffolds and scientific reasoning ability on web-based scientific inquiry. *International Journal of Contemporary Educational Research, 3*(1), 12-24.

IJCER International Journal of Contemporary Educational Research
Volume 3, Number 1, June 2016, Page 12-24 ISSN: 2148-3868

# Effects of Scaffolds and Scientific Reasoning Ability On Web-Based Scientific Inquiry

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## Abstract

This study examined how background knowledge, scientific reasoning ability, and various scaffolding forms influenced students' science knowledge and scientific inquiry achievements. The students participated in an online scientific inquiry program involving such activities as generating scientific questions and drawing evidence-based conclusions, while being scaffolded either directly or indirectly. Results indicated that student knowledge and scientific reasoning can predict scientific inquiry ability development. Only scientific reasoning has a significant effect on student comprehension. Level of scientific reasoning and types of scaffolding significantly influenced students' scientific inquiry abilities. In particular, prior reasoning skills significantly affected how they identified variables and made conclusions in both post- and retention tests. Students who used the online program benefitted from direct scaffolding, which helped them make hypotheses and draw conclusions better than indirect scaffolding. Direct scaffolding was especially useful for students with high prior reasoning skills. Students with high prior reason skills who used direct scaffolding were better able to make hypotheses and draw conclusions.

**Key words:** Scaffolding, Direct and indirect scaffolding, Scientific inquiry, Web-based learning

## Introduction

Researchers and educators frequently recognize the various benefits that inquiry-based learning has for student learning, and have paid particular attention to scientific inquiry, which many countries encourage their teachers to apply in their science classrooms. In China, for instance, scientific inquiry is one of the key elements in their recent basic educational reform (Wang, Zhang, Clarke, & Wang, 2014). Australian science curricula also reiterate the effort to engage students in scientific inquiry activities by broadly applying inquiry-based teaching and learning from Foundation to Year 10 (Australian Curriculum, Assessment and Reporting Authority, 2015). According to the National Research Council's (2000) scientific inquiry standards, middle school students need to possess such fundamental scientific inquiry abilities as identifying questions, designing and conducting scientific investigations, using appropriate tools and techniques to collect and analyze data, and making evidence-based explanations. When students can devote most of their time to hands-on activities and drawing conclusions from data, they are most likely to "learn science content and gain insights about science" (Jiang & McComas, 2015, p.574). Elliott and Paige (2010) showed that Australian secondary school students believed that they learned science best by doing, and that the use of technology would enhance their science lessons. Research has documented that inquiry-based learning enhances students' scientific reasoning skills. Gerber and his colleagues (2001) found that students in an inquiry-based science classroom achieved higher scientific reasoning abilities than those exposed to non-inquiry science learning. Research suggests that children aged 10 to 12 are "developing and consolidating a variety of new skills in scientific reasoning, including the generation and interpretation of evidence" (Schauble, Glaser, Duschl, Schulze, & John, 1995, p.160). Despite this, Australian students in the 2006 PISA report admitted that they did not regularly experience student-led inquiry (Woods-McConney, Oliver, McConney, Schibeci, & Maor, 2014). Therefore, further studies must explore the practice of inquiry-based teaching and learning, including how to support student learning and the factors which may influence the results of implementing inquiry activities.

While scientific inquiry promotes the development of one's problem solving, critical thinking, and communication abilities, students often encounter difficulty with scientific inquiry (Cuccio-Schirripa & Steiner, 2000; van Rens, Pilot & van der Schee, 2010). To solve this, the current study explores various attributes that

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might affect the development of scientific inquiry skills. We are particularly interested in how internal cognitive ability (i.e. background knowledge and reasoning ability) and external environmental factors (i.e. instructional scaffolding) affect students' engagement in the scientific inquiry process. Robert Glaser identified the effective use of one's prior knowledge and cognitive ability as one of the seven principles in instructional design that can support and scaffold new learning in a particular domain (Bransford, Brown, & Cocking, 1999). Hmelo-Silver and Azevedo (2006) also noted that students need to have some background understanding, such as domain knowledge and scientific reasoning skills, in order to learn about complex simulations or models. In addition, scientific inquiry combines ''the use of processes of science and scientific knowledge" as students "use scientific reasoning and critical thinking'' (National Research Council, 1996, p. 105). But the extent to which reasoning ability influences scientific inquiry remains unclear.

## Background

### Scientific inquiry

Scientific inquiry often appears in different forms but usually follows Cuevas and colleagues' (2005) generic inquiry framework. Scientific inquiry starts with generating questions which encourage students to state a problem and make a hypothesis, followed by planning (making plans), implementing (carrying out investigation), drawing conclusions, and reporting findings.

The advantages and significance of encouraging students to compose their own research questions has been well documented. Forming research questions stimulates excitement and curiosity (Keys, 1998), and is therefore likely to motivate students to learn (Graesser & Olde, 2003). In this regard, questioning helps individuals explore new concepts and encourages them to think about the relationships among questions, tests, evidence, and conclusions (Keys, 1998). Cuccio-Schirripa and Steiner (2010) stated that questioning is "one of the thinking processing skills which is structurally embedded in the thinking operations of critical thinking, creative thinking, and problem solving" (p.210). A lack of student questions would be "a serious barrier that prevents other components of inquiry from developing" (Graesser, McNamara, & VanLehn, 2005, p.226). In particular, students do not always have sufficient knowledge or experience to ask high order questions, and may require additional support (Kaya, 2015).

