



Published online: 2-13-2010

A Cognitive Support System to Scaffold Students' Problem-based Learning in a Web-based Learning Environment

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IJPBL is Published in Open Access Format through the Generous Support of the [Teaching Academy at Purdue University](#), the [School of Education at Indiana University](#), and the [Educational Technology program at the University of South Carolina](#).

Recommended Citation

Ge, X., Planas, L. G., & Er, N. (2010). A Cognitive Support System to Scaffold Students' Problem-based Learning in a Web-based Learning Environment. *Interdisciplinary Journal of Problem-Based Learning*, 4(1).

Available at: <https://doi.org/10.7771/1541-5015.1093>

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A Cognitive Support System to Scaffold Students' Problem-based Learning in a Web-based Learning Environment

Xun Ge, Lourdes G. Planas, and Nelson Er

Abstract

An experimental study was conducted to investigate the effects of question prompts and peer review on scaffolding students' problem-based learning in a web-based cognitive support system. Ninety-six pharmacy students were randomly assigned to a treatment or control condition. The students in both conditions were asked to generate solutions to a real-world problem on clinical communication in a web-based learning environment. The results indicated that students who received question prompts significantly outperformed those who did not in each of the five problem-solving steps in both initial and revised reports. The results also showed that students in both conditions significantly improved their problem solving scores given a chance to revise their initial problem-solving reports. In addition, the study revealed a positive effect of the expert modeling mechanism in supporting students' reasoning and problem solving processes. Implications are discussed for designing web-based scaffolds to support students' problem-solving processes.

Keywords: problem-based learning, problem solving, cognitive support system, question prompts

A Cognitive Support System to Scaffold Students' Problem-based Learning in a Web-based Learning Environment

Problem-based learning (PBL) has gained attention across different disciplines in higher education as educators have become increasingly concerned with students' difficulties in developing a valid and robust knowledge base (Koschmann, Kelson, Feltovich, & Barrows, 1996). Concerns include students' difficulties in 1) reasoning; 2) applying knowledge to solve complex, ill-structured problems; and 3) transferring knowledge to new situations (Bransford, Brown, & Cocking, 2000; Greeno, Collins, & Resnick, 1996; Koschmann et al., 1996). PBL provides a way to alleviate these educational problems. However, implementing PBL presents some challenges to both learners and instructors. Often students in a PBL environment are left on their own to explore and figure out problems with minimal

guidance from instructors, which leads to less effective and efficient results. Kirschner, Sweller, and Clark (2006) argued that students benefit more deeply from guided learning than discovery learning. Nonetheless, instructors are often faced with limited human resources to provide sufficient instructional support to students during the implementation of PBL (Hmelo-Silver, 2004).

How to effectively provide guidance, efficiently facilitate the PBL process, and maximize students' learning experience in a web-based learning environment has become an acute issue for educators who are dedicated to promoting PBL. Therefore, this study examined how to facilitate a PBL experience using a web-based cognitive support system that would support PBL in an online learning environment, as well as in a classroom setting. We argue that a cognitive support system is particularly needed for distance learning programs with students on multiple campus sites, especially when universities are attempting to optimize the use of their resources during times of economic recess.

Literature Review

Problem-based Learning and Instructor's Support

PBL originated in the 1950s when medical educators began to see problems associated with teaching through a traditional lecture format. Medical students were skilled at remembering information from textbooks and passing examinations, but they often forgot what they had learned after the examinations. In other words, there was little residual knowledge that could be recalled and applied (Barrows & Tamblyn, 1980). Dissatisfied with traditional medical education, which placed too much emphasis on memorization and failed to equip students with problem-solving and critical thinking skills (Savin-Baden & Major, 2004), a student-centered and group-based PBL approach was developed. PBL used packaged problems as a stimulus to motivate students, challenge their clinical problem-solving skills, and drive them to review basic science knowledge (Barrows & Tamblyn, 1980).

However, evidence has shown that PBL presents a challenge to novice learners. When students explore complex problems in a PBL environment, the problems may generate a heavy load on students' working memory due to their lack of proper schemas to integrate new information with their prior knowledge (Kirschner et al., 2006). Given the complex nature of PBL, it is critical that instructors provide guidance to learners through each of the PBL activities while providing "direct instruction on a just-in-time basis" (Hmelo-Silver, 2004, p. 260).

PBL proponents (e.g., Barrows & Tamblyn, 1988; Hmelo-Silver, 2004) have emphasized the importance of structure and guidance to a successful PBL experience. Barrows and Tamblyn (1988) argued that PBL involved a rigorous and structured approach rather than simply presenting a problem to students. Hmelo-Silver (2004) stated that PBL was "focused,

experiential learning organized around the investigation, explanation, and resolution of meaningful problems” (p. 236). The goals of PBL were to guide learners to develop an extensive and flexible knowledge base, effective problem-solving skills, self-directed, life-long learning skills, and become effective collaborators and intrinsically motivated learners (Hmelo-Silver, 2004).

The successful guidance of PBL is largely dependent on the availability and skills of instructors who can scaffold students’ problem-solving activities with strategies such as providing hints and cues, asking questions to direct students’ attention, eliciting their causal explanations, and elaborating their thinking (Brown, Collins, & Duguid, 1989). These strategies serve as scaffolds to encourage students to reflect on their problem solving processes, which helps them to mindfully abstract knowledge for transfer. According to Vygotsky’s (1978) sociocultural theory, scaffolds are forms of support provided by a teacher, an expert, or a more capable peer within a learner’s zone of proximal development (ZPD). Scaffolding enables learners to bridge the gaps between their current abilities and the intended goals that would be unachievable with their unassisted efforts (Rosenshine & Meister, 1992).

