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The effects of Web-based/non-Web-based problem-solving instruction and high/low achievement on students' problem-solving ability and biology achievement

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This study investigates the effects of two factors: the mode of problem-solving instruction (i.e. Web-based versus non-Web-based) and the level of academic achievement (i.e. high achievers versus low achievers) on students' problem-solving ability and biology achievement. A quasi-experimental design was used, in which the experimental group received six weeks of Web-based problem-solving instruction in biology and the control group received non-Web-based problem-solving instruction for the same content and for the same period of time. Pre-, post- and retention tests of problem-solving and biology achievement were administered before and at two different time intervals after the instruction. With the pretest scores as a covariate, the results of MANCOVA followed by protected univariate *F* tests suggest that Web-based problem-solving instruction has the potential to enhance and sustain the learner's problem-solving skills over an extended period of time.

Keywords: Web-based learning; problem solving; middle school biology

Introduction

Promoting students' problem-solving ability has been a prevalent objective in the science education community (Blosser, 1988; Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000). For instance, in the USA, the Benchmark of Science Literacy states that 'preparing students to become effective problem solvers alone and in concert with others, is a major purpose of schooling' (American Association for the Advancement of Science, 1993, p. 282). In addition to problem solving being an educational goal, Watts (1994) suggested that problem solving should be a core skill in the curriculum because incorporating problem solving into the curriculum helps motivate learning, provide enjoyment, stimulate interest and foster creativity.

Problems, by their nature and solution strategies, can be divided into two major categories: well-structured problems and ill-structured problems. Jonassen (1997) defined well-structured problems as 'constrained problems with convergent solutions that engage the application of a limited number of rules and principles within well-defined parameters' (p. 65). Most problems solved in regular science and mathematics classrooms fall into the category of well-structured problems. Ill-structured problems, according to Jonassen (1997), 'possess multiple solution paths, fewer parameters

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which are less manipulable, and contain uncertainty about which concepts, rules, and principles are necessary for the solution or how they are organized and which solution is best' (p. 65). Decision-making in everyday contexts usually involves solving ill-structured problems.

Although solving well-structured problems and solving ill-structured problems share some similar cognition steps, the latter requires more cognitive and metacognitive skills than the former (Shin, Jonassen, & McGee, 2003). Jonassen (1997) elaborated seven steps for the process of solving ill-structured problems: (1) articulating the problem space and contextual constraints; (2) identifying and clarifying alternative opinions, positions, and perspectives; (3) generating possible problem solutions; (4) assessing the viability of alternative solutions by constructing arguments and articulating personal beliefs; (5) monitoring the problem space and solution options; (6) implementing and monitoring the solution; and (7) adapting the solution.

In comparison with solving well-structured problems, teaching students to solve ill-structured problems has long been neglected in formal science education (Shin et al., 2003). In addition, most research on problem-solving instruction focuses on instructional strategies that promote students' skills in solving well-structured problems (Huffman, 1997; Lyle & Robinson, 2001). The so-called problem-based learning (PBL), which while emphasising learning through authentic problems, is mainly offered in tertiary education (Bowdish, Chauvin, Kreisman, & Britt, 2003; Dochy, Segers, den Bossche, & Gijbels, 2003). Students at the tertiary level of education have already gained a certain amount of academic expertise; therefore a major purpose of PBL is to provide authentic situations for the learners to integrate and apply the knowledge they mastered in different courses.

The researchers of this study argue that PBL is not an appropriate approach for most students at the middle school level. Two major reasons account for this argument. First, middle school students typically lack enough knowledge and skills, making it difficult to design an authentic problem which meets the zone of proximal development of the students. Second, most middle school students have not yet learned the 'intellectual strategies' needed to solve authentic problems. By 'intellectual strategies' we mean those intellectual activities involved in the seven ill-structured problem-solving steps suggested by Jonassen (1997). Accordingly, the authors suggest that ill-structured problem-solving instruction, which stresses problem-solving steps, is more appropriate for pre-college students.

Elementary and middle school students of Taiwan have been performing very well in international comparisons of academic achievement for mathematics and science. However, in the results of the 1992 International Assessment of Educational Progress (IAEP), Yang (1992) pointed out that, although Taiwanese students demonstrated fairly high scores at the knowledge level, they had relatively low scores for problem solving. Enhancing students' problem-solving ability is an urgent goal shared among science education practitioners in Taiwan. The authors believe that coaching students the steps for solving ill-structured problems shall be a good start to achieving the goal.