In spite of its importance, scholars recognize that students have difficulty posing questions. Researchers suggested that most middle school students had difficulty forming researchable questions (Cuccio-Schirripa & Steiner, 2000). One study suggested that students cannot ask meaningful questions without the support of instructional scaffolding (Olsher, 1999), perhaps because limited prior experience or knowledge about the topic may prevent students from asking appropriate questions. In this regard, the quality of students' questions tend to be disappointing (Graesser et al., 2005).

Generating a hypothesis is an important feature of scientific inquiry as it leads individuals to test ideas. When an individual formulates a hypothesis, he tries to make a "tentative specification of the relation between input and output variables" (de Jong, 2006, pp.111). However, some studies have noted that students have difficulty finding correct variables, stating testable hypotheses, and drawing appropriate conclusions. Young learners tend to have difficulty generating complex hypotheses that involve the interactions between two variables (Wilhelm, Beishuizen, & van Rijn, 2005). Wilhelm and colleagues (2005) found that sixth grade students could not state complex hypotheses, nor could they "translate their data into valid statements about the effects of the input variables on the output variables" (p. 942) They also noted that manipulating multiple variables might make it more difficult for students to inspect data sets, which might result in the students overlooking evidence. These problems were not found among young learners only; even college students might not know how to make hypotheses (Guisasola, Ceberio, & Zubimendi, 2006).

### Reasoning

Reasoning, scientific inquiry, and critical thinking are interrelated. Reasoning, broadly defined, encompasses the "ability to think and to make logical and rational decisions" (Lajoie, Guerrera, Munsie, & Lavigne, 2001, p.158). Scientific reasoning involves activities such as generating, testing and revising theories, and reflecting on the process of knowledge acquisition and change (Zimmerman, 2007). Thus, reasoning promotes the development of scientific knowledge. Reasoning and critical thinking also influence student conceptual understanding and science literacy (Hand, Prain, Lawrence, & Yore, 1999).

Scientific reasoning abilities can be categorized into three learning cycles: descriptive, empirical-abductive, and hypothetical-deductive (Lawson, Abraham, & Renner, 1989). Among these, Grandy and Duschl (2007) argue that hypothetical-deductive reasoning especially dominates science education. According to Lawson (2003), scientific inquiry is determined by cycles of hypothetical-deductive reasoning. This inquiry model focuses on designing an experiment and using the experimental results to validate a hypothesis (Oh, 2010). For example, hypothetical-deductive reasoning guides students to test alternative hypotheses using such prompt as "if….and…then…therefore…" (Lawson, 1999). In addition, the ability to compose research questions might depend upon one's hypothetical-deductive reasoning ability (Chin, 2002). In sum, hypothetical-deductive reasoning promotes critical thinking by encouraging learners not only to make observations from experiments but also to draw evidence-based conclusions.

Considering the importance of reasoning to science education, researchers have actively explored how reasoning affects student learning. For example, Lawson, Banks, and Logvin (2007) found that reasoning ability strongly predicted self-efficacy achievement. In their 1995 study, Williams and Cavallo concluded that one significant predictor of college students' understanding of physics concepts was their formal reasoning ability. In addition, both Cavallo (1996) and Chang (2010) showed that reasoning ability predicted secondary school student abilities to solve science problems. Even for college students, prior reasoning ability was an important predictor of biology comprehension in inquiry classes (Johnson & Lawson, 1998). Whereas science education researchers have found that reasoning ability has a positive effect on scientific inquiry, the question of to what extent prior reasoning ability and other attributes influence the scientific inquiry process of secondary school students still remains unclear.

## Scaffolding

Scaffolding derives from the Zone of Proximal Development (ZPD) framework addressed by Vygotsky. ZPD refers to the difference between an individual's current capability and the potential which he can achieve through instructional support. While engaging in complex scientific inquiry activities, students often require instructional support. For example, students with little science inquiry experience may not know how to do the assigned work and understand what the process entails (Quintana & Fishman, 2006). One study showed that some higher-level secondary education students had difficulty identifying key concepts such as dependent variables (Arnold, Kremer, & Mayer, 2014), thus indicating that instructional scaffolds that support "procedural knowledge and understanding" (p.2719) during inquiry tasks are needed. Also, even though students are able to design and carry out simply investigation, they often "collect insufficient or inadequate data, and state conclusions that are inconsistent with their data or are not warranted by it" (Kanari & Millar, 2004, p.749). Furthermore, Oh (2010) pointed out that not all science studies provide necessary support and guidance to help students with inquiry procedures. Therefore, using scaffolds to help learners achieve independent learning deserves researchers' special attention.

Scaffolds designed in prior computer-mediated research generally support student learning for different purposes. Among these, conceptual scaffolding refers to the support which guides individuals to determine what knowledge to consider (Hannafin, Land, & Oliver, 1999; Saye & Brush, 1999).Conceptual scaffolds include prompts, hints, or organized structures to help individuals identify key conceptual knowledge and use relevant information in the learning context. For instance, Brush and Saye (2001) used an interactive essay to provide an overview of an historical event and suggestions for possible direction that students may explore. They also highlighted menus designed to assist students with selecting key documents to explore. Rosenshine, Meister, and Chapman (1996) also noted that diverse types of prompts may lead to different learning effects. For example, scaffolds may be delivered explicitly or implicitly. Lorch, Jr., and colleagues (2010) stated that "learning is much faster if students are systematically guided through the logic and/or the logic is explicitly presented for them" (p.91). They believed that explicit instruction and opportunities for exploratory, hands-on experimentation both help students learn how to control variables. Directive scaffolding often seems especially appropriate for young children (Sharma & Hannafin, 2007). Sharma and Hannafin (2007) further suggested that directive scaffolds may help to correct misunderstanding whereas non-directive ones may trigger metacognitive exploration of understanding. However, this perspective still lacks the support of experimental studies. Therefore, this research compares how directive and non-directive scaffolding influence student online inquiry learning.