Although instructor’s guidance and scaffolding are essential to PBL, there is a lack of sufficient instructors, especially experienced and skilled instructors, to facilitate problem-solving processes. Therefore, a lack of human resources and scaffolding becomes a barrier to implementing PBL effectively (Hmelo-Silver, 2004). Often a classroom has more students than an instructor can easily facilitate, which leads to the instructor providing only sources of information to students instead of scaffolding them through the PBL processes.

Additionally, implementing PBL in a web-based environment may present a greater challenge to students than in a classroom learning environment. Many students find it difficult to cope with the independent nature of web-based learning, particularly when they are asked to complete complex tasks and rely on their own problem solving abilities without immediate help or feedback from the instructor (Kauffman, 2004; Kauffman, Ge, Xie, & Chen, 2008). When students lack problem-solving and metacognitive skills, their cognitive load might be increased, resulting in anxiety, frustration, and even failure (Kauffman et al., 2008).

Designing Technology to Support PBL

Technology makes it possible to adapt some of the strategies that are commonly practiced and found effective in the classroom for a web-based learning environment. Thus, technology provides a possible solution to address the lack of sufficient instructor’s guidance in a PBL environment. In addition, technology can be designed to provide both cognitive and affective support to facilitate the PBL processes and promote self-reflections (e.g., ChanLin & Chan, 2007; Stewart, MacIntyre, Galea, & Steel, 2007). Some researchers (e.g.,

Lajoie & Azevedo, 2000; 2006) have proposed creating a technology-rich environment to promote active transfer of knowledge and self-monitoring through expert prompting, modeling, and feedback.

Technology should be designed to provide modeling for learners, support learners' problem-solving processes, and encourage their metacognitive awareness and self-regulatory abilities (Lajoie, 1993; Salomon, 1993a). Based on Vygotsky's (1978) sociocultural theory, social interactions are important to learners' cognitive development. According to the notion of cognitive apprenticeship (Brown et al., 1989; Collins, Brown, & Newman, 1989), while the mentor and novices engage in the same problem-solving experience, the mentor makes his or her thinking visible to novices through social dialogues and scaffolds their problem-solving activities. The literature described above provides a theoretical framework for designing technology scaffolds to support students' problem-solving processes through the following strategies: question prompting, peer reviewing, expert modeling, and reflective thinking.

Question prompts. Past research has found question prompting to be an effective instructional strategy for directing students to the most important aspects of a problem, as well as encouraging self-explanation, elaboration, planning, monitoring and self-reflection, and evaluation (Bransford & Stein, 1993; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; King, 1991, 1992; Lin & Lehman, 1999; Palincsar & Brown, 1984; Scardamalia & Bereiter, 1989). Other studies have found that prompting students with questions facilitated their ill-structured problem-solving processes (e.g., Ge & Land, 2003; Ge & Land, 2004; Ge, Chen, & Davis, 2005), particularly in problem representation, making justifications, developing solutions, and monitoring and evaluating problem solving. Furthermore, question prompts also proved to be beneficial in developing learners' metacognitive awareness and self-regulatory abilities. Students who were provided with question prompts used them as a checklist to monitor their problem solving process, to confirm if they were on the right track, and to check their courses of action (Ge & Land, 2003; Ge et al., 2005). Simons and Klein's (2007) study confirmed that scaffolds might enhance inquiry and performance, especially when students are required to access and use them.

Peer review. Peer review is an important component of the peer interaction process. The peer review process makes one's thinking visible, which allows students to learn from multiple perspectives and solutions (Ge & Land, 2003; Linn, Bell, & Hsi, 1998). Researchers have argued that a pooled knowledge base for any group is larger than one for any individual (King, 1991; 1992; Pea, 1993; Perkins, 1993, Salomon, 1993b); thus, it has been assumed that peer review leads to individuals' elaborations and problem representations that are more complete and accurate than those produced by an individual learner. Ge and Land (2003) found that students working in groups generated a wider range of factors and constraints during problem representation than students working individually, if properly guided.

Expert modeling. Modeling, coaching, and scaffolding are the major characteristics of a cognitive apprenticeship approach (Jonassen, 1999). Research on expert-novice comparison has shown that experts and novices demonstrate different patterns in problem solving (e.g., Anderson, 2000; Bereiter & Scardamalia, 1993; Bransford, Brown, & Cocking, 2000; Dreyfus & Dreyfus, 1986). Bransford and his colleagues (2000) summarized the expert-novice differences as follows: Experts notice features and meaningful patterns of problem solving that are often not noticed by novices; they organize knowledge in ways that reflect a deeper understanding of their subject matter and they have varying levels of flexibility in their approach to new situations.

In Pedersen and Liu's (2002) study, a hypermedia-based expert tool was used to scaffold sixth graders' reasoning and application of problem solving strategies. The results showed that cognitive modeling offered through the expert tool had a positive effect on the quality of the rationales the students wrote for their problem solving solutions. The expert modeling gave the students an opportunity to observe the cognitive processes of an expert and compare these with their own problem solving processes (Pedersen & Liu, 2002).

According to Piaget's (1985) cognitive development theory, the expert-novice comparisons could result in *disequilibrium*, a mental state when students have a need to *assimilate*, incorporate new events into preexisting cognitive structures, or *accommodate*, change existing structures to accommodate to new information, the new information in order to attain *equilibrium*, which is a balance between their understanding and the new environment (Piaget, 1985).