The World Wide Web has several unique characteristics that lead many educational researchers and practitioners to regard it as a potential tool for improving teaching and learning. For instance, the World Wide Web provides a media-rich environment for teachers and learners to access vast resources, and it supports synchronous and asynchronous communication which overcomes time and spacial constraints of learning (Tiene & Ingram, 2001). Haury and Milbourne (1999) surveyed ways of incorporating Web-based contexts for learning science which resulted in eight major areas: (1) facilitating productive interactions; (2) finding new sources of information; (3) seeking assistance; (4) staying informed; (5) extending classroom activities; (6) doing research; (7) getting involved in projects; and (8) enriching personal experience. In addition, many studies have demonstrated that Web-based learning increases learners' interest and intrinsic motivation for learning (Seng & Mohamad, 2002; Wang & Yang, 2002) as well as facilitates co-operative or collaborative learning (Jung, Choi, Lim, & Leem, 2002; Uribe, Klein, & Sullivan, 2003).

Although Web-based learning has been applied in various domains to achieve diverse learning outcomes (McLoughlin & Luca, 2002; Slotta, 2002), there is relatively little research on using Web-based learning contexts to facilitate problem-solving instruction (Thompson, Martin, Lynne, & Branson, 2003). Examining the characteristics of problem-solving instruction and the features of Web-based learning, we believe it is valuable to connect these two in real classroom practice. The combination of these two is due to four considerations. First, this conforms to Taiwan's national educational objectives proclaimed in the Guidelines for a 9-Year Joint Curricula Plan for Elementary and Junior High Schools. Second, the vast resources on the Web enable the students to search instantaneously for the information they need to solve the problems. In addition, the teacher can monitor the websites the students browse; therefore, the possibility of students surfing inappropriate or low-quality websites is highly reduced. Third, the broadcast system in the school computer lab enables the teacher to control the information appearing on the students' monitors. This allows the teacher to direct the students' problem-solving process in a step-by-step way, which is less controllable in a regular classroom. Fourth, research results indicate Web-based learning arouses learners' interest and motivation in learning; and interest and motivation are crucial factors determining learning outcomes (Lucking & Manning, 1996; Richard, 1997). Therefore, we believe it is valuable to investigate the effects and learning outcomes of incorporating problem-solving instruction with a Web-based learning environment.

Research question

This study investigates the following research questions:

(1) Do different modes of problem-solving instruction (i.e. Web-based versus non-Web-based) affect students' learning outcome in biology class?
(2) Do different modes of problem-solving instruction (i.e. Web-based versus non-Web-based) affect students' problem-solving ability?
(3) Does the effect of instructional modes on problem-solving ability and biology achievement, respectively, differ as a function of the level of academic achievement?
(4) Is students' problem-solving ability affected by their initial level of academic achievement in biology?

Method

In this section of the paper, the study design is described as follows: the subjects, the course context and data collection.

Subject

This study adopted a quasi-experimental design. A total of 156 seventh-grade students from four average classes at a junior high school in Northern Taiwan participated in this study. While two classes (78 students) were randomly assigned to an experimental group (the Web-based group), the remaining two classes (78 students) were assigned to a control group (the non-Web-based group). The students were further classified as high academic achievers (those who received a score higher than the average on the first biology mid-term examination; $n = 104$) and low academic achievers (those with a score lower than the average; $n = 52$).

Course context

The participants received six weeks of instruction on the topics of evolution, the varieties and classifications of species, and ecological conservation. All participants were taught by the same teacher to ensure that the same content was covered and to eliminate the factors other than the teaching mode (i.e. Web-based versus non-Web-based) that might interfere with the results.

The focus of the instruction for both groups was on solving ill-structured problems, and the seven steps of ill-structured problem solving suggested by Jonassen (1997) were simplified to three steps. In the first step, the teacher helped the students to construct a problem representation by guiding them to first recall and write down the knowledge they had learned that was relevant to the problem (we call this 'known concepts'). In the second step, the teacher guided the students to identify and list what knowledge or information they had not mastered but which might be essential to solving the problem (we call this 'unknown concepts'). Based on the list of unknown concepts, the students were encouraged to find the missing knowledge or information. Finally, the students were required to come up with all possible solutions according to the knowledge and information at hand (we call this 'the solutions').