## Purposes of the Study

The present study aims to investigate how different types of scaffolding and student prior reasoning skills influence scientific inquiry development. Four research questions guided the present study:

1. To what extent does biology comprehension and scientific reasoning skills predict the development of student scientific inquiry abilities?
2. How do different kinds of scaffolding and levels of prior reasoning skills influence students' biology comprehension and scientific inquiry scores?
3. How do different kinds of scaffolding and levels of prior reasoning skills influence students' scientific inquiry abilities in web-based environments?
4. For students with different levels of prior reasoning skills, does the use of various kinds of scaffolding influence the development of their online scientific abilities?

## Methods

### Research design and participants

We adopted a quasi-experimental design to investigate how different types of scaffolding and levels of prior reasoning abilities influence student learning. The participants were randomly assigned to one of the four experimental conditions so that two of four classes implemented one of the two types of scaffolding (direct or indirect) and the other two classes used the other type. Students' reasoning knowledge which was measured before the intervention was also divided into two levels (low and high) and thus considered as one of the independent variables. The dependent variables included student biology comprehension, reasoning skills, and scientific inquiry abilities.

The participants in this study were 138 seventh grade students from a junior high school in Northwestern Taiwan. They all came from one of four science classes, taught by two instructors. The number of students in each class was ranged from 33 to 36. The participating students had not previously learned the curriculum before the intervention.

### Instructional program

A web-based scientific inquiry program was developed for this study. The program included three learning units (nerve system, plants and environments, and respiration) and one practice unit. Before the intervention, students joined a practice learning unit to familiarize themselves with the web-based learning environment and the instructional scaffolding. Each science learning unit included two main topics. During the learning units, students conducted three web-based inquiry learning activities (learning scientific concepts, generating scientific questions, making hypotheses) and hands-on scientific experiments based on these activities. Students then reported their experimental results and scientific explanations online which were supported with experimental data. To help students visualize the concepts, the content was presented with animation in the computer program (see Figure 1).

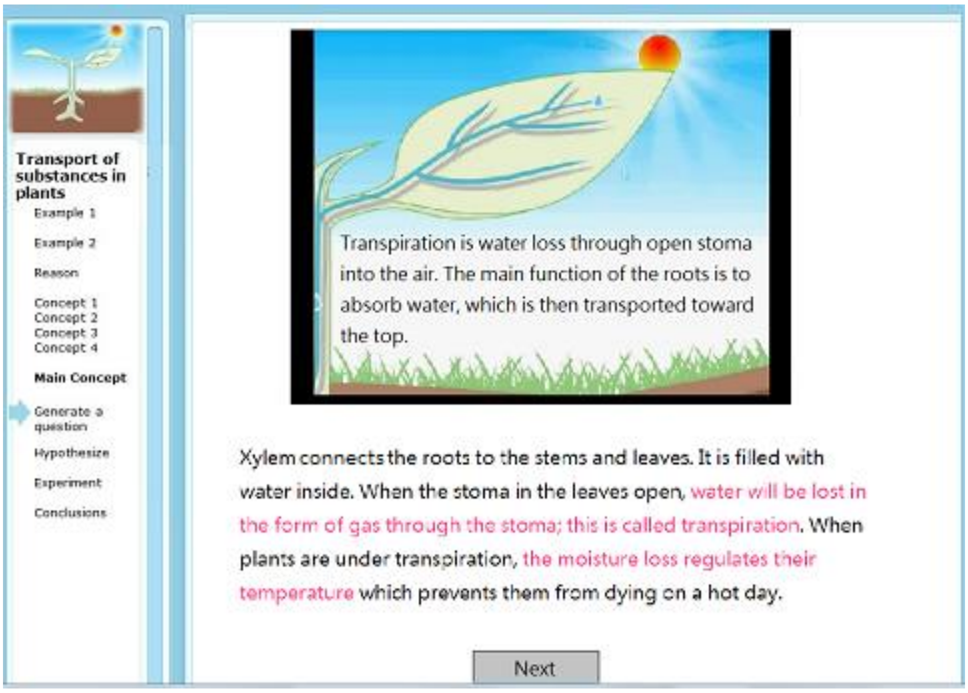


*Figure 1.* An example of concept presentation in the program

**Instructional scaffolding**

The participants were given one of two instructional scaffolds (direct or indirect) to support each scientific inquiry step. Both scaffolding conditions began with an identical learning unit involving the presentation of term definitions and examples of scientific inquiry steps (generating scientific questions, identifying operating and dependent variables, and making hypotheses). For example, the web-based learning program helped students formulate scientific questions by suggesting that they "*identify variables and operate particular conditions in experiments (i.e. the condition of more and less leaves) in order to observe their effects (i.e. the speed of evaporation). You should also use some tools and materials to verify the hypotheses in order to form reasonable scientific questions.*" After this presentation, each scaffolding condition provided either indirect or direct scaffolding support.

*Indirect and direct scaffolding.* The main difference between indirect and direct scaffolding is the level of instructional support given to students when they develop conceptual knowledge during the inquiry procedure. Scientific inquiry activities in the current study began with concept learning. At this phase, direct scaffolding provided individuals with basic conceptual support in order to help them develop necessary cognitive skills. It was designed based on the principle of direct instructional guidance (Kirschner, Sweller, & Clark, 2006) which provided students with information to help them understand concepts. Direct scaffolding first introduces several scientific concepts to students and continually prompts them to think about the unit's main concepts.