Self-reflection. While it is beneficial for learners to observe an expert's thinking and problem solving processes, it is also important to scaffold students' reflective thinking and help them to understand why the information they have learned from an expert is particularly relevant (Lin, Hmelo, Kinzer, & Secules, 1999). Lin and her colleagues (1999) stated that the ability to reflect on one's state of understanding was closely related to one's flexible thinking and problem-solving abilities. Davis and Linn (2000) argued that scaffolding students to reflect could encourage metacognition at a level students did not generally consider; thus, it engaged learners in self-monitoring and self-evaluation processes. These processes helped them to construct new understanding without direct teaching of specific strategies and to consider various perspectives and values regarding their selected solutions (Davis & Linn, 2000). Therefore, these researchers proposed design technology to support reflective thinking, including providing question prompts.

Purpose

To address the demand for providing guidance to scaffold students' PBL experience and to complement the instructor's support, we designed a web-based cognitive support

system grounded on Vygotsky's (1978) sociocultural theory and based on a critical review of the literature. The cognitive apprenticeship approach (Brown et al., 1989; Collins, Brown, & Newman, 1989) was applied to provide modeling and scaffolding for students' problem-solving processes and to develop their self-awareness and self-regulatory abilities (Lajoie, 1993). The system consisted of a suite of support mechanisms characterized by mentorship and social interactions: question prompts, peer review, expert modeling, and self-reflection, each of which is explained in the Method section.

By using the support system, we anticipated that students would receive appropriate guidance when working independently on a complex problem-solving task. We also anticipated that students would be able to record their thoughts in the system, which could be shared with peers and made available to individuals for self-reflection. Through recording students' responses in a database and retrieving them to be displayed on a screen, technology could support cognitive processes, such as memory and metacognition (Lajoie, 1993). The students' responses would also be accessible to instructors, peer groups, and raters. The purpose of this study was not to compare online versus in-person methods, but rather to test the feasibility and effectiveness of using an online support system to guide and scaffold learners' PBL processes, particularly in a web-based environment.

The purposes of this study were to investigate: a) the effect of question prompts in a web-based cognitive support system on facilitating students' problem solving performance; b) the effect of a peer review mechanism in a web-based cognitive support system measured by students' revisions of initial problem-solving reports; and c) the role of an expert modeling mechanism on students' metacognition expressed in their written self-reflections. Students' problem-solving performance was specifically measured on each of five problem-solving steps adapted from Longest's (1984) work for health professional decision-making: a) identify the problematic situation, b) define the problem, c) list and evaluate alternative solutions, d) choose, justify, and implement a plan, and e) evaluate the plan. The following research questions were generated.

1. What is the impact of question prompts on students' problem solving, as represented in their problem-solving reports?
2. What is the impact of peer review on students' problem solving, particularly when revising problem-solving reports?
3. What is the role of expert modeling? How do students respond when asked to compare their problem-solving reports to an expert's?

It was hypothesized that 1) students who receive question prompts would outperform those who do not receive question prompts in the previously mentioned five problem-solving steps, and 2) students who engage in a peer review process would outperform those who do not engage in a peer review process in revising their problem-solving reports.

Method

Design

An experimental study was designed to investigate the effects of two independent variables, the question prompts (Question 1) and peer review (Question 2) mechanisms of a cognitive support system, in scaffolding students' problem-solving processes and metacognition in a PBL environment. The problem-solving reports that students submitted, both initially and after a revision, served as the study's dependent variables. Students in the treatment condition received a list of question prompts associated with each of the five problem-solving steps (Appendix 1) while students in the control condition did not receive the question prompts; they only received the five problem-solving steps. Before submitting revised problem-solving reports, students in the treatment condition viewed their peers' and their own reports while students in the control condition viewed only their own reports. In addition, a qualitative examination of the role of an expert was conducted through collecting and analyzing students' reflections after the experimental study.

Participants and Context

The participants were 96 students (32 male; 64 female) enrolled in a Clinical Communications course in a College of Pharmacy at a major southwestern university. The students had a weekly lab associated with the course, which used the PBL approach. Prior to the study, the instructor (one of the researchers) provided the students the instructions on PBL and guided them to work in small groups to investigate a simulated pharmacy case study on clinical communication. Students were assigned to small groups in a systematic random manner; students were listed in alphabetical order by their first names and assigned to lab groups (e.g., 1-25, 1-25, etc.). As part of the lab assignments, the students were instructed to role-play a pharmacist and carry out conversations with a simulated patient according to the scenario provided by the instructor. The students had to apply different types of knowledge and skills: domain-specific knowledge on medication use, communication skills, and problem solving skills. According to the results of a pre-assessment, almost all the students had scored poorly in these skill areas.

The students were aware of the concept of PBL from previous courses, but had few opportunities to apply it in practice. Since the length of the lab was limited, practicing PBL could be a challenge to both students and the instructor, so this web-based cognitive support system was designed to facilitate the students' understanding of PBL, develop their competence and confidence in the problem-solving steps, and promote their problem solving strategies and self-regulation skills.

Materials and Support Mechanisms

The materials embedded in the cognitive support system consisted of a real-world case study, the five-step problem-solving outline for both treatment and control groups, question prompts for the treatment group only, expert modeling (i.e., the expert's problem-solving report) for both groups, and reflection prompts for both groups. The support mechanisms were characterized by question prompts, peer review, expert modeling, and self-reflection, which are explained specifically below.

As mentioned earlier, the five-step problem-solving outline was based on Longest's (1984) work for health professional decision-making. The case study and question prompts were generated by one of the researchers, who was the domain expert in pharmacy and clinical communication. Below are brief descriptions of each of the materials.

Case study. The case study involved a patient who was experiencing a medication problem related to controlling her asthma, and the students were asked to carry out the specific problem-solving steps to generate an appropriate solution that would both satisfy the patient and allow the students to adhere to professional standards of practice.