The class activities and instructional sequence in each of the instructional modes are presented in Table 1. The major differences of the problem-solving sequences in the two teaching modes are as follows. First, for the experimental group, most instruction was presented on the Web, including the PowerPoint file and the problem-solving activities; whereas, for the control group, oral explanations and the textbook were the dominant ways to deliver instruction. Second, for the experimental group, the teacher controlled the class progress with the broadcast system. The students worked in groups to list and submit via the computer the known concepts, unknown concepts and solutions with a rigorous step-by-step sequence. For the control group, the students also worked in groups but they wrote down the known concepts, unknown concepts and solutions on their working sheets. Although the teacher told the students to follow the sequence, there was no restriction for the students jumping back and forth among the three sections. Third, only the experimental group surfed on the Internet to learn the 'unknown concepts' they identified during the class. Fourth, students in the experimental group were able to instantly share answers.

Data collection

Quantitative data were collected to examine students' progress in terms of two learning outcomes: (1) academic achievement in biology, and (2) problem-solving

Table 1. Sequence of class activities and major differences between two instructional modes.

Class activity	Differences: Experimental group (Web-based)	Differences: Control group (non-Web-based)
Present curricular content.	• The students viewed the PowerPoint file online and browsed the webpages designated by the teacher. Oral guidance was provided only when needed.	• The teacher introduced the content mainly by oral explanation. A text book was used.
Instruct on the process of solving ill-structured problems (only the first two weeks).	• Guide the students to identify the known concepts and unknown concepts. Search for the unknown concepts. List all possible solutions based on the information at hand.	
	• Show the process on the computer. • Search for information on the unknown concepts online.	• Show the process by oral explanation and writing on the chalkboard. • Search for information on the unknown concepts in books prepared by the teacher.
Students work in small groups to solve ill-structured problems.	• Follow a rigorous step-by-step sequence by responding to the request of the computer. • Search for the information of the unknown concepts online. • Each group submits group answers online. • Able to view each other's answers on the computer.	• Each group writes down its answers on the working sheets. • Search for the information of the unknown concepts in books brought by the students. • No restriction on the sequence of filling out the working sheets. • Not able to view the answers of other groups.
A representative of each group presents group answers to the class.	• Answers are shown on the computer.	• Oral presentation only.
Each individual student turns in his/her own answers (one week after class).	• Post the answers on the discussion board of the class website. • All students' answers can be viewed at any time.	• Hand in a copy of written answers. • Students cannot view others' answers.

ability. A pretest, post-test and retention test were administered to measure both these aspects, respectively.

In terms of examining the students' academic achievement in biology, the first mid-term examination served as the pretest. An independent *t*-test performed on the pretest scores showed no statistically significant difference between the two groups ($t = 1.135$, $p = 0.258$). Therefore, it was assumed that the control and the experimental group were at the same entry level of academic achievement.

The pretest was followed by six weeks of problem-solving instruction, which in turn was followed by a post-test. The retention test was administered two months after the six-week instruction. The second mid-term examination of biology served as the post-test and the retention test.

To evaluate problem-solving ability, a pretest which included two ill-structured problems was administered two weeks after the beginning of the instruction. The two-week delay was because the students had no experience in solving ill-structured problems. During the first two weeks of instruction, students were guided to learn the three steps for solving an ill-structured problem, i.e. recognising the known concepts, identifying the unknown concepts, and developing solutions. A post-test was administered right after the six-week instruction and a retention test was administered five months after the post-test. The post-test contained four ill-structured problems which were different from those in the pretest. In the retention test the six problems used in the pretest and the post-test were contained. An example of an ill-structured problem is shown in Appendix 1.