In contrast, indirect scaffolding provides individuals with advanced conceptual support to help students recognize the level of their content knowledge, thereby strengthening their conceptual understanding and enhancing their critical thinking. As each scientific concept in the unit was introduced, the students were given a multiple-choice question and required to explain their response. Thus, students were prompted to think about scientific concepts before they were prompted to organize and develop an understanding of the main concept. The presentation of their learning process thus attempted to promote their higher order thinking.

Direct and indirect scaffolds provided different levels of assistance to support student formulating scientific questions. Direct scaffolds required students to respond a multiple-choice question for the main concepts they have learned earlier and reiterated their main concept to help students discover science questions on their own (see Figure 2). The scaffolds gave students hints regarding to the scientific question generation, such as "*It is still unclear what the relationships exist among the speed of transpiration, the number of leave and the rate of water transportation upwards*" In contrast, indirect scaffolding created a subject-specific contextual scenario to remind students of targeted concepts. The scenarios in indirect scaffolding help students to identify possible scientific questions through contextual hints. In addition, it promotes critical thinking by adding different or even conflicting perspectives (see Figure 3). For instance, students learned that plants absorb water through roots and transport it upwards. But they were also reminded that water moves from high levels toward low levels.

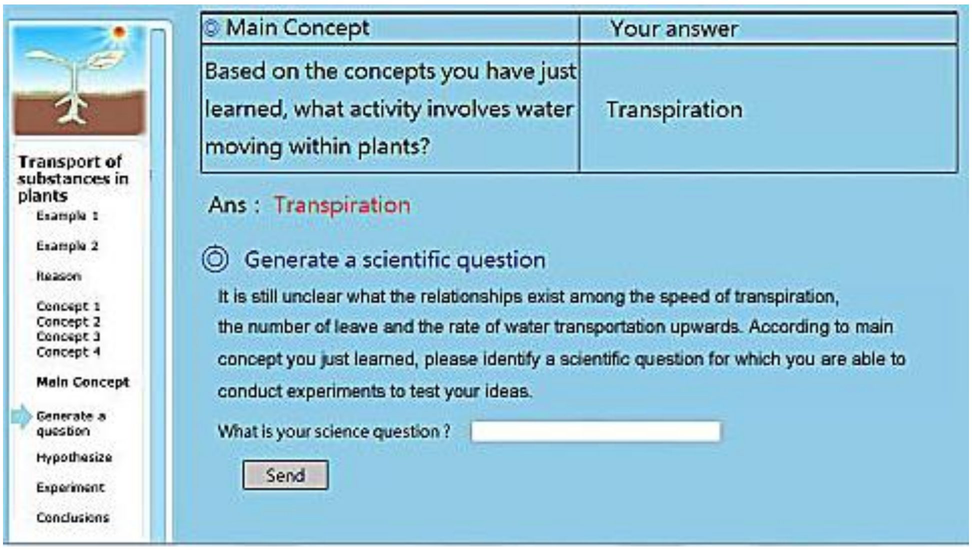


*Figure 2.* Direct scaffolding example in the web-based inquiry program

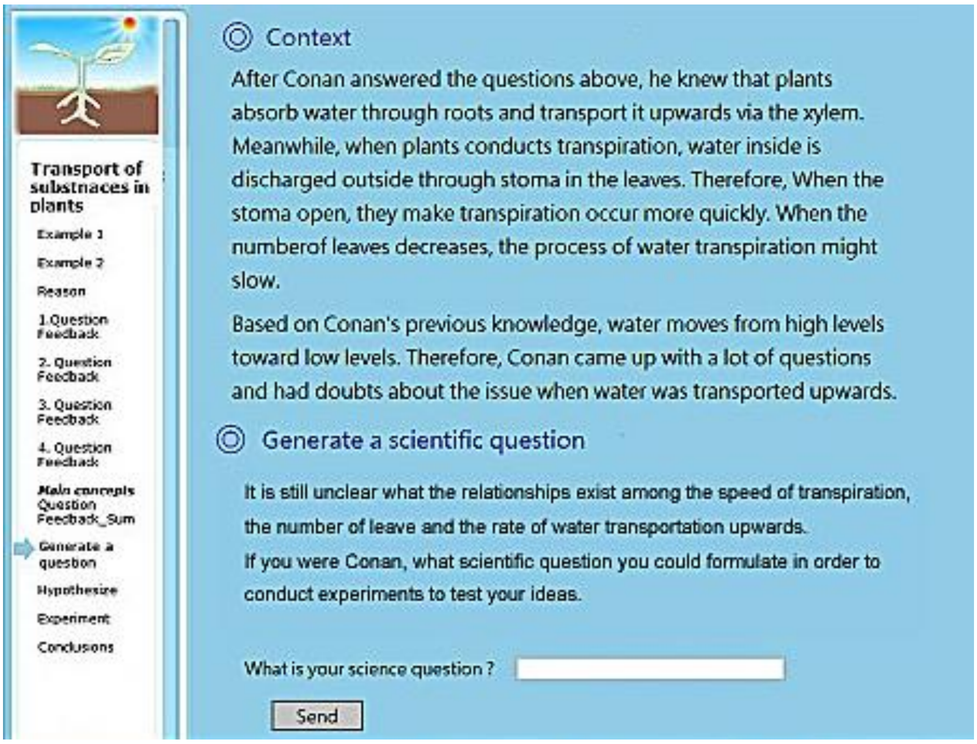


*Figure 3.* Indirect scaffolding example in the web-based inquiry program

As far as the next scientific inquiry procedures are concerned, both direct and indirect scaffolds offer identical assistance. Students from both conditions received the same level of support while identifying variables, forming hypotheses, conducting experiments, and making evidence-based explanations. During the "forming hypotheses" phase, students were given three generic question stems ("*What is the indepent variable?*", "*What is the dependent variable?*" and "*if……then……*") in order to help them identify variables and how they interact with each other. After students conducted the scientific experiments, the scaffolds offered question stems that prompted students to make conclusions. Students needed to complete such question as "*What were your experimental results?*", "*Were your experimental results support your hypothesis?*", and "*What were your explanations?*"