Problem-solving steps. The five problem-solving steps served as a procedural list for both treatment and control groups:

- Step 1. Identify the problematic situation,
- Step 2. Define the problem,
- Step 3. List and evaluate alternative solutions,
- Step 4. Choose, justify, and implement a plan,
- Step 5. Evaluate the plan.

Question prompts. In addition to the problem-solving outline, the treatment group received prompts consisting of elaboration and metacognitive questions with each problem-solving step (refer to Appendix 1). For instance, for "Step 4, Choose, justify, and implement a plan," the following question prompts were presented: Which option will you implement as a plan? Why is this plan the best choice? How will you implement this plan?

Peer review. The peer review mechanism was designed to enable students to see multiple perspectives from peers' reports and help them notice things they might not have thought about previously. By reviewing their peers' thinking, students were supposedly compelled not only to attend more closely to their peers' ideas, rationales, plans and solutions, but also to their own for self-reflection.

Expert modeling. Expert modeling was provided by presenting students with an expert's responses to the five problem-solving steps. This support mechanism was expected to offer students an opportunity to observe the expert's reasoning, which they would compare with their own reasoning. It was assumed that the comparison would result in disequilibrium.

Self-reflection. Self-reflection was an important mechanism to supplement the expert modeling mechanism. While the purpose of expert modeling was to allow students to observe an expert's reasoning and find discrepancies in problem solving between their and the expert's reasoning, reflection prompts enabled students to contemplate and articulate those gaps at a deeper level. Both the treatment group and the control group were asked to respond to two reflective questions after reviewing the expert's responses:

1. By comparing Dr. P's responses with your responses, do you see anything different in each of the following problem-solving steps? If you do, what are those differences? Please explain each of the differences specifically.
2. What have you learned from Dr. P's responses? Please list and explain them.

The visual presentations of the expert's and students' problem-solving reports that appeared side by side on the same screen also facilitated students' self-reflection on the gaps between their thinking and the expert's thinking.

In addition, the students in the treatment group were asked to reflect on their peer review experience by answering questions, such as "What did your peers do/think differently?" and "What have you learned from peer responses?"

Procedure

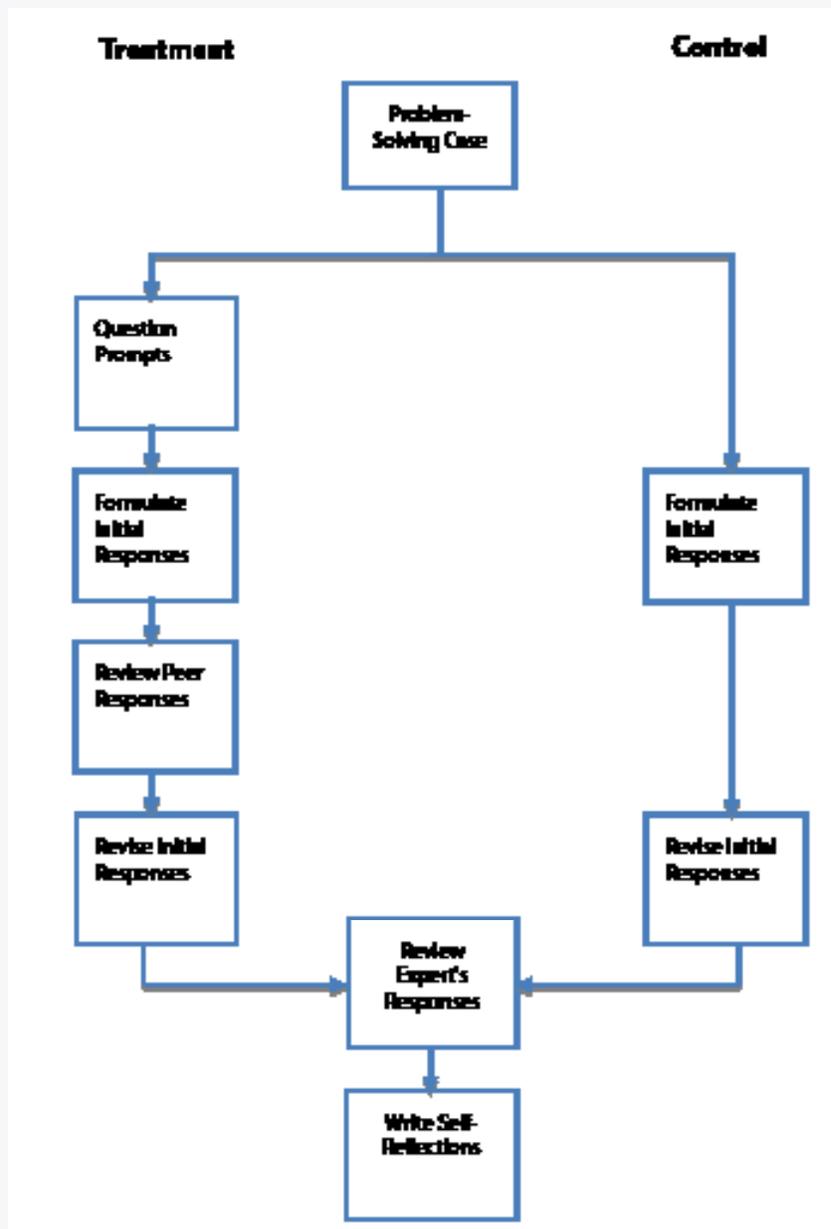
The study was divided into three sequential sessions: 1) solve the problem as described in the case scenario; 2) peer review and revision for the treatment condition or revision only for the control condition, and 3) review the expert's problem-solving report and write reflections.

Figure 1 on the next page illustrates the procedures and the problem-solving activities carried out by students in the two conditions (experimental vs. control), with or without the support of question prompts and peer review mechanisms.