Students' answers were evaluated by a rubric scoring system since there were no standard answers to the problems. The rubric addressed both the quantity and quality of students' answers on the known concepts, unknown concepts, and the solutions. The quantity part concerned the number of known concepts and unknown concepts the student identified, and the number of solutions he or she provided. For the quality part, it concerned the correctness of the concepts the student listed and the feasibility of the solutions he/she came up with. The more relevant known concepts and unknown concepts the student was able to clearly state, the more points he/she got. In addition, the more practical solutions the student was able to present, the more points he/she got. Appendix 2 shows the rubric for scoring the students' answers to the 'known concepts'. Independent *t*-tests performed on the pretest scores of problem solving showed no significant difference between the control and experimental group in terms of each of the three elements and the total score (known concepts: $t = 1.101$, $p = 0.272$; unknown concepts: $t = 1.507$, $p = 0.134$; solutions: $t = 0.000$, $p = 1.00$; total score: $t = 1.097$, $p = 0.275$). This indicated that the starting ability of problem solving for the control and experimental group was statistically undifferentiated.

Results

Learning outcome of biology

Table 2 presents the mean scores and standard deviations of the post-test and retention test of the academic achievement in biology. A MANCOVA was conducted with the pretest score of biology as a covariate and the scores of post-test and retention test of biology as the dependent measures. The MANCOVA results are summarised in Table 3. As can be seen in Table 3, the covariate, which is the pretest score of biology, accounts for a significant portion of model variance, Wilk's $\Lambda = 0.658$; $F(2,150) = 38.937$; $p < 0.001$. This indicates that, although the *t*-test shows no significant difference on the pretest, it is essential in the MANCOVA model. Also as shown in Table 3, there is no significant interaction between the two factors under investigation: instructional mode and level of academic achievement. Therefore the effect of the two factors is considered separately.

Although the descriptive statistics listed in Table 2 show that the experimental group has higher mean scores than the control group on both the post-test and retention test, the MANCOVA results (Table 3) indicate that when the pretest score is considered as a covariate, the difference in the mean score of post-test and retention test is not statistically significant. This finding suggests that when problem-solving instruction is accompanied by a Web-based learning environment, students do not demonstrate better learning outcomes in biology than their counterparts who receive

Table 2. Descriptive statistics of control versus experimental groups' and high- versus low-achieving students' post- and retention academic biology test scores.

	Post-test			Retention test		
	n	Mean	SD	*n*	Mean	SD
Instructional mode						
Experimental group	78	77.0	15.9	78	70.7	17.1
Control group	78	75.7	17.2	78	69.4	18.5
Level of academic achievement						
High achievers	104	85.0	9.3	104	78.2	13.3
Low achievers	52	58.9	13.9	52	53.8	14.1

Table 3. The effects of instructional mode and level of academic achievement on students' post- and retention academic biology test scores ($n = 176$).

Source of variance	Wilk's Λ	df	Multivariate *F*
Covariate pretest scores	0.658	2	38.937***
Instructional mode	0.997	2	0.255
Level of academic achievement	0.982	2	1.386
Instructional mode × Level of academic achievement	0.998	2	0.158

***$p < 0.001$.

problem-solving instruction in a traditional text-based context. In other words, in response to the first research question, the instructional mode factor does not have a significant effect on the learning outcome in biology. No follow-up analysis was conducted since the omnibus MANCOVA showed a non-significant result.

In terms of the second factor, the level of academic achievement, Table 2 shows that high achievers consistently outperformed low achievers on all tests. In addition, the result of independent *t*-tests indicated that the differences reached statistical significance (pretest: $t = 16.272$, $p < 0.000$; post-test: $t = 12.239$, $p < 0.000$; retention test: $t = 10.547$, $p < 0.000$). While both high achievers and low achievers have lower mean scores in the retention test than in the post-test, the drop of the mean score for the low achievers (−5.1) is smaller than that of their high-achieving counterparts (−6.3). However, the MANCOVA result (Table 3) indicates that when the pretest score is considered as a covariate, the difference in the mean score of post-test and retention test is also not statistically significant.

Problem-solving ability

Table 4 presents the mean scores and standard deviations of the post-test and retention test of problem solving. As revealed in Table 4, in the post-test the control group had a higher mean score than the experimental group on 'known concepts', 'unknown concepts', and total score. However, in the retention test, which was given five months after the post-test, the experimental group outperformed the control group on all sections. In terms of the level of academic achievement, high achievers did not perform better than their low-achieving counterparts. Except for the mean score of

Table 4. Descriptive statistics of control versus experimental groups' and high- versus low-achieving students' post- and retention ill-structure problem-solving test scores (known concepts, unknown concepts, solutions and total).