## Data collection

### Biology comprehension test

A biology comprehension test was developed to assess how well participants understood the topics covered in this study before, directly after, and three months after the intervention. To achieve this, the test included eight sets of multiple-choice questions which derived from three learning units. Each question was composed of two sub-questions. The first tier of questions measured one's conceptual understanding. Following this, students needed to explain their answer on the second tier of questions which also appeared in multiple choice form. Only when students answered both questions accurately did they gain one score for the set. The test was administered for 30 minutes. The reliability of the pretest, posttest, and retention test was 0.76, 0.89, and 0.95, respectively. The quality of the test was ensured by two science teachers and one science education expert.

### Scientific reasoning test

The revised version of Lawson's Classroom Test of Scientific Reasoning is a two-tier instrument which contains twelve sets of multiple choice questions to measure student scientific reasoning before, immediately after, and three months after the intervention. Each question has two tiers, one for solving the problem/making a prediction and the other for providing explanations for the selected answer. The validity and reliability of the test have been established by prior studies (i.e. Lawson, Alkhoury, Benford, Clark, & Falconer, 2000). The test measures student reasoning regarding such aspects as conservation of weight, proportional thinking, identification and control of variables, probabilistic thinking, and hypothetic-deductive reasoning. The answers to a set of questions both need to be accurate in order to receive one point. The reliability of the pretest reached 0.58.

### Scientific inquiry abilities

Both quantitative and qualitative data were collected to analyze the participants' scientific inquiry abilities, including generating scientific questions, understanding experimental variables, making hypotheses, and drawing conclusions. First, this study implemented a scientific inquiry multiple-choice test which was administered before, immediately after, and three months after the intervention. The measurement of each topic began with a scenario, followed by four questions. This test assessed the extent of the participants' scientific inquiry abilities, including identifying scientific questions, distinguishing between operating and dependent variables, and recognizing hypotheses. For example, participants were asked, "*Based on the scenario, which of the following scientific questions is reasonable*?" Students received one point when they identified correctly both the operating and dependent variables in each question. As a result, the scores of the scientific inquiry multiple-choice test ranged from 0 to 18. A panel of three science educators examined the test to ensure its validity. The reliability results of the pretest, posttest, and retention test all reached satisfactory levels, with Cronbach's α equal to 0.79, 0.83, and 0.88, respectively. Students' qualitative learning progress was recorded and analyzed in terms of four measurements: forming scientific issues, recognizing variables, making hypotheses, and providing scientific explanations. Two science educators used a rubric (see Table1) to assess the quality of the students' responses to each measure. Based on the rubric, each response was divided into two or three levels (0, 1, or 2). The inter-rater agreement yielded a value of 0.9.

Table 1. *Rubric for measuring web-based inquiry performance*

| Inquiry phases | Score levels | | |
|---|---|---|---|
| | 0 | 1 | 2 |
| Formulate scientific questions | Couldn't identify scientific issues which were formed based on key features | Could identify both scientific issues which were formed based on key features and incomplete operating or dependent variables in order to conduct experiments | Could identify both scientific issues which were formed based on key features and complete operating or dependent variables in order to conduct experiments |
| Identify variables | Included both | Included one incomplete | Included both complete |

| | | | |
|---|---|---|---|
| | incomplete operating and dependent variables | operating or dependent variables | operating and dependent variables |
| Make hypotheses | *If* was not followed by an operating variable, or *then* was not followed by a dependent variable | *If* was followed by an operating variable, and *then* was followed by a dependent variable | N/A |
| Draw conclusions | Couldn't describe results and explanations. Or provided inaccurate explanations | Couldn't describe results and explanations. Or provided accurate or partially accurate explanations but was lack of the application of scientific principles | Used scientific vocabularies to provide accurate explanations about scientific concepts |

## Results

### The prediction of both biology comprehension knowledge and scientific reasoning skills on student scientific inquiry abilities

Three multiple regression analyses were conducted to investigate which independent variables (biology knowledge and scientific reasoning ability) were significant predictors of learners' scientific inquiry skills at three measurement periods: before the intervention, immediately after the intervention, and three months after the intervention. A scientific inquiry test was treated as the dependent variable. As shown in Table 2, for the posttest results, only biology knowledge accounted for a significant amount of unique value in predicting student scientific inquiry scores ($p < 0.01$); however, reasoning skills did not significantly predict scientific inquiry posttest scores ($p > 0.05$). But in the retention test, both biology knowledge and reasoning skills significantly predicted scientific inquiry abilities ($p < 0.01$). The adjusted R squared value was 0.54, indicating that 54% of the variance in the scientific inquiry test was explained by the retention test model.

