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Web-based undergraduate chemistry problem-solving: The interplay of task performance, domain knowledge and web-searching strategies

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ABSTRACT

This study investigates the effect of Web-based Chemistry Problem-Solving, with the attributes of Web-searching and problem-solving scaffolds, on undergraduate students' problem-solving task performance. In addition, the nature and extent of Web-searching strategies students used and its correlation with task performance and domain knowledge also were examined. We recruited a total of 183 undergraduate students, all of whom are taking the freshman chemistry course, to participate in the study to solve three chemistry tasks across a semester. Mandated screen-capture software captured participants' on-screen Web-searching processes were recorded every five seconds. Results demonstrated that students' problem-solving performance was significantly improved from task 1 to 3, and students with more domain knowledge outperformed students with less domain knowledge. Students with higher problem-solving performance employed more existing knowledge and metacognitive Web-searching strategies; and students with lower problem-solving performance employed more cognitive Web-searching strategies. In addition, students' problem-solving performance was correlated with their domain knowledge, use of existing knowledge, and metacognitive Web-searching strategies. Moreover, students' use of existing knowledge was the major factor for predicting their problem-solving performance according to the regression model.

1. Introduction

For more than two decades, problem-solving has been considered a pivotal ability for students (American Association for the Advancement of Science [AAAS], 1993; Bransford, Brown, & Cocking, 2000; Watts, 1994).Watts (1994) suggested that problem-solving could foster students' ability to think, and even more to promote their creativity and motivation in learning science. Other researchers addressed the idea that problem-solving offers the potential to help students develop flexible knowledge and effective problem-solving skills (Hmelo-Silver, 2004). Problem-solving ability is important, therefore, we are specifically interested in examining undergraduate students' chemistry problem-solving in the study. Thompson, Martin, Richards, and Branson (2003) reported that using a Web-based learning context can facilitate problem-solving instruction. However, many studies indicated that students' failure to construct meaning from the problem statements, their inability to link the meaning of the problem with their prior knowledge, and a lack of the appropriate knowledge for specific content areas were possible reasons why problem-solving remains so difficult for students (Gabel, Sherwood, & Enochs, 1984; Lee, 1985). The question is how to structure a potential Web-based learning environment to overcome the obstacles reported above. We believe that there is a need to revisit theories of problem-solving to offer a more feasible and effective pathway to promote undergraduate students' chemistry problem-solving.

Researchers have proposed a number of problem-solving models over the last three decades. Garrison (1991) decomposed the process as problem identification, problem description, problem exploration, applicability, and integration. Other researchers divided the problem-solving process into four steps, which are problem representation, searching for solutions, and implementing solutions (Bransford, 1994;

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Jonassen, 1997; Newell & Simon, 1972). When problem solvers are faced with a problem, they attempt to represent it in terms of their understanding of the givens and the underlying structure of the problem (Voss, Wolfe, Lawrence, & Engle, 1991). In short, it is necessary to extract the given and goal information, search through the mental problem space which accesses prior domain knowledge and connects it to existing knowledge, and implement the hypothesis-generating and solution-finding processes required to act on the problem. During the construction of a problem representation, certain features of the problem may activate knowledge in memory (Kintsch & Greeno, 1985). A schema for that particular type of problem may then be activated. The schema is a cluster of knowledge related to a problem type. It contains information about the typical problem goal, constraints, and solution procedures useful for that type of problem (Gick & Holyoak, 1983). Gick (1986) pointed out that problem-solving strategies are schema driven. If the problem solvers recognize the problem type that they have represented, they can more easily apply the solution that is associated with the problem space. All of these aforementioned studies of problem-solving serve as the basis for developing our problem-solving learning materials.

Dochy, Segers, Van den Bossche, and Gijbels (2003) proposed that problem-based learning is an instructional student-centered approach in which they learn by analyzing and solving representative problems. Problem-solving involves a mental process in which the student needs both analytical and creative skills, so designing a Web-based learning environment that facilitates the construction of knowledge, and the success of problem-solving has become challenging for researchers. Chen (2010) indicated that a combination of integration and procedure prompts in the context of Web-based learning environment has a great benefit to students' knowledge acquisition and their problem representation for ill-structured problems. On the other hand, one of the studies reported that providing hints to students during, instead of after, the problem-solving process, is most effective at improving their strategic knowledge (Pol, Harskamp, Suhre, & Goedhart, 2009). Cripper and Earl (2007) gave the combination of a Web-based worked example with a self-explanation prompt that produces an improvement in their factual and conceptual knowledge, and a well-structured problem-solving performance. Current studies about Web-based problem-solving learning have paid much attention to how to effectively scaffold students' problem-solving in that environment (Gok, 2010; Kim & Hannafin, 2011; Yang, Tzuo, & Komara, 2011). These Web-based problem-solving studies with different scaffolds succeeded in dimensions such as problem representation, strategic knowledge, factual and conceptual knowledge. Those Web-based problem-solving learning environments often employ medical science, physics, management, and mathematics as learning content (Beal, Arroyo, Cohen, & Woolf, 2010; Demetriadis, Papadopoulos, Stamelos, & Fischer, 2008; Hwang, Chen, & Hsu, 2006; Maloy, Edwards, & Anderson, 2010; Singh & Haileselassie, 2010); however, there is a lack of study in the field of undergraduate chemistry. Therefore, this study specifically designed the undergraduate Web-based chemistry problem-solving program to take these studies into consideration and with the intention to facilitate undergraduate students' chemistry problem-solving ability.

To guide learners in solving complex problems, appropriate instructional support should be provided for, and integrated into, the learning environment (Van Merriënboer, Kirschner, & Kester, 2003). We structured our Web-based learning environment to scaffold students' problem-solving with four major components: *identify known conceptions* (search prior domain knowledge from memory), *identify proposed problem* (determine unknown information), *provide more than two possible solutions* (provide detail steps and strategies for each solution), and *evaluate their own solutions* (decide which solution is more plausible and providing explanations). One of the tasks requires students to draw the chemical structure before generating their individual solutions, which was intended to help students generate solutions easily. It has been found that expert problem solvers use strong, domain-specific strategies related to the problem types, making them more efficient (Mayer, 1992). Besides, Voss, Greene, Post, and Penner (1983) found that domain-specific knowledge best predicts performance in solving ill-structured problems. These studies demonstrated that domain-specific knowledge and strategies are critical for problem-solving. Thus, this study expects to find a similar pattern in the correlation between undergraduates' chemistry problem-solving task performance and their domain knowledge, in terms of the chemistry summative exam scores and use of existing knowledge. Searching for solutions includes the steps of recalling a previously solved problem, decomposing and simplifying the problem, brainstorming potential and possible solutions and evaluating their potential to solve the problem (Simon, 1978). Undoubtedly, these previous studies all showed that existing domain knowledge indeed plays an influential role in problem-solving; however, is it the only thing that matters? The authors believe that students' existing domain knowledge may not be enough for them to find workable solutions, particularly when the problems have not been experienced in their existing schema. We also believe that there is a need for providing students with the opportunity to search information from somewhere besides their existing domain knowledge while they are solving the problem. As the World Wide Web rapidly grows, the Internet has become a major resource for students to search for information which can assist their problem-solving. Several studies have defined the term "information problem solving" as a problem that requires people to access information from a variety of information resources, organize and synthesize information from each source, and finally produce solutions to solve the problem (Brand-Gruwel, Wopereis, & Vermetten, 2005; Moore, 1995). Therefore, we purposely designed our chemistry problem-solving tasks as a type of information problem-solving, which requires students to search either from their existing domain knowledge or from the Web to solve the problem. By constructing such information-based chemistry problem-solving tasks, we hope reach a better understanding about how Web-searching strategies employed by students interact with their use of existing knowledge while solving chemistry problems.