	Post-test			Retention test		
	n	Mean	SD	*n*	Mean	SD
Known concepts						
Instructional mode						
Experimental group	78	1.67	0.87	78	1.74	0.73
Control group	78	1.81	0.85	78	1.60	0.64
Level of academic achievement						
High achievers	104	1.68	0.87	104	1.63	0.72
Low achievers	52	1.86	0.84	52	1.75	0.64
Unknown concepts						
Instructional mode						
Experimental group	78	1.28	0.70	78	1.27	0.53
Control group	78	1.38	0.64	78	1.17	0.43
Level of academic achievement						
High achievers	104	1.36	0.70	104	1.21	0.51
Low achievers	52	1.28	0.61	52	1.24	0.44
Solutions						
Instructional mode						
Experimental group	78	2.02	0.79	78	1.81	0.71
Control group	78	1.94	0.76	78	1.50	0.54
Level of academic achievement						
High achievers	104	1.94	0.80	104	1.62	0.65
Low achievers	52	2.05	0.72	52	1.71	0.65
Total score						
Instructional mode						
Experimental group	78	4.96	2.04	78	4.81	1.75
Control group	78	5.13	1.91	78	4.27	1.44
Level of academic achievement						
High achievers	104	4.98	2.08	104	4.46	1.67
Low achievers	52	5.18	1.75	52	4.70	1.51

'unknown concepts' in the post-test, the low achievers had higher mean scores than the high achievers on all other sections.

A MANCOVA analysis with one covariate (pretest) and two factors (i.e. instructional mode and level of academic achievement) was also performed on the two dependent measures (i.e. total score of post-test and retention test of problem solving). The MANCOVA results are tabulated in Table 5, indicating that the pretest score performed its function as a covariate. Also, no statistical significance was found in the interaction between the two factors. When the F values for two factors are examined, only the instructional mode has a significant effect, Wilk's $\Lambda = 0.929$; $F(2,150) = 5.766$; $p < 0.01$. Therefore, two univariate F tests on the instructional mode were further conducted. No follow-up test was performed for the level of academic achievement factor.

Table 5. The effects of instructional mode and level of academic achievement on students' post- and retention ill-structure problem-solving test scores (total, known concepts and solutions) ($n = 176$).

Source of variance	Wilk's Λ	df	Multivariate *F*
Total scores for problem solving			
Covariate pretest scores	0.616	2	46.660***
Instructional mode	0.929	2	5.766**
Level of academic achievement	0.996	2	0.320
Instructional mode × Level of academic achievement	0.997	2	0.198
Known concepts			
Covariate pretest scores	0.720	2	29.103***
Instructional mode	0.948	2	4.147*
Level of academic achievement	0.995	2	0.371
Instructional mode × Level of academic achievement	0.991	2	0.673
Solutions			
Covariate pretest scores	0.851	2	13.085***
Instructional mode	0.939	2	4.886**
Level of academic achievement	0.998	2	0.176
Instructional mode × Level of academic achievement	0.998	2	0.152

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

The purpose of the univariate *F* tests was to see the effect of the instructional mode, respectively, on the post-test and the retention test. The pretest score also served as a covariate in the univariate *F* tests (ANCOVA). The instructional mode showed a significant effect only on the retention test, $F(1,153) = 9.977$; $p < 0.01$. This finding reveals that problem-solving instruction together with a Web-based learning context has a positive effect on learners' ability to solve ill-structured problems. Although this positive effect is not immediate (no significant effect was found on the post-test), it is sustained over a longer period of time.

The same MANCOVA procedure was performed on each of the three subsections of problem-solving test: known concepts, unknown concepts, and solutions. Similar results were obtained in the 'known concepts' and 'solutions': only instructional mode showed a significant effect on the retention test (Table 5).

Follow-up univariate *F* tests with the pretest scores as a covariate showed that there was only a significant effect on the retention test (known concepts: $F(1,153) = 4.232$; $p < 0.05$; the solutions: $F(1,153) = 10.376$; $p < 0.01$). No significant effect was found in the post-test.