Table 2. *Regression analyses of scientific ability test results*

| Model | Outcome variable | Predictor variable | B | SE | β | p |
|---|---|---|---|---|---|---|
| Regression 1: Pretest | | | | | | |
| | Scientific inquiry abilities | Biology knowledge | 0.33 | 0.08 | 0.37 | 0.00 |
| | | Scientific reasoning | 0.36 | 0.17 | 0.19 | 0.04 |
| Regression 2: Posttest | | | | | | |
| | Scientific inquiry abilities | Biology knowledge | 0.40 | 0.06 | 0.62 | 0.00 |
| | | Scientific reasoning | 0.14 | 0.17 | 0.08 | 0.40 |
| Regression 3: Retention | | | | | | |
| | Scientific inquiry abilities | Biology knowledge | 0.32 | 0.05 | 0.55 | 0.00 |
| | | Scientific reasoning | 0.54 | 0.16 | 0.26 | 0.00 |

### The effects of scaffolding types and prior reasoning skills on biology comprehension acquisition

A two-way multivariate analysis of covariate (MANCOVA) approach was employed to measure how different types of scaffolding and levels of prior scientific reasoning skills influenced the development of biology knowledge. A biology test before the intervention was used as the covariate. Student post and retention biology tests were the dependent variables. The assumptions of both equality of error variance and homogeneity of variance-covariance matrices were met. MANCOVA results which are presented in Table 3 showed significant differences between the reasoning groups on the combined dependent variables, $F_{(2, 104)} = 9.30$, $p < 0.01$, Wilk's $\lambda = 0.85$, partial $\eta^2 = 0.15$. Further univariate follow-up analyses revealed that prior scientific reasoning skills influenced both student biology knowledge comprehension posttest ($F_{(1, 105)} = 3.98$, $p = 0.05$, partial $\eta^2 = 0.04$)

and retention test ($F_{(1, 105)}$ = 18.16, $p$ = 0.00, partial $\eta^2$ = 0.15) scores significantly . Especially, the biology knowledge retention test result revealed that students with high prior reasoning skills had scores that were 4 points higher than those with low prior reasoning skills, approximately four times better than the mean difference of two groups in the posttest. However, students who were supported with either direct or indirect scaffolds did not have significantly different biology knowledge test scores from each other (p> 0.05). Neither was a significant interactive effect found between types of scaffolding and prior reasoning levels on biology knowledge comprehension tests (p > 0.05). This indicated that different types of scaffolding did not influence students with either low or high prior scientific reasoning skills as regards their development of biology knowledge comprehension.

Table 3. *MANCOVA in biology comprehension and scientific inquiry test*

| | Wilk's Λ (Partial $\eta^2$) | Multivariate F (p) | Univariate F Posttest (p) | Retention (p) |
|---|---|---|---|---|
| Biology comprehension | | | | |
| Pretest | 0.43 (0.57) | 70.06 (0.00) | | |
| Reasoning | 0.85 (0.15) | 9.30 (0.00) | 3.98[a] (0.05) | 18.16[b] (0.00) |
| Scaffold | 0.97 (0.03) | 1.50 (0.23) | 0.11 (0.75) | 2.39 (0.13) |
| Reasoning X Scaffold | 0.99(0.01) | 0.64 (0.53) | 0.03 (0.87) | 0.62 (0.43) |
| Scientific Inquiry | | | | |
| Pretest | 0.57 (0.43) | 38.42 (0.00) | | |
| Reasoning | 0.95 (0.05) | 2.73 (0.07) | 5.37[c] (0.02) | 1.82 (0.18) |
| Scaffold | 0.97 (0.03) | 1.80 (0.17) | 0.09 (0.76) | 3.32[d] (0.07) |
| Reasoning X Scaffold | 0.97 (0.03) | 1.74 (0.18) | 1.62 (0.21) | 0.47 (0.50) |

Note: a: High reasoning > Low reasoning (mean difference = 1.67)
b: High reasoning > Low reasoning (mean difference = 4.04)
c: High reasoning > Low reasoning (mean difference = 1.36)
d: Direct scaffolding > Indirect scaffolding (mean difference = 1.28)

**The effects of different types of scaffolding and levels of prior reasoning skills on scientific inquiry abilities**

To determine how types of scaffolding and levels of prior reasoning skills influenced student scientific inquiry abilities, quantitative inquiry posttest and retention test scores were first examined. A two-way MANCOVA was conducted with students' prior test scores as the covariate. The scientific inquiry posttest and retention test scores were treated as dependent variables. The results, as shown in Table 3, show that the combination of different types of scaffolding and prior scientific reasoning levels did not influence students' performance on the scientific inquiry tests (p >0.05). Although types of scaffolding had no significant effect on the combined posttest and retention test outcomes, between-subject analysis indicated that students who used different types of scaffolding had significantly different scientific inquiry retention test scores ($p$ = 0.07). Direct scaffolding helped students to perform in scientific inquiry slightly better than indirect scaffolding, with mean difference equaling 1.28. On the other side, there was a significant main effect of prior reasoning on student scientific inquiry test scores, $F_{(2, 103)}$ = 2.73, $p$ = 0.07, Wilk's $\lambda$= 0.95, partial $\eta^2$ = 0.05. Univariate between-subject tests further revealed a significant effect of different levels of prior reasoning on the scientific inquiry posttest scores, $F_{(1, 104)}$ = 5.37, $p$ <0.05, partial $\eta^2$ = 0.05. Students with high prior reasoning skills overall performed better in scientific inquiry abilities (posttest = 1.36 points) than those with low prior reasoning skills. Moreover, each scientific inquiry ability on both the posttest and retention scientific inquiry tests was examined in terms of different prior reasoning levels (see Table 4). The one-way multivariate of analysis showed that students with high prior reasoning skills significantly outperformed those with low reasoning skills in identifying variables and making hypotheses in the posttest.