At the beginning of the first session, students in both conditions were instructed to log into the cognitive support system website with an assigned user name and password. The existing peer groups, which were set up at the beginning of the semester and independent of the study, were randomized into control and treatment using a random number generator computer program. Then the students were presented with the clinical case study and were instructed to assume the role of a pharmacist in helping the patient deal with a complex problem with her asthma prescriptions. For the treatment condition, the students were presented with the five problem solving steps, each of which was followed by a list of elaboration question prompts and a text box for students to type their responses. Meanwhile, students in the control condition were presented with the five problem-solving steps with no elaboration prompts provided. A text box was displayed below each of the problem-solving steps for students to type their responses. Students in both conditions were instructed to submit their responses upon completing their writing.

After all the students had submitted their initial solutions, the second study session was made available. Students' initially submitted responses were retrieved from the database and displayed on screen when students logged onto the website so that they could revise them for resubmission. In the treatment condition, the screen would display an individual student's responses and his or her peers' names. One could click on a peer's name, and this peer's responses were revealed on the same screen, which could be closed by another click. The students were instructed to review, reflect on, and make

Figure 1. Problem-solving study sessions and activities for treatment and control groups



necessary changes to their initial responses. The treatment group could read peers' responses, but they were not asked to make comments or provide feedback. On the other hand, the students in the control condition were simply instructed to evaluate their initial responses, which appeared on the same screen as the textbox where they would type their revisions. However, the students in the control condition did not have access to their peers' responses. For both conditions, the students could copy and paste their initial responses into the new text boxes for reorganization and revisions. Like the initial responses, the revised responses were submitted by the students and saved in the database. Consequently, there were two sets of quantitative data for a total of 96 x 2 reports: initial reports and revised reports.

During the third session, after students had submitted their revised reports, the screen presented the expert's problem-solving report to both the treatment group and the control group. The students in both groups were instructed to review the expert's report and compare it with their own reports that appeared on the same screen. After reviewing the expert's report, the students were instructed to type their responses to the reflection prompts that appeared on the top of the same screen.

Rubrics and Inter-Rater Reliability

Scoring rubrics to measure student problem-solving performance were developed by the research team led by the domain expert, the instructor of the course. The rubrics were used to score students' initial and revised reports in each of the five problem-solving steps. Every step had two or three scoring criteria, each ranging from 0 to 3 points, with some qualitative attributes for assigning points to the students' responses. The summative points earned for each of the criteria formed the total score for a problem-solving step. A sample of the scoring rubrics is shown in Appendix 2.

To maximize scoring objectivity, two professors of clinical pharmacy were solicited to assist with scoring the students' solution reports. The research team, particularly the researcher who was the domain expert, supervised the scoring process but was not involved in scoring. The domain expert went through the scoring rubrics with the two raters, going through a rigorous process of testing the scoring rubrics, discussing issues arising from the scoring process, negotiating differences, and reaching consensus. If the inter-rater difference on a criterion was greater than 1 point, the two raters and the domain expert would discuss the difference until an agreement was reached or the difference was minimized. If the difference was 1 point, the average of the two scores was used. The inter-rater reliability was strong ($r = 0.94$ for both initial and revised reports, $p < 0.01$). The two raters were blind to the groups, but were aware of whether they were viewing a student's initial or revised report.

Data Analysis

A one-way multivariate analysis of variance (MANOVA) was conducted to examine the effects of the question prompts between the treatment group and the control group for the initial reports and the revised reports, Wilks's Lambda F ($\alpha = 0.05$) was used to interpret the multivariate test results. The use of MANOVA was justified because of an overall correlation among the five dependent variables (i.e., the scores of the five problem solving steps) including all students (treatment and control), as indicated by the results of Pearson's correlations, which were significant at the 0.01 level and ranged from 0.4 to 0.7. Univariate tests were conducted to examine the differences between the two conditions on each of the five problem-solving steps. The repeated measures general linear model was conducted to determine if there were main time effects, treatment effects, or interactive effects between the initial and revised reports and between the two conditions. All the statistical analyses were carried out with the Statistical Package for the Social Sciences (SPSS).

The students' responses to the reflection prompts were qualitatively analyzed to determine individuals' perceived gaps between their thinking and the expert's thinking in this problem-solving activity. Four groups of 15 students in the treatment condition and 15 students in the control conditions were randomly selected for data analysis of their reflective thinking. Our analysis of the reflection data was focused on two aspects: a) the gaps between the expert's problem-solving report and their own problem solving report, and b) what they had learned from this comparison.

Initially, the key words or phrases were identified. These were the words or phrases which repeatedly appeared in students' reflections, such as "detailed," "specific," "thorough," "elaboration," "organized," "follow the standards," and so on, including the noun counterparts of these key words. We organized the key words into several aspects with which students said they had found discrepancies compared with the expert's thinking. Then, we examined what students said they had learned from the expert. Through some initial data analysis, it became clear that the students operated at two different levels of metacognitive thinking, which we categorized as "superficial" and "deeper" reflection. "Superficial" reflection referred to reflections that students described as being similar to the expert's, except for some minute details, or in which students discretely listed the things they had learned by comparing the specific details of each of the five problem solving steps. "Deeper" reflection referred to reflections in which students articulated the gaps they saw in their reasoning processes in comparison with the expert's reasoning, for example, failing to justify problem identification with clinical guidelines, lack of elaboration or explanation, the need to be thorough and specific as a professional, and considering factors from the professional perspective. Therefore, we used these two labels to differentiate the levels of students' reflective thinking on the expert's problem-solving reports.