Discussions and conclusions

Our first research question was whether the modes of problem-solving instruction have any effect on students' learning outcome in biology. According to the MANCOVA result, the students in the experimental group did not perform better than their control group counterparts on academic achievement in biology. Two factors may account for this. First, both modes were taught by the same teacher. The teacher tried to convey the academic content fully and equally in both teaching modes; therefore, learning mainly by viewing information on the computer and learning mostly by listening to lectures would have similar results. Second, since Taiwan has a very competitive educational system, students have developed techniques to cope with academic examinations. In addition to attending biology class in school, many students have private tutors or go to cram school after class. As a result, the effectiveness of using the second mid-term examination as the post-test and retention test might be obscured by the effects of this extramural schooling.

The second research question asks whether the instructional modes affect the students' problem-solving ability. Although our data indicate no statistically significant differences in the post-test, the retention test gives a positive answer to this research question. The delayed effect is a very interesting finding, which we have not yet seen in any related literature. This lack of similar findings might be because most quasi-experimental design work does not incorporate a retention test. The authors speculate that it takes some time for a novice to internalise the steps of solving an ill-structured problem. When the post-test was undertaken, the problem-solving procedure was still new to all participants, so no significant difference was achieved. The experimental group students were required to follow rigorously three steps to solve problems, which helped them internalise the steps of solving an ill-structured problem. On the contrary, the control group students did not have to follow rigorously these three steps. As a result, the difference appeared in the retention test.

The third research question asks whether there is an interaction effect between instructional mode and students' level of academic achievement on the learning outcome of biology. The researchers had expected that the unconventional teaching mode (Web-based context) would motivate the low achievers to learn. Nevertheless, it was found that no statistically significant interaction effect exists, as the MANCOVA result indicates. In our informal observation on the experimental group, most low achievers were engaged in the website surfing activities but were less active in those activities with high reading load. However, those high reading load webpages contained more information that was directly related to the test.

The last question asks if students' problem-solving ability was affected by their initial level of academic achievement in biology. According to our data, the answer is no. However, an interesting phenomenon is that although the low achievers consistently had statistically significant lower mean scores than the high achievers on all academic tests of biology, they had higher mean scores than the high achievers in most tests of problem solving. The statistics indicated that except for the 'solutions' section in the pretest, the mean differences were not statistically significant. Although there was not enough data to account for why the low academic achievers performed better than the high academic achievers in a non-traditional test form, the authors believe the findings indicate that a non-traditional format for learning (i.e. ill-structured problem solving in this case) might provide lower achievers with a learning experience of success, which would increase the level of self-confidence in lower achievers. This requires further investigation.

In sum, this study demonstrates that when ill-structured problem-solving instruction is incorporated with a Web-based learning environment, it improves the students' ability to identify the essential information, so their use of the concepts they have learned and those they have not yet learned is improved. Students are also more capable of developing potential solutions to solve ill-structured problems. Although these improvements did not appear immediately after the instruction, they were seen in the retention test, which was five months after the instruction. As was addressed in the introduction section, abilities in problem solving and in utilising the World Wide Web are both emphasised in Taiwan's educational policy for science and technology education. We hope the results of this study can encourage more science teachers to incorporate a Web-based learning environment to enhance problem-solving instruction.

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Appendix 1. An example of an ill-structured problem

The community of biologists has changed the focus of ecological conservation from sustaining endangered species to biodiversity. The United Nations made the Convention on Biological Diversity in 1992. Since then, more than 100 countries have participated. Conservation of biological diversity is an obligation of each individual global villager, regardless of his and her ethnicity, age, and gender. As a junior high school student, what can you do to contribute to the conservation of biodiversity? Please write down your answer according to the following format.

(1) The concepts concerning this problem you have learned.
(2) Additional information you need to know about this question.
(3) Your strategies of solving this problem.

Appendix 2. Rubric scoring system for 'known concepts'

Score	Criteria
5	More than two major and more than one minor known concepts are provided. The concepts have to be clear, accurate, and related to the problem.
4	Two major known concepts are provided. The concepts have to be clear, accurate, and related to the problem.
3	More than one major and more than one minor known concepts are provided. The concepts have to be clear, accurate, and related to the problem.
2	One major or two minor known concepts is/are provided. The concept(s) might be partially incorrect or blurred.
1	The concepts provided are incorrect or not related to the problem. Or no concept is provided.