Table 4. *MANOVA of inquiry tests (pretest reasoning as the factor)*

| | Pillai's trace (Partial $\eta^2$) | Multivariate F (p) | Univariate F | | |
|---|---|---|---|---|---|
| | | | Step I (p) | Step II (p) | Step III (p) |
| Posttest | 0.09 (0.09) | 3.84 (0.01) | 4.32[a] (0.04) | 10.55[b] (0.00) | 7.28[c] (0.01) |
| Retention | 0.08 (0.08) | 3.43 (0.02) | 3.42 (0.07) | 9.11[d] (0.00) | 6.82[e] (0.01) |

Note: Step I = Generate scientific questions, Step II = Identify variables, and Step III = Make hypotheses
a: High reasoning > Low reasoning (mean difference = 0.58)
b: High reasoning > Low reasoning (mean difference = 0.85)
c: High reasoning > Low reasoning (mean difference = 0.76)
d: High reasoning > Low reasoning (mean difference = 0.87)
e: High reasoning > Low reasoning (mean difference = 0.75)

On the other hand, students' online scientific inquiry performance was analyzed by a 2 x 2 MANOVA, with types of scaffolding and prior reasoning skills as independent variables and performances in each scientific inquiry activity throughout three web-supported scientific inquiry units as dependent variables. The dependent variables included four inquiry steps: generating scientific questions, identifying variables, making hypotheses, and drawing conclusions. Assumptions for multivariate tests were met for linearity (Bartlett's test of sphericity, $p<0.001$) and homogeneity of covariances (Box's M test, $p > 0.05$). However, the Levene's tests were not statistically significant for all dependent measures, indicating that homogeneity of variances among the groups was satisfied in all dependent measures except the one *identifying variables.* Thus, Pillai's trace which was most robust to violations of assumptions was used to examine the multivariate tests. MANOVA results showed significant differences between the two scaffolding groups on the combined online scientific inquiry competencies, $F_{(4, 70)} = 3.13$, $p < 0.05$, Pillai's trace = 0.15, partial $\eta^2 = 0.15$. Analyses of variances on each dependent variable (ANOVA) showed that whether students used direct or indirect scaffolding influenced their online scientific inquiry performance significantly when they made hypotheses and provided scientific conclusions (see Table 5). During these two scientific inquiry steps, students in the direct scaffolding groups on average had significantly better performance than those in the indirect scaffolding group.

Table 5. *Measurement of inquiry activities using pretest reasoning and scaffolds*

| | Pillai's trace (Partial $\eta^2$) | Multivariate F (p) | Univariate F | | | |
|---|---|---|---|---|---|---|
| | | | Step I (p) | Step II (p) | Step III (p) | Step IV (p) |
| Reasoning | 0.07 (0.07) | 1.39 (0.25) | 3.59 (0.06) | 0.03 (0.86) | 2.40 (0.13) | 1.11 (0.30) |
| Scaffolds | 0.15(0.15) | 3.13 (0.02) | 0.18 (0.67) | 3.05 (0.09) | 5.77[a] (0.02) | 7.01[b] (0.01) |
| Reasoning X Scaffold | 0.04(0.04) | 0.69 (0.60) | 0.93 (0.34) | 0.10 (0.75) | 1.08 (0.30) | 2.32 (0.13) |

Note: Step I = Generate scientific questions, Step II = Identify variables, Step III = Make hypotheses, and Step IV = Draw conclusions
a: Direct scaffolding > Indirect scaffolding (mean difference = 1.13)
b: Direct scaffolding > Indirect scaffolding (mean difference = 1.42)

### The effects of prior reasoning skills on online scientific inquiry performance for students with various scaffolds

A one-way MANOVA was conducted to measure how types of scaffolding influenced online scientific inquiry performance for each group of students with high or low prior reasoning skills. Students' online scientific inquiry performances in terms of the four scientific inquiry steps were treated as dependent variables. MANOVA results indicated that different types of scaffolding did not influence student online scientific inquiry performance especially when they had low prior reasoning skills (see Table 6). However, for students with high prior reasoning skills, the types of scaffolding significantly affected online scientific inquiry performance when engaged in identifying variables, making hypotheses, and providing conclusions, $F_{(4, 42)} = 2.94$, $p < 0.05$, Wilk's $\lambda = 0.78$, partial $\eta^2 = 0.22$. Students with direct scaffolding performed significantly better than those with indirect scaffolding when they made hypotheses and provided conclusions. Direct scaffolding also helped students with high reasoning skills to identify variables in scientific inquiry ($p = 0.06$).

Table 6. *Measurement of inquiry abilities using different reasoning levels*

| | Wilk's Λ (Partial $\eta^2$) | Multivariate F (p) | Univariate F | | | |
|---|---|---|---|---|---|---|
| | | | Step I (p) | Step II (p) | Step III (p) | Step IV (p) |
| High reasoning students | | | | | | |
| Scaffolds | 0.78(0.22) | 2.94 (0.03) | 0.18 (0.68) | 3.83[a] (0.06) | 6.83[b] (0.01) | 9.98[c] (0.00) |
| Low reasoning students | | | | | | |
| Scaffolds | 0.85(0.15) | 1.08 (0.39) | 0.88 (0.36) | 0.57 (0.46) | 0.93 (0.34) | 0.67 (0.42) |

Note: Step I = Generate scientific questions, Step II = Identify variables, Step III = Make hypotheses, and Step IV = Draw conclusions

a: Direct scaffolding > Indirect scaffolding (mean difference = 1.76)
b: Direct scaffolding > Indirect scaffolding (mean difference = 1.62)
c: Direct scaffolding > Indirect scaffolding (mean difference = 2.23)

**Discussions and conclusions**

Scientific inquiry is one of the core elements and significant method of enhancing science literacy, as well as having other beneficial effects on student learning (Schwartz, Lederman, & Crawford, 2004; Abd-El-Khalick, BouJaoude, Duschl, Lederman, Mamlok-Naaman, Hofstein et al., 2004, p.408). The purpose of science education is to enhance students' understanding of the nature of scientific inquiry and develop the ability to use a range of scientific inquiry methods (Australian Curriculum, Assessment and Reporting Authority, 2015). The findings of this study contribute to this effort by broadening our current understanding of inquiry-based instruction, and offering suggested directions for future research studies in the field of science education. In particular, the web-based delivery of inquiry-based instruction in this study will be useful to those interested in developing effective implementation methods for scientific inquiry in Australia, particularly given the fact that the Australia Science Curriculum advocates the use of digital technologies in order to help educators "engage and maintain the interest of students" (National Curriculum Board, pp.12).