After we coded the reflection data from all the selected participants, we performed a cross-group comparison to determine if there were any salient differences in their responses to the reflective prompts and in the levels of metacognitive thinking. During this process, we looked for a link between the reflection data and the problem-solving reports. We examined if the students in the treatment group found less discrepancy than the control group between their thinking with the expert's thinking because they had received the elaborated question prompts elicited from the expert in the earlier session.

The primary author and the domain expert coded the data independently at first, and then compared codings. Specifically, they shared their interpretations of some important or interesting quotes. They used Excel spreadsheets to help analyze and organize the qualitative data.

Results

Results to Question 1

The MANOVA revealed a significant difference between the treatment and control conditions on the problem solving performance measured by the five problem solving steps. Similarly, univariate tests revealed significant differences between each of the five problem-solving steps across the two conditions. The means and standard deviations of the scores for the treatment and control groups' initial and revised reports are presented in Table 1. The MANOVA revealed statistically significant effects of the question prompts for both initial reports ($p < 0.01$) and revised reports ($p < 0.01$). Univariate tests showed that the treatment group did significantly better than the control group in each of the five problem-solving steps for both the initial and revised reports (all $p < 0.01$). Therefore, the results supported the first hypothesis.

Results to Question 2

The results of repeated measures showed a main time effect; that is, both groups had significant differences in revised reports compared to initial reports in the five problem-solving steps across time, $F(5, 90) = 11.478, p < 0.01, \text{Eta}^2 = 0.389$ (see Table 1). The univariate tests for time showed significant differences between the initial report scores and the revised report scores in each of the problem-solving steps, $F(1, 94) = 15.44, 21.76, 12.16, 7.00, \text{ and } 8.06, p < 0.01$, respectively for Steps 1 through 5 with effect sizes, $\text{Eta}^2 = 0.14, 0.19, 0.12, 0.07, \text{ and } 0.08$ respectively. Overall, regardless of the conditions, students made progress in their revised reports, given that they had time to evaluate, reflect, and revise their initial reports.

Table 1. Means and standard deviation of students' problem solving performance measured by initial reports and revised reports for the two groups

	Condition ^a	Initial Reports ^b		Revised Reports ^c	
		M	SD	M	SD
Step 1 (9 points): Identify problem situation	Treatment	4.03	1.37	4.20	1.45
	Control	1.97	1.04	2.17	1.04
Step 2 (9 points): Define the problem	Treatment	5.39	1.73	5.95	1.71
	Control	1.84	1.00	1.99	1.11
Step 3 (6 points): List and evaluate alternative solutions	Treatment	4.87	1.27	5.23	0.96
	Control	2.78	0.94	2.89	0.71
Step 4 (7 points): Choose, justify, and implement a plan	Treatment	4.59	0.93	4.74	0.87
	Control	3.07	1.14	3.16	1.16
Step 5 (6 points): Evaluate the plan	Treatment	3.13	1.07	3.24	1.06
	Control	1.15	1.33	1.38	1.39

^aTreatment group: $n = 49$; control group: $n = 47$.

^bMultivariate analysis of variance (MANOVA) revealed a group main effect between treatment and control groups on all five steps of *initial* reports: $F(5, 90) = 51.98, p < .01, \text{Eta Sq.} = .74$. Univariate tests for each step: $F(1, 94)$ ranged from 51.49 to 149.99, Eta^2 ranged from .35 to .62, all $p < .01$.

^cMANOVA revealed a group main effect between treatment and control groups on all five steps of *revised* reports: $F(5, 90) = 62.97, p < .01, \text{Eta}^2 = .78$. Univariate tests for each step: $F(1, 94)$ ranged from 54.60 to 183.04, Eta^2 ranged from .37 to .66, all $p < .01$.

In addition, there was an interactive effect between time and treatment, $F(5, 90) = 2.955, p < 0.05, \text{Eta}^2 = 0.141$. The univariate tests revealed that the treatment group made a significantly greater improvement in *Step 2 – Define the problem* in the revised reports, $F(1, 94) = 7.33, p < 0.01, \text{Eta}^2 = 0.07$, than the control group; the treatment group improved 0.56 points while the control group improved 0.15 points. However, in the other four steps the treatment group did not show statistically significant improvements over the control group in the revised reports. Therefore, the results partially supported the second hypothesis. Further investigation is needed to explain why there was an interactive effect in Step 2 only.

By reviewing and comparing the student's responses between the two groups, we found that responses to Step 1, Identify the problematic situation from students in the

treatment group formed a foundation that may have led to better performance in their revised responses to Step 2, Define the problem. Many students in the treatment group were able to articulate “clinical standards” in Step 1 while the students in the control group did not mention the standards. This made sense because students in the treatment group were prompted by the questions specifically directing them to the clinical standards so their answers were more elaborated, detailed, and specific. Thus, they were more likely to have better problem representation in identifying problem situations and defining problems. Below are typical responses by a student from a treatment group and a student from a control group in response to Step 1, Identify the problematic situation and Step 2, Define the problem:

Student A in the treatment group responding to Step 1 (responses preceded by question prompts):

a. What facts from this case suggest a problem?

“She is refilling her prescription for albuterol every 2 weeks for the last 2 weeks compared to the usual 6 weeks.”

b. Is there a standard for comparing these facts? If so, what is (are) the standard(s)?

“She reports being short of breath a lot more recently than in the past and therefore is relying on her rescue inhaler a lot more. The clinical standards are that a patient that relies on the rescue inhaler this much needs a corticosteroid everyday to reduce inflammation and reduce attacks.”

c. Are the facts out of line? Why or why not?

“The facts in this case are [out of line] because the patient is only receiving a rescue inhaler and this therapy will not help treat the underlying disease. The rescue albuterol inhaler will only help with symptoms.”