Web-searching skills have become fundamental for all people and have been widely studied during the last ten years. Lawless, Schrader, and Mayall (2007) found that people who have more domain knowledge spent more time browsing, viewed more multimedia resources from the Web, and demonstrated significantly better learning outcomes. Particularly when time is limited so that people must search quickly, domain knowledge might be the key that determines whether people successfully retrieve and use information from the Internet (Willoughby, Anderson, Wood, Mueller, & Ross, 2009). Höscher and Strube (2000) indicated that Web experience and domain knowledge had a combined effect on information searches. Together, these studies imply that domain knowledge has positive impacts either on on-line users' learning performance or on their Web-searching effectiveness. It would be valuable to explore the difference between high and low performance problem-solving groups' students' use of Web-searching strategies and existing knowledge across three problem-solving tasks.

While searching for information on the Web, people can easily become confused and lost because of the immense information resources and inconsistent searching outcomes. In other words, many people have difficulties in obtaining the information that they require from the Web (Large & Beheshti, 2000; Walraven, Brand-Gruwel, & Boshuizen, 2008). Many studies have specifically focused on examining different strategies of Web searches that people use. In summary, the Web-searching strategies that have been widely examined are: (1) Number of keywords/terms (Lin & Tsai, 2007; Willoughby et al., 2009); (2) Number of first/second/subsequent links/deviation from base pages (Lawless et al., 2007; Willoughby et al., 2009); (3) Number of relevant/irrelevant sites (Willoughby et al., 2009); (4) Refinement of keywords (Lin &

Tsai, 2007; Tu, Shih, & Tsai, 2008); (5) Revisiting Webpages (Lin & Tsai, 2007); and (6) Number of pages visited (Lawless et al., 2007; Tu et al., 2008). Most Web-searching studies have looked at how learners use Web-searching strategies to help them in solving the tasks of open-ended questions, close-ended questions or essay questions. None of the studies have focused on examining how Web-searching behaviors impact ill-structured chemistry problem-solving, and no study attempts to investigate how learners' existing domain knowledge influences their ill-structured chemistry problem-solving performance in a Web-based learning environment. Therefore, we feel the need to explore the Web-searching strategies and domain existing knowledge that learners would use for solving chemistry problems. Investigating the interplay of task performance, domain knowledge and Web-searching strategies might offer us a better understanding of how students solve ill-structured chemistry problems in a Web-based learning environment.

These earlier Web-searching strategies serve as our basis for studying Web-searching strategies. Three strategies of total pages viewed, keyword search, and modification were chosen from studies reported above. The strategies of task-relevant keywords, information filtration and reconfirmation have not been looked into by previous studies; however, these three Web-searching strategies were largely used by the undergraduate students while they were solving three chemistry problem-solving tasks. Thus, we added them into our coding system as well. Task-relevant keyword means keywords that are relevant to the task and which the participant uses for the information search. Information filtration means that the participant chooses to click to further search for task-relevant information. Reconfirmation means the participant searches information on the Web to confirm previously entered answers. Finally, we included a total of six Web-searching strategies in this study – *total pages viewed*, *keyword search*, *task-relevant keyword*, *information filtration*, *modification* and *reconfirmation*. Strategies of total pages viewed, keyword search, task-relevant keywords, and information filtration were classified as cognitive strategies, as these strategies are usually used to help students solve problems. Strategies of modification and reconfirmation which require students to evaluate and judge the accuracy between what they already know and what they get from the Web were classified as metacognitive strategies, as they are often used to ensure that problem-solving has been reached. Hence, metacognitive strategies generally precede or follow the cognitive ones (Livingston, 2003). In addition, we also measured the frequency of students' use of their existing knowledge while solving the chemistry problem tasks. It would be valuable to investigate how students' chemistry problem-solving performances interact with their existing knowledge and Web-searching strategies.

2. Research questions

This study explored the effect of Web-based Chemistry Problem-solving on undergraduate students' problem-solving task performance; and further examined the nature and extent of Web-searching strategies students used and their correlation with task performance and domain knowledge. Therefore, the following five research questions were examined. The first research question examines the progression of undergraduate students' chemistry problem-solving task performance across three problem-solving tasks, and the progression in task performance between students with high and low levels of domain knowledge across three tasks. The second question examines the nature and extent of Web-searching strategies and Websites/searching engines employed by students across three tasks. The third question examines the nature and extent of Web-searching strategies and existing knowledge which were used, across three problem-solving tasks, by groups with both high and low problem-solving performance. The fourth question examines the correlations between task performance, their chemistry domain knowledge, and their use of existing knowledge. The fifth question examines the correlations between task performance, use of existing knowledge, and Web-searching strategies across three tasks. Finally, we examined whether or not students' use of existing knowledge and Web-searching strategies would predict their chemistry problem-solving performance across three tasks.