The current study explored how different types of scaffolding and student scientific reasoning skills before the intervention influenced students' scientific inquiry abilities. Researchers have investigated the improvement of student scientific inquiry by incorporating various instructional supports. But how each individual's characteristics, such as their initial reasoning skills and prior conceptual understandings, affect student scientific inquiry abilities still requires more research.

Like prior research (Chen & Klahr, 1999), this study found that reasoning skills influenced the acquisition of domain-specific conceptual knowledge. Students with high levels of prior scientific reasoning skills comprehended biology knowledge better than those with low levels of prior scientific reasoning skills in both post and retention conceptual knowledge tests. This result not only confirms Liao and She's (2009) scientific reasoning findings but also indicates that scientific reasoning had the potential to increase conceptual knowledge as indicated in the retention test scores. For participants with high prior reasoning skills, their biological conceptual understanding appeared much improved even long after the intervention ended. The retention test scores of students with high reasoning skills showed higher levels of concept knowledge (M = 15.56) than the posttest scores (M = 12.05).

Students' ability to comprehend scientific concepts and to scientifically reason affected the development of their scientific inquiry abilities to various degrees at various times. The regression analysis of this study showed that biology knowledge significantly predicted student scientific inquiry abilities in the posttest and this effect continuously occurred in the retention test. Minner, Levy, and Century (2009) concluded that encouraging students to think actively and engage constantly in the inquiry process helped them to increase their understanding of science concepts. In this regard, the scientific inquiry process supports the development of conceptual knowledge, which facilitates the development of scientific inquiry abilities. While student reasoning skill level was not a significant predictor of scientific inquiry abilities in the posttest, it became one of the important indicators for the development of scientific inquiry abilities in the retention test. These findings demonstrated the long term positive effects of scientific reasoning skills on scientific inquiry abilities. In particular, the beta weight in the regression model showed that scientific reasoning skills contributed most to predict scientific inquiry abilities for a long period of time when compared with the effects of biology knowledge.

This study found that the level of scientific reasoning affected the development of scientific inquiry abilities. As indicated in the scientific inquiry posttest, students with high reasoning skills achieved significantly better understanding of scientific inquiry than those with lower reasoning skills when their pretest scores were controlled (Mean difference =1.36, $p < 0.05$). Moreover, students who had higher prior reasoning skills had significantly better understanding in such aspects as generating research questions, identifying variables, and making hypotheses than low reasoning students in the posttest. The findings of the multiple-choice scientific inquiry tests were consistent with Chin (2002) and Chin and Osborne's (2008) studies, indicating that student reasoning ability could affect student-generated questions. Moreover, Germann's (1985) observation regarding reasoning ability could predict student achievement in generating hypotheses was also reflected in the findings of the current study.

In addition, it appeared that the applications of various kinds of scaffolding in the current study only influenced the development of scientific inquiry activities to some extent. While people generally tended to persist in their ideas even when confronted with experimental data (de Jong, 2006), this study found that middle school students were able to make effective conclusions along with evidence-based explanations when provided with appropriate assistance. This was especially evident when students were supported with direct scaffolding. The current study revealed that students who used direct scaffolding outperformed those who used indirect scaffolding in making hypotheses and drawing conclusions deriving from their online learning experiences.

There is no significant difference between the scores of those students with low reasoning skills who use direct and indirect scaffolds. However, significant differences do exist between the scores of students with high reasoning skills who use direct and indirect scaffolds. Direct scaffolding promoted the development of students' high reasoning skills and ability to identify variables, make hypotheses, and compose scientific conclusions. Thus, even students with high reasoning skills still need direct instruction to support their learning in complex web-based inquiry activities. As Hmelo-Silver and Azevedo (2006) indicated, it is crucial for students to have some scientific reasoning skills in order to succeed in complex learning. Lawson (2005) further emphasized that some students lacking advanced hypothetico-deductive reasoning skills might fail to understand scientific concepts and the nature of scientific inquiry. That might explain why students with low reasoning skills did not have significantly different performances when they were supported with different kinds of scaffolding.

Given that different scaffolding use did not significantly influence student performance at each inquiry step, future studies should continue exploring whether additional learning support will improve students' achievements in the phases of scientific inquiry. Azevedo, Winters, and Moos' (2004) study showed that even high school students might use "mostly ineffective strategies and metacognitive monitoring" to regulate their learning (p.235). Thus, participants in the current study might need additional support for their self-regulated inquiry in order to engage in scientific inquiry effectively. In addition, while Sharma and Hannafin (2007) suggested that indirect scaffolding may trigger metacognitive exploration of understanding, the findings of this study did not present such potential in regard to scientific inquiry performance. Although indirect scaffolding in this study provided learners with opportunities to reflect on their conceptual knowledge, the feedback was not given until students answered all questions in the unit. Krajcik and colleagues (1998) suggested that students need to "receive timely, informative, and critical feedback from teachers, peers, and others" (p.342) in order to help students to revise their questions. Future research may investigate whether timely feedback along with indirect scaffolding would affect student learning.

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