Student B in the control group responding to Step 1:

“The problem is that Ms. Smith's asthma is not under control and she is having to use her rescue inhaler more often than she used to.”

Student A in the treatment group responding to Step 2 (responses preceded by question prompts)

a. What do you already know about the problem?

“The problem is that the patient is not at a therapeutic goal for the main-

tenance to asthma. The patient's asthma appears to be progressing and could become very dangerous if the required therapy is not obtained."

b. Do you need additional facts to define the cause(s) of the problem?

"There is additional information needed to fully evaluate her therapy. [Added after peer review: The patient may not have been instructed well on how to use the inhaler. Without proper technique, the inhaler won't be very effective.] Questions about the season that is currently taking place, any pets in the household, dusting issues, and location of home (rural, big city, country). These questions could help determine her allergens, which could then be avoided."

c. What is (are) the probable cause(s) of the problem?

"I suspect this is an acute attack due to seasonal changes or a new animal in the home. These symptoms could get worse if not treated properly."

Student B in the control group responding to Step 2:

"Ms. Smith is having to use her rescue inhaler more often than she used to. This is a problem because it tells us that she is not having control of her asthma."

As we can see from the excerpts above, Student A in the treatment group was more elaborative and extensive in her responses and her problem space was much larger than the student's responses in the control group. She asked more questions and considered a wider spectrum of factors and constraints. Her response to Step 1 impacted her reasoning and responses to Step 2. In Step 2, Student A added two sentences in her revision to elaborate why additional information was needed to fully evaluate the patient's therapy, which may have been a result of the peer review. By comparison, Student B in the control group was briefer and did not explain her statement, such as why it was a problem that Ms. Smith had to use her rescue inhaler more often and the clinical ramifications of her overuse in terms of lack of asthma control, progression of asthma severity, and prevention of future asthma attacks.

In addition, the students in the treatment condition shared the view that peer review allowed them to see multiple perspectives, different ideas, and different approaches. For example, a student pointed out in his reflection about the peer review:

"I learned that we all perceive a problem a little different and choose to treat it to different degrees. The best solution appeared to be a blend of all of our perceptions and treatment ideas. That is why working as a team in healthcare is so vital."

As a result of the peer review, this student stated while making revisions to Step 2, Define the problem:

“One issue I failed to mention was [medication] compliance. The patient may not have been instructed well on how to use the inhaler. Without proper technique, the inhaler won’t be very effective.”

Results to Question 3

We found that the expert modeling mechanism served as a standard to which the students looked up, to compare with their own problem solving approaches, and to confirm if they were on the right track or not. For many students, the expert comparison created a disequilibrium (Piaget, 1985), which helped them see where the discrepancies were between the expert and their thinking, reflect on what they had learned from the expert, and determine what must be improved next time. In addition, seeing how an expert solved an ill-structured problem increased the students’ confidence in solving similar problems themselves.

The students described the problem solving approaches they had learned from the expert, for example: the expert used a structured approach to problem solving; the expert used clinical guidelines or standards to help her define problems and to support her problem analysis and solutions; and the expert organized the available information to help her identify factors and define problems. Below were some excerpts of students’ reflections about what they had learned from Dr. P:

“I have learned to have a more structured approach to answering the problem . . . I would say the most important thing still would have to be structure.” (Treatment)

“She used asthma guidelines and recommendations from these guidelines to define the problematic situation and as a basis for the rest of the steps, unlike myself.” (Control)

“Dr. P’s responses have taught me to be more thorough. I need to look up guidelines and use the information in them to help me define, implement, and evaluate a plan.” (Treatment)

In addition, just as the last excerpt shows that Dr. P’s responses were very thorough, the students in both conditions were impressed by the level of thoroughness, details, and specificity of the expert in representing the problem for analysis and for developing or selecting solutions. Some of the key words the students used frequently and repeatedly

in their reflections were thorough, thoroughly, details, specific, elaboration, organized, accurately. Here is another example from a student's reflection,

"Dr. P's responses were a lot more detailed than mine, and I think it shows that I need to be more specific in my recommendations and have literature or guidelines for my reasoning." (Control)

What is more important was that the students learned from the expert how to solve a problem from a professional perspective and consider various factors from a real-world context when making a decision, such as following guidelines and evaluating information by judging its credibility. For example,

"I like Dr. P's evaluation in the sense that she pointed out that both the doctor had to be willing to prescribe and that the patient needed to be satisfied. Dr. P keeps in mind the clinical standards when she is going to re-evaluate the patient. She also keeps high-priority side effects in mind." (Treatment)

"Dr. P's evaluation of her plan was oriented to the asthma guidelines to determine if her plan worked, unlike mine where I just evaluated my performance and didn't worry about the patient." (Control)

These two examples show the student reflected on how to use clinical standards for evaluating a plan, in addition to defining a problem.

"She looked at the problem from various angles. She looked at the responsibilities and roles played by the different parties. My responses were very brief and did not put down the thought process I went through, but she laid hers out nicely... She made it easier for the clinician and the patient to decide on the proper action by listing out the advantages and disadvantages of the various options." (Control)

This excerpt shows that the student learned it was important to look at the problem from different angles and how others (e.g., a patient, a clinician, or a physician) viewed the problem.

Despite the fact that every student indicated that they had learned from the expert's problem solving report, we found that regardless of the condition they were in, the students processed the information at different metacognitive levels: superficial reflection or deeper reflection. An example of superficial reflection was that the student thought his/her thinking was similar to an expert's, with a difference only in degree of thinking

process. For instance, in the example below, the student thought that she was on the right track, but just didn't carry out her thought process as far as listing the clinical guidelines, from which we could infer that she thought it was just a matter of listing the guidelines, but not that she had missed something critical in the problem representation process.