3. Methods

3.1. Web-based chemistry problem-solving (WBCPS)

The Web-based problem-solving learning content was designed to promote undergraduate students' ability in solving chemistry problems. Two chemistry professors, one science education professor, and one science education post-doctorate student worked together to develop three problem-solving tasks. The three problem-solving tasks were specifically modified from the textbook of Chemical principles: The Quest for Insight (Atkins & Jones, 2007) to cover the concepts of liquids and solids, physical equilibrium, and organic chemistry that students learned from their freshman chemistry course in the second semester. We hoped to further develop the students' problem-solving ability after they had acquired the knowledge from their freshman chemistry courses. We structured each task into four steps to scaffold students' ability to solve the problem. The task started with identifying known conceptions – students needed to search their memories for domain knowledge which might help solve the problem (Fig. 1). We hoped to cultivate their ability to efficiently retrieve relevant information from their schema. After they identify the known conception, students must identify the proposed problem, which is to determine unknown information, collect, and organize information to facilitate problem-solving. This is to develop the competencies of decomposing unknown information, organizing relevant information and further identifying the core problem. Once they finish these two parts, students must then provide more than two possible solutions to solve the task, with proposed steps and strategies (Fig. 2). We hoped to cultivate a habit of brainstorming to generate possible solutions for the problems. Finally, students must evaluate their own solutions and decide which solution is more applicable, with explanations (Atkins & Jones, 2007). This is to develop their metacognitive ability to facilitate their problem-solving efficiency. Students were instructed to search for information from the Web, if necessary, during their problem-solving. The ability to visualize the chemical structure is critical for students to figure out its properties and develop solutions for the problem. Thus, one of the tasks required students to draw the chemical structure before they started to solve the problem (Fig. 3), to help them more efficiently find a solution.

3.2. Subjects and procedures

A total of 183 undergraduate students (40 females and 143 males) 18–19 years old, all of whom are taking the freshman chemistry course, were recruited to participate in the study to solve three chemistry tasks across a semester. Three Web-based chemistry problem-solving

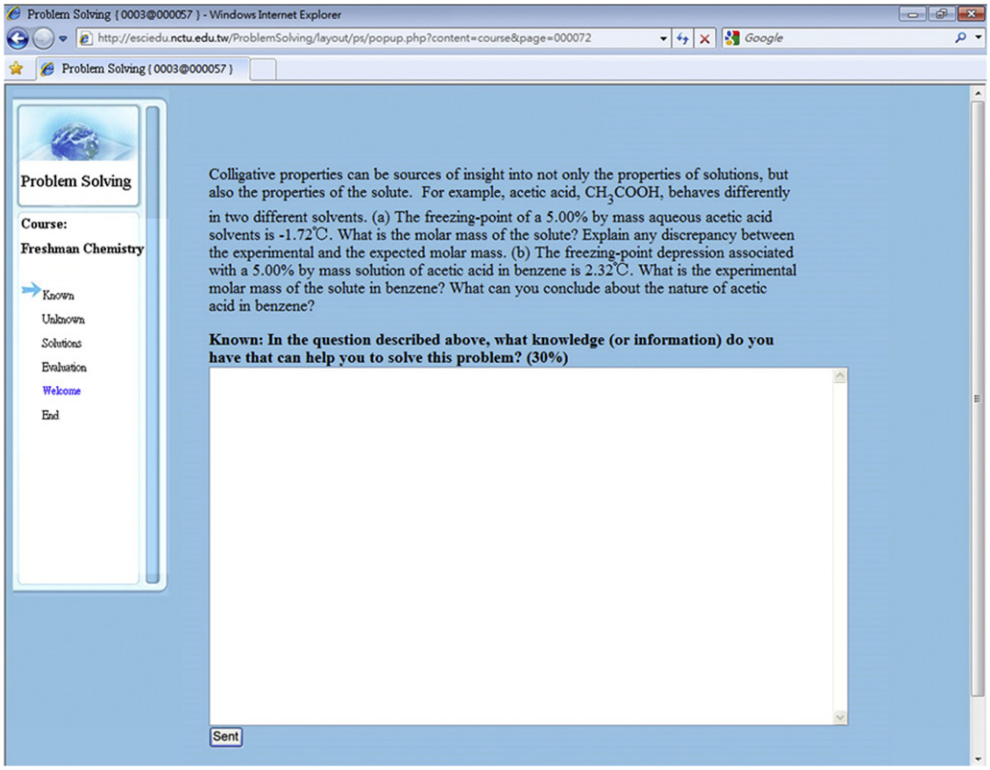

Fig. 1. Identify known conceptions of problem-solving task 1.

tasks were designed, each lasting about two hours. The three problem-solving learning tasks were allocated in the beginning of the semester, middle of the semester, and close to the end of the semester in the spring of 2008.Students' domain knowledge in chemistry was determined from their 1st semester chemistry summative exam before receiving WBCPS and 2nd semester chemistry summative exam after receiving WBCPS. The quantity and quality of the Web-based Chemistry Problem-solving, including the problem-solving process and

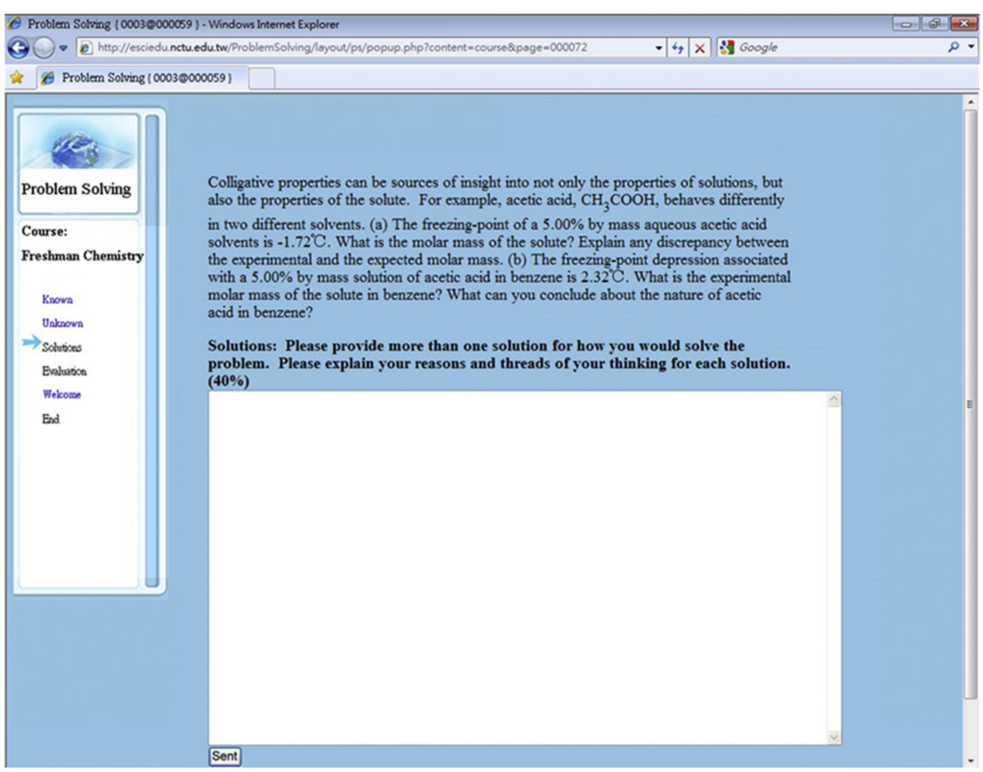

Fig. 2. Provide solutions in problem-solving task 1.

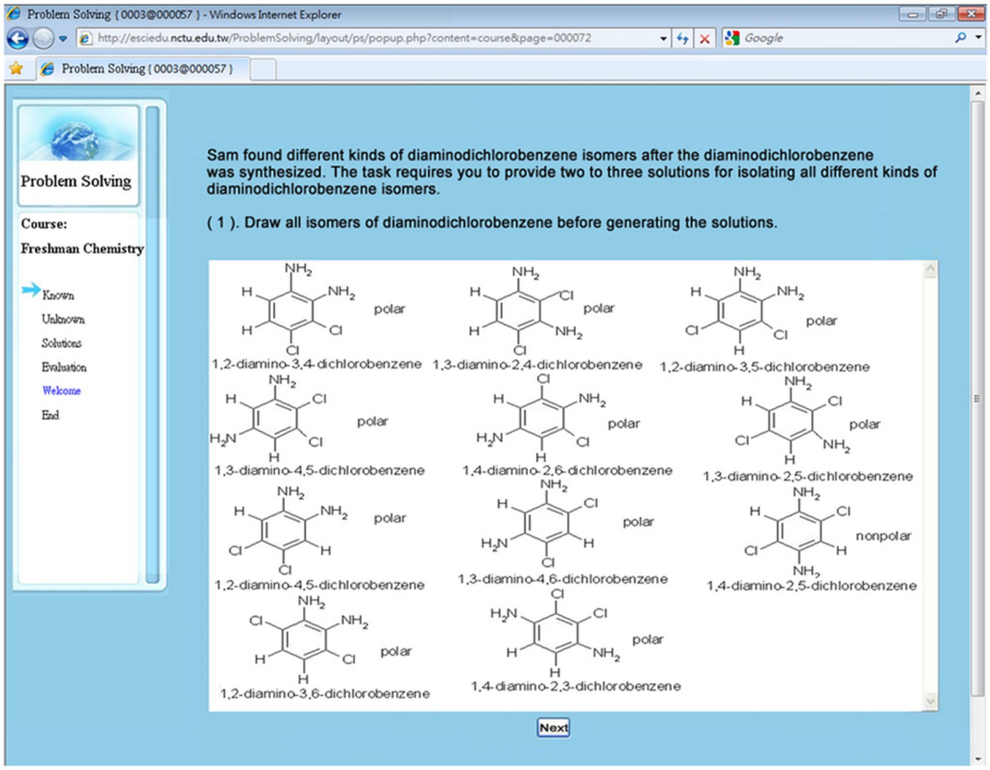

Fig. 3. Isomers of diaminodichlorobenzenes were drawn by student in the problem-solving task 2.

Web-searching process that students generated across the three tasks during the on-line problem-solving process, were collected and analyzed. Students' on-line Web-based problem-solving and Web-searching strategies were captured and recorded every five seconds as data resources in the study for us to analyze their problem-solving process, use of existing knowledge and Web-searching strategies. The search engines students used and websites they visited were recorded every five seconds.

3.3. *Scoring system of analyzing problem-solving process*

The WBCPS platform was the FreeBSD running on an Apache WWW server. The core of the WBCPS system was programmed in PHP, Perl, Java Applet, Java script, and works with MySQL to efficiently handle extremely large data sets and analytical programs. Students' problem-solving process was recorded in the database. The database successfully recorded 74, 134, and 102 students' problem-solving processes at task 1, 2 and 3 and then exported this information to an Excel file for data analysis. The students' problem-solving process was evaluated by a rubric scoring system. The rubric system evaluates their problem-solving according to the following four dimensions: identify known conceptions (search prior knowledge from memory), identify the proposed problem (determine unknown information), provide more than two possible solutions to solve the problem-solving task with proposed steps and strategies, and evaluate their own solutions and decide which solution is more plausible, providing explanations. The rubric combined both quantity and quality measures for known concepts, proposed problem, solutions and evaluations that students provided. For the quality, it addressed the correctness of the known conceptions, relevance of the proposed problem the student listed, feasibility of the solutions he/she developed, and appropriateness of the student's evaluation. For instance, each piece of the proposed problem was classified as relevant, partially relevant, or irrelevant, with 2, 1 or 0 points awarded. Each solution was classified as workable, partially workable, and non-workable, again with points awarded of 2, 1, or 0. Each evaluation was classified as appropriate, partially appropriate, and non-appropriate with points awarded of 2, 1, or 0. Finally, students' problem-solving performance for each task was achieved by adding the scores of the four dimensions together.

3.4. *Coding system of analyzing existing knowledge and Web-searching strategies*

Screen-capture software recorded participants' on-screen Web-searching activities every five seconds, and saved this information as raw data. 74, 134, and 102 students' Web-searching activities at task 1, 2, and 3 were successfully captured and recorded as an image file for data analysis. These raw data files were then transcribed and formatted according to the nature of events (typing in a keyword for which to search; clicking on a link; entering answers into the text box on the Web; etc.) for further analysis. The researchers developed a coding system by repeatedly viewing the transcripts and by reviewing existing literature on examining the use of existing chemistry knowledge and Web-searching strategies during problem-solving. These definitions of these strategies are as follows:

Access prior chemistry knowledge

1. Existing knowledge: The correct information that participant enters into the text box based on their prior chemistry knowledge without searching the Web would be coded. Each of the correct concepts they entered was scored as 1 point and incorrect ones were scored as 0 points. A total score of existing knowledge was scored for each task.

Web-searching strategies

1. Total pages viewed: Each chemistry-related Web page that the participant searched for while resolving the task was coded as 1 point and a total score of total pages viewed was scored for each task. The less prior knowledge the participant has, the more Webpages he/she might view to perform the task, and the higher score of total pages viewed he/she might receive. For example, searching for http://en.wikipedia.org/wiki/Colligative_properties for information regarding colligative properties was coded 1 point.
2. Keyword search: Each chemistry-related keyword that the participant searched for while resolving the task was coded as 1 point, and a total score of keyword search was scored for each task. The less prior knowledge the participant has, the more keywords he/she might use to search for while completing the task, and the higher score of keyword search he/she might receive. For example, the participant might use “periodic table of the chemical elements” as the keyword to search information in task 1 – this was coded as 1 point.
3. Task-relevant keyword: Each task-relevant keyword that the participant used for information search was coded as 1 point, and a total score of task-relevant keywords was scored for each task. The more task-relevant keywords the participant uses, the better he/she might perform the task, and the higher task-relevant keyword score he/she might receive. For example, using the keyword “colligative properties” to search information in task 1 was coded as 1 point.
4. Information filtration: Each chemistry-related link that the participant chose to click for further searching task-relevant information was coded as 1 point, and a total score of information filtration was scored for each task. The fewer links the participant chooses to click on, the better his/her ability to filter information, and the lower information filtration score he/she might receive.
5. Modification: Each time the participant modified the inputted information after searching for chemistry-related information on the Web was coded as 1 point, and a total score of modification was scored for each task. The more modifications the participant makes, the better he/she might perform the task, and the higher modification score he/she might receive.
6. Reconfirmation: Each time the participant searched chemistry-related information on the Web to confirm previously entered answers was coded as 1 point, and a total score of reconfirmation was scored for each task. The more reconfirmation the participant makes, the better he/she might perform the task, and the higher reconfirmation score he/she might receive.

Participant received a score for each Web-searching strategy from adding up the points they received from each strategies in each problem-solving task. The Web-searching strategies were further divided into two categories, cognitive and metacognitive. Strategies of *total pages viewed*, *keyword search*, *task-relevant keyword*, and *information filtration* were classified as cognitive strategies. The strategies of *reconfirmation* and *modification* were classified as metacognitive strategies which require students to evaluate and judge the accuracy between what they already know and what they get from the Web (Table 1).

Twenty percent of the transcripts were analyzed and coded by two researchers to obtain inter-rater reliability. The percentage of agreements between the two researchers was 89% and disagreements were resolved by discussion. After this, to investigate participants’ use of existing domain knowledge and Web-searching strategies, one of the researchers coded the remaining transcripts based on our coding system.

Table 1
Coding system of analyzing domain knowledge and Web-searching strategies: Indicators, definitions, and representations.

Categories	Indicators	Definitions	Representations
Domain knowledge	Existing knowledge	The correct information that the participant enters into the text box based on their prior chemistry knowledge without searching the Web	Representing the participant’s prior knowledge that is used to complete a task. It is supposed that the more prior knowledge a participant uses, the less Web-searching behaviors he/she performs.
Cognitive strategies	Total pages viewed	Each chemistry-related Webpages participant adopts for resolving the task.	Representing the variation of information sources the participant needs for resolving a task. It is supposed that participants with less prior knowledge need to view more Webpages as information sources to perform a task.
	Keyword search	Each chemistry-related keyword the participant searches for while resolving the task.	Representing the variation of keywords the participant uses for resolving a task. It is supposed that participants with less prior knowledge have to use more keywords for information search to complete a task.
	Task-relevant keyword	Each task-relevant keyword participant uses for information search.	Representing the variation of keywords which are relevant to resolving a task the participant uses. It is supposed that the more task-relevant keywords a participant adopts, the better he/she performs a task.
	Information filtration	Each chemistry-related link that participant chooses to click for further search task-relevant information.	Representing the variation of links the participant clicks on for further search. It is supposed that the more links a participant chooses to click on, the worse his/her ability to filter information is.
Metacognitive strategies	Modification	The participant modifies the inputted information after searching chemistry-related information on the Web.	Representing an indicator the participant’s metacognition. After making an evaluation between the entered answers and the obtained information from the Web, the participant modifies the inputted answers. It is supposed that the more modification a participant performs, the better his/her task performance is.
	Reconfirmation	The participant searches chemistry-related information on the Web to confirm previous entered answers.	Representing an indicator of the participant’s metacognition. He/she confirms and evaluates if the entered answers are correct by checking information on the Web. It is supposed that the more reconfirmation a participant performs, the better his/her task performance is.

3.5. Data analysis

The descriptive statistics were conducted to show the nature and extent of Web-searching strategies and engines that students used for solving problems across three tasks. The repeated measure of ANOVA was used to measure any increase in students' problem-solving task performance from task 1 to 3. Students were categorized into high level of domain knowledge (score above 81, $N = 32$) and low level of domain knowledge (score below 68, $N = 27$) according to their first semester summative exam scores. One-factor repeated measure of ANOVA was used to measure the effect of domain knowledge levels on their tasks 1 to 3 performance.

According to participants' task performance, we selected the top thirty percent as the higher problem-solving performance group and classified the lower thirty percent as the lower problem-solving performance group according to each task. A series of independent *t*-test analyses were conducted for each task to investigate the differences in task performance of problem-solving, use of existing knowledge and Web-searching strategies between high and low problem-solving performance groups. In addition, Cohen's *d* values were calculated to indicate effect size. Pearson's correlations were further employed to examine the relationships among students' problem-solving task performance, use of existing knowledge, and Web-searching strategies by each task. Finally, we applied multiple regression analyses using stepwise selection, with variables entered at the 0.05 significance level and removed at the 0.1 significance level, to build regression models for predicting each task performance. All statistical analyses were performed with SPSS 18.0.0 for Windows.

4. Results

4.1. Task performance vs. level of domain knowledge

Repeated measures of ANOVA were used to examine any increases in students' mean scores for task 1, task 2 and task 3. The results showed an increase in mean scores for task 1, 2 and 3, reaching statistical significance ($F = 25.27$, $p = 0.000$). The post-hoc analysis suggested that the task 3 score was significantly higher than the score for task 1 ($p_{(3>1)} = 0.000$) and task 2 ($p_{(3>2)} = 0.000$). The result indicated that Web-based Chemistry Problem-solving is very effective for improving students' problem-solving performance from task 1 to task 3 across a semester.

In addition, one-factor repeated measures of ANOVA was used to examine the effects of domain knowledge levels using task 1, task 2 and task 3 problem-solving performance as the dependent variables (Table 2). We categorized students as having either a high level of domain knowledge (score above 81, $N = 32$) or a low level of domain knowledge, (score below 68, $N = 27$) according to their first semester summative exam scores. The result indicated that the levels of domain knowledge ($F = 10.48$. $p < 0.002$) reach a statistically significant effect on students' problem-solving task performance. The mean scores of problem-solving task performance increased from task 1 to task 3 and reached a statistically significant difference level ($F = 25.86$. $p < 0.000$). The interaction did not reach a statistically significant difference level ($F = 1.24$, $p < 0.30$). The post-hoc result indicated that students with a high level of domain knowledge had better task performance than did the students with a low level of domain knowledge ($p = 0.002$). This clearly shows that Web-based Chemistry Problem-solving is very effective for promoting students' problem-solving performance from task 1 to task 3 across a semester, regardless of their level of domain knowledge. Moreover, it also demonstrated that students with more domain knowledge outperformed the students with less domain knowledge.

4.2. The nature and extent of Web-searching strategies

Appendix 1 shows the descriptive statistics of Web-searching strategies that students used to solve problems across three tasks. In general, students used more Web-searching strategies in task 1 and 2 than in task 3; and they used more existing knowledge in task 3 than in task 1 and 2. Students had more total pages viewed, keyword searches and task-relevant keyword searching behavior across three tasks. Students used less modification and reconfirmation than other web-searching strategies.

In general, undergraduate students used two categories of websites and search engines: general and chemistry-specific. The general websites include Google, Yahoo, Yahoo Knowledge, Yahoo Dictionary, Wikipedia, and etc. The chemistry-specific websites include ChemBioFinder, TCI AMERICA, etc. The descriptive statistics of the websites and search engines that students visited indicated that students spent more time searching information from general websites than from chemistry-specific websites. The most frequently searched websites and search engines were Yahoo, Google, Yahoo Knowledge, Yahoo Dictionary, and Wikipedia (Appendix 2).

4.3. Use of existing knowledge and Web-searching strategies

According to participants' task performance, we selected the top 30 percent as the higher problem-solving performance group and classified the lower 30 percent as the lower problem-solving performance group by each task. Results showed that group differences in the use of existing chemistry knowledge and Web-searching strategies by independent *t*-test analysis for task 1, 2, and 3 individually (Figs. 4–6).

Table 2
One-factor repeated measure of ANOVA of web-based problem-solving task 1-3 performance according to domain knowledge level.

	F	Sig	Partial eta	Post-hoc	
				Level of domain knowledge	Task performance
Task performance	25.86***	0.000	0.480	[a]High level > [b]Low level	Task 3 > Task 1***
Level of domain knowledge	10.48**	0.002	0.155		Task 3 > Task 2***
Task performance × Level of domain knowledge	1.24	0.296	0.043		

***$p \leqq 0.000$, **$p \leqq 0.01$.
[a] High level: high level of domain knowledge.
[b] Low level: low level of domain knowledge.

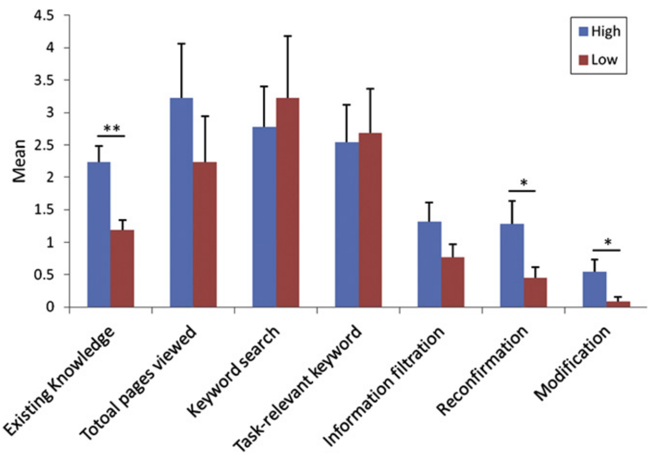

Fig. 4. Comparison means of web-searching strategies between higher and lower problem-solving performance groups in task 1 by independent t-test analysis.

In order to perform task 1, participants in the higher problem-solving performance group used more existing chemistry knowledge ($t = 3.50$, $p < 0.01$, Cohen's $d = 1.06$), reconfirmation ($t = 2.11$, $p < 0.05$, Cohen's $d = 0.64$), and modification ($t = 2.23$, $p < 0.05$, Cohen's $d = 0.68$) than did those in the lower problem-solving performance group (Fig. 4). Similarly, the higher problem-solving performance group also outperformed the lower problem-solving performance group in the use of their existing chemistry knowledge ($t = 5.02$, $p < 0.000$, Cohen's $d = 1.11$), reconfirmation ($t = 3.25$, $p < 0.01$, Cohen's $d = 0.73$), and modification ($t = 2.40$, $p < 0.05$, Cohen's $d = 0.52$) for task 2 (Fig. 5) and in using their existing chemistry knowledge ($t = 3.34$, $p < 0.01$, Cohen's $d = 0.85$) for task 3 (Fig. 6). Effect size ranged from medium to high. The results showed a consistent pattern across tasks, indicating that those who performed better on Web-based problem-solving tasks employed more existing chemistry knowledge. Moreover, they applied more metacognitive strategies such as reconfirmation and modification, which helped them to evaluate the accuracy of their existing chemistry knowledge and/or the information obtained from searching on the Web.

4.4. Correlations between students' task performance, domain knowledge and use of existing knowledge

We also examined whether there was any relationship between students' domain knowledge (first and second semester chemistry summative exam), use of existing knowledge and their problem-solving task performance across three tasks. Pearson's correlations were conducted (Table 3). It was found that task 1 was positively correlated with their first semester summative scores ($r = 0.24$, $p < 0.05$); task 2 was positively correlated with their second semester summative scores ($r = 0.22$, $p < 0.05$); and task 3 was highly correlated with their first semester summative score ($r = 0.26$, $p < 0.05$) and second semester summative scores ($r = 0.25$, $p < 0.05$). A consistent pattern of positive correlations across tasks could be found, specifically that the use of existing chemistry knowledge was significantly correlated with problem-solving performance for task 1 ($r = 0.29$, $p < 0.01$), task 2 ($r = 0.41$, $p < 0.000$), and task 3 ($r = 0.40$, $p < 0.000$) separately. This indicated that students' domain knowledge and use of existing knowledge significantly correlated with problem-solving task performance.

4.5. Correlations among students' task performance, use of existing knowledge and Web-searching strategies

Pearson's correlations among task performance, use of existing knowledge and Web-searching strategies by each task are shown in Table 4. A consistent pattern of correlations across tasks was found in the study. For all tasks, the positive correlations were found between task performance and use of existing knowledge across three tasks, but negatively correlated with keyword search at two tasks and task-relevant

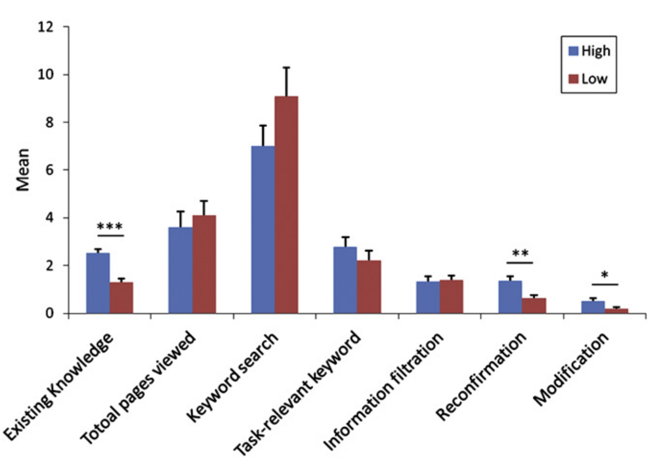

Fig. 5. Comparison means of web-searching strategies between higher and lower problem-solving performance groups in task 2 by independent t-test analysis.

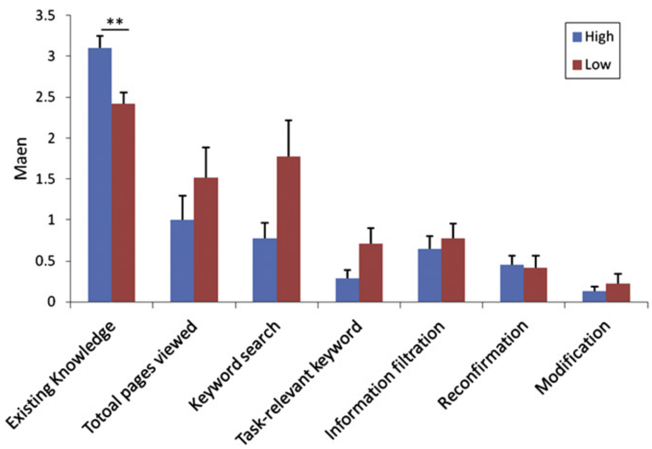

Fig. 6. Comparison means of web-searching strategies between higher and lower problem-solving performance groups in task 3 by independent *t*-test analysis.

keyword search at one task. In addition, we found positive correlations between problem-solving task performance and metacognitive Web-searching strategies (reconfirmation and modification) for task 2, and a similar pattern in Task 1, with a fairly close 0.05 significance level. Three conclusions were found: (1). The more existing knowledge they used, the less cognitive Web-searching strategies (keyword search and task-relevant keyword search) they employed for solving chemistry problems; (2). The more existing knowledge they used, the better task performance they performed; (3). The more metacognitive Web-searching strategies they employed in problem-solving, the better task performance they performed.

Across three tasks, their use of existing knowledge negatively correlated with total pages viewed ($r = -0.33$, $p < 0.01$ for task 1; $r = -0.32$, $p < 0.01$ for task 2; and $r = -0.05$for task 3), keyword search ($r = -0.39$, $p < 0.01$ for task 1; $r = -0.45$, $p < 0.01$ for task 2; and $r = -0.17$, $p < 0.05$ for task 3), task-relevant keyword ($r = -0.43$, $p < 0.01$ for task 1; $r = -0.21$, $p < 0.01$ for task 2; and $r = -0.12$ for task 3) and information filtration ($r = -0.17$ for task 1; $r = -0.25$, $p < 0.01$ for task 2; and $r = -0.08$ for task 3). According to the results, it could plausibly be assumed that the more existing chemistry knowledge students employed to complete a task, the less Web-searching strategies such as keyword search, task-relevant keyword, and information filtration they performed, as they did not have to search for much information on the Web. Hence, a pattern of negative correlations among existing chemistry knowledge and other strategies appears regardless of task.

Across three tasks, positive correlations were found among total pages viewed, keyword search, task-relevant keyword, information filtration, reconfirmation and modification. This implies that the strategies of total pages viewed, reconfirmation and modification increased as students adopted more strategies of keyword search and task-relevant keyword to perform information searches on the web for solving problems.

4.6. Stepwise multiple regression

Finally, the stepwise multiple regression method was employed to build a series of regression models for predicting problem-solving performance across three tasks, using cognitive Web-searching strategies, metacognitive Web-searching strategies, and existing knowledge as independent factors (Table 5). The results indicated that the use of existing knowledge was the only significant factor for predicting their performance at task 1 ($\beta = 0.29$, $p < 0.05$). Similar results were found for task 2, existing knowledge ($\beta = 0.41$, $p < 0.000$) being the primary factor for predicting their performance. In the regression model, the use of existing knowledge ($\beta = 0.39$, $p < 0.000$) was the most significant factor for predicting their task performance, followed by reconfirmation (metacognitive Web-searching strategy) ($\beta = 0.17$, $p < 0.018$). For the task 3 regression model, existing knowledge ($\beta = 0.40$, $p < 0.001$) was the only significant factor for predicting their problem-solving performance. In conclusion, students' use of existing knowledge was the major factor for predicting their problem-solving performance across three tasks.

5. Discussion

Our study takes a major step from previous problem-solving studies, as we incorporated problem-solving and information searching theories and pedagogy into the on-line chemistry problem-solving program. This program provided students with the opportunities to search for information on the Web in order to solve the chemistry problems, in addition to searching from their existing knowledge. Moreover, the learning content was specifically structured and decomposed into four components in order to scaffold the students' problem-solving process. The results of this study are quite encouraging as they demonstrate that undergraduate students' chemistry

Table 3
Pearson's correlations among students' domain knowledge and task performance.

	1st semester summative	2nd semester summative	Use of existing knowledge
Task 1	0.240*	0.205	0.23*
Task 2	0.180	0.217*	0.33**
Task 3	0.260*	0.244*	0.32*

**$p \leqq 0.01$, *$p \leqq 0.05$.

Table 4
Pearson correlations among students' domain knowledge and web-searching strategies.

		Existing knowledge	Total pages viewed	Keyword search	Task-relevant keyword	Information filtration	Reconfirmation	Modification
Problem – solving task performance	Task 1	0.29**	0.07	−0.05	0.02	0.11	0.17	0.19
	Task 2	0.41***	−0.08	−0.18*	0.06	−0.08	0.22**	0.20*
	Task 3	0.40***	−0.07	−0.19*	−0.18*	−0.06	−0.00	−0.12
Existing knowledge	Task 1		−0.33***	−0.39***	−0.43***	−0.17	−0.01	−0.07
	Task 2		−0.32***	−0.45***	−0.21***	−0.25**	0.09	0.09
	Task 3		−0.05	−0.17*	−0.12	−0.08	−0.02	−0.02
Total pages viewed	Task 1			0.79***	0.78***	0.81***	0.60***	0.42***
	Task 2			0.63***	0.47***	0.76***	0.41***	0.31***
	Task 3			0.87***	0.80***	0.89***	0.75***	0.43***
Keyword search	Task 1				0.95***	0.54***	0.50***	0.33**
	Task 2				0.59***	0.38***	0.36***	0.23**
	Task 3				0.82***	0.75***	0.72***	0.47***
Task-relevant keyword	Task 1					0.52***	0.49***	0.28*
	Task 2					0.31***	0.36***	0.28**
	Task 3					0.67***	0.73***	0.52***
Information filtration	Task 1						0.56***	0.42***
	Task 2						0.33***	0.29**
	Task 3						0.73***	0.42***
Reconfirmation	Task 1							0.64***
	Task 2							0.59***
	Task 3							0.68***

***$p \leqq 0.000$, **$p \leqq 0.01$, *$p \leqq 0.05$.

problem-solving performance was indeed facilitated by the on-line chemistry problem-solving content across a semester, regardless of their level of domain knowledge. This supports an earlier study showing that using a Web-based learning context can facilitate problem-solving instruction (Thompson, et al., 2003). Our study adds new evidence that Web-based Chemistry Problem-solving with the support of Web-searching indeed enhances students' chemistry problem-solving task performance. This supports Hwang and Kuo's study (2011) which showed that training on information summarization significantly improved their use of keywords, ability to select information sources, ability to extract important content and problem-solving ability. Moreover, it also supports earlier studies showing that on-line problem-solving with a well-developed theory and well-constructed scaffolds would foster students problem-solving efficiently within a very short period of 2–6 h or even with one problem-solving task (Yu, She, & Lee, 2010; Chen, 2010; Chen & Bradshaw, 2007; Pol et al., 2009), respectively. Our tasks lasted for two hours each and provided students with recurrent opportunities for three tasks across a semester, which again supports earlier studies showing that problem-solving can be efficient if the design is based on a well-developed theory and with well-constructed scaffolds.

Our study made another significant contribution in exploring the relationships among Web-searching strategies, problem-solving performance and the use of existing knowledge in chemistry problem-solving. Several major accomplishments were achieved in this study. First, students' problem-solving task performance was highly correlated with their domain knowledge (chemistry academic achievement scores) across three tasks. The frequency of their use of existing knowledge also highly correlated with their task performance across three tasks. In addition, students with more domain knowledge outperformed the students with less domain knowledge. All of these results clearly support Voss et al.'s (1983) report that domain-specific knowledge best predicts performance in solving ill-structured problems. Moreover, our results show that even when the tasks are presented as Web-based, domain knowledge can still be used for predicting ill-structured problem-solving performance.

Second, we found that students tended to use greater existing knowledge at task 3 as compared to task 1 and 2, regardless of the performance group they were in. As we closely examined the tasks, we found that a lower frequency of existing knowledge was used to solve task 2 only because it deals with diaminodichlorobenzene(s) isomers separation, with which students are not familiar. For task 1, students are familiar with acetic acid and benzene solution and the conception of molar mass; however, they are not familiar with colligative properties and the method of achieving the correct molar mass by requiring a decrease of the frozen point to the specific temperature of

Table 5
Stepwise multiple regression models for predicting problem-solving performance.

Variable	*B*	*SE B*	*β*	*Sign.*	*R*	R^2
Problem-solving task 1						
(Constant)	2.79	0.89		0.002		
Existing knowledge	1.03	0.40	0.29*	0.013	0.29	0.08
Problem-solving task 2						
Model 1						
(Constant)	8.09	0.82		0.000		
Existing knowledge	1.84	0.35	0.41***	0.000	0.41	0.17
Model 2						
(Constant)	7.30	0.88		0.001		
Existing knowledge	1.77	0.35	0.39***	0.000		
Reconfirmation	1.08	0.45	0.17*	0.018	0.45	0.20
Problem-solving task 3						
(Constant)	2.66	1.19		0.027		
Existing knowledge	1.86	0.43	0.40***	0.001	0.40	0.16

***$p \leqq 0.000$, *$p \leqq 0.05$.

benzene solution with acetic acid solutes. Therefore, the greater frequency of Web-searching strategies used were observed in task 1 for their unfamiliar part. For task 3, students have more relevant existing knowledge regarding analysis of the unknown compounds and ways of getting the structure of the compounds, thus the frequency of using existing knowledge was quite high. This pattern is consistent with the correlations of task performance with existing knowledge which show that existing knowledge highly correlated with task performance across three tasks. This clearly indicates that students are very flexible when deciding when to search for information from either existing knowledge or the Web.

Third, we found that students with higher problem-solving task performance tended to use their existing knowledge to solve problems more frequently than did lower task performance students across three tasks. This reached a statistically significant difference level. The results were very consistent across three tasks and it aligns well with earlier studies, demonstrating that problem-solving strategies used by experienced problem solvers are domain-specific; nevertheless, those employed by novice problem solvers tend to be domain-independent (Ernst & Newell, 1969; Mayer, 1992). However, in these previous studies, general problem-solving tasks were presented; they did not provide students with opportunities to search information on the Web. Our study further shows that students with significant problem-solving task performance rely on their domain-specific knowledge to solve problems as well, even when the Web is provided as an information resource.

Fourth, in addition to existing chemistry knowledge, problem solvers with high problem-solving task performance employed significantly greater Web-searching metacognitive strategies of reconfirmation and modification in order to facilitate their problem-solving than lower problem-solving task performance students for task 1 and 2. Our interpretation is that for expert problem solvers, information on the Web is not only a source of information they can access and simply “copy and paste”. Instead, they use it like references which they can use to verify their existing chemistry knowledge and/or to double check the validity of information they obtained; therefore, they performed more high level cognition during the process of problem-solving when they had opportunities to access information from the Web. Our study supports that metacognitive monitoring was significantly correlated with problem-solving performance (Rozencwajg, 2003). Mayer (1998) mentioned that three components, domain-specific knowledge, metacognitive skills, and motivational skills, are required to achieve successful problem-solving.

Fifth, the correlations results revealed that there were negative correlations between existing chemistry knowledge and Web-searching strategies (e.g. total pages viewed, keyword search, task-relevant keyword search, and information filtration), and the results were also consistent across three problem-solving tasks. On the basis of the previous findings in the study, we reasonably assume that while solving a problem, students tend to use their existing domain knowledge first if they already have similar experiences. And if their domain knowledge is not enough for solving the problem, they then do some information searching on the Web and try to obtain useful information from the Web. It clearly implied that the less existing knowledge students hold, the more Web-searching strategies they used for solving chemistry problems.

Sixth, the regression findings showed that existing knowledge was the best variable for predicting Web-based problem-solving task performance. We focused on investigating the interplay among problem-solving, domain knowledge, and Web-searching strategies and have shown the importance of existing domain knowledge in the Web-based problem-solving process. Previous studies mainly focused on how factors affect students’ basic Web navigation and Web-based learning outcomes; however, our findings have revealed that students tend to rely on more existing chemistry knowledge for the task if they have better prior knowledge. While being asked to solve problems which are ill-structured and given the opportunity to research information from the Web, students actually are very flexible and show incredible intelligence in deciding when to search for information from either their existing knowledge or from the Web. While creating a Web-based learning content with information-based problem-solving tasks, designers and researchers might take this into consideration.

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Appendix. Supplementary material

Supplementary material related to this article can be found on-line at doi:10.1016/j.compedu.2012.02.005.

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