"I am on the right track, I just did not carry my thoughts out as far as what was needed. Next time, I will list out the clinical guidelines." (Treatment)

In contrast, the other student reflected much more deeply regarding the use of the clinical criteria (i.e., guidelines) by Dr. P.

"The main differences are the research criteria she documents and identification of the problem. Dr. P has documented where she found information for her plan. This is good in that individuals who read your plan in a clinical setting will know where you got it, rather than think you're just saying what you think is correct." (Treatment)

In this example, this student identified a gap in her reasoning in comparison with Dr. P's problem solving regarding documenting criteria and identifying problems. Unlike the other student, she did not treat this gap as a degree of difference, but rather something upon which she pondered. She was able to articulate in her reflection why "this is good" (i.e., citing the criteria) because it provided justification for others to understand and enhanced how others perceived the credibility of the solution and the person recommending it. Because many potential solutions to the problem would require a physician to prescribe a medication, and since pharmacists do not have prescriptive authority, the probability of a solution being carried out is highly dependent on a student (pharmacist) to persuade a physician to act.

Although we did not find major differences among conditions in the students' responses and reactions towards reviewing the expert's report, we did find some differences in the wordings regarding what they had learned from the expert. For instance, the students in the treatment group seemed to be more specific in articulating the differences they had observed in the student-expert comparison. For example, more students mentioned that the expert used "guidelines," "standards" or "criteria," when they described how detailed and thorough the expert was in identifying and analyzing the problematic situation; whereas many students in the control group did not mention in what ways the expert was specific or detailed. We attributed this difference to the impact of question prompts because the question prompts specifically directed students to the issue of standards and prompted them to elaborate their thinking, which facilitated their expert-novice comparison and self-reflections.

Discussion and Implications

The results of this study are encouraging for adapting PBL in a web-based learning environment. The cognitive support system provided expert guidance to students through presenting relevant question prompts and an expert's problem-solving report instead of leaving them with five steps of problem solving. While confirming the findings of previous studies (e.g., Ge & Land, 2003; Ge, Chen, & Davis, 2005) on the effects of question prompts in scaffolding student problem-solving processes, this study also examined the effect of presenting an expert view on developing students' problem-solving skills. It showed that a cognitive support system could play the role of an expert through question prompting, eliciting explanations, prompting students for justifications, modeling the expert's problem-solving reasoning and approach, and monitoring students' problem-solving processes.

When novices were required to elaborate on their thinking or provide an explanation in response to question prompts through the cognitive support system, they were provided with a mind-extension cognitive tool that helped them to become better problem solvers than those who were simply instructed to go through the problem-solving procedure. The findings of this study supported Simons and Klein's (2007) study, which suggested that scaffolds were effective in enhancing learners' inquiry process and problem-solving performance, especially when students were required to access and use them. Based on the results of this study, we believe that a cognitive system can be designed and integrated into the web-based PBL environment to support students through their problem-solving processes and enhance their PBL experiences.

With that said, it should be noted that it was not the intention of this study to substitute the role of an instructor or a facilitator who is capable of adapting strategies to provide dynamic guidance and feedback and to support reflection in the PBL environment (Simons & Klein, 2007). Neither was it our intention to simplify the PBL processes by guiding students through the five-problem solving steps in the web-based instructional setting. Students were required to elaborate on and justify their decisions in every problem-solving step in response to the question prompts. They also worked with peers to analyze case studies, investigate the problem situations, search for useful resources, and test their solutions over a longer period.

This study also revealed that the treatment group did not perform better than the control group in terms of their progress from the initial reports to the revised reports, except in Step 2, Defining the problem, indicating that self-revision was effective but peer review was not more effective. This finding might be explained by the fact that the treatment was not long enough to produce a stronger effect on the other four problem solving steps. In fact, in analyzing students' responses and self-reflections, we found that many students in the treatment group had better problem representation in Step 1, Identify the

problematic situation; however, the experiment might not have been strong enough to pick up the statistical differences. In contrast, the finding about Step 2 could also suggest that peer review alone might not be a sufficient strategy; students should also be allowed to interact with one another through communication, providing feedback, negotiating meanings, and providing constructive suggestions. On the other hand, however, these findings supported the effects of self-revision, indicating that giving students sufficient time to review and revise their own initial reports could encourage self-evaluation and self-reflection. It is inferred that self-review and self-revision can be effective techniques to promote self-monitoring, self-regulation, and self-directed learning in a PBL environment.

Through this study, we were also trying to understand the roles played by different support mechanisms in this cognitive support system, such as question prompts, peer review, and expert view. It was clear that the three mechanisms fulfilled different cognitive functions in scaffolding students' problem solving performance. The question prompts served to direct students to important aspects of problem solving, prompt them for elaboration, explanation, and justification, and facilitate self-monitoring in problem solving. The peer review enabled students to see multiple perspectives and different problem solving approaches, which facilitated their problem representations. The expert modeling mechanism served to make the expert's thinking visible by displaying the expert's reasoning processes, such as problem representation, problem analysis, and justification for selecting solutions. The process of reviewing the expert's problem-solving report resulted in students seeing the discrepancies between the expert's reasoning and their own reasoning, which helped them to reflect on their learning experience and improve their future performance.

We argue that the disequilibrium experience, such as failure to understand or feelings of cognitive gaps, is a precursor for self-regulated learning (De Lisi & Golbeck, 1999) because metacognition consists of two components: self-awareness and self-regulation (Pressley & McCormick, 1987). The students should first recognize the inadequacies or fallacies in their problem solving performances before they are able to take actions to self-regulate these processes. Therefore, we considered our finding on providing an expert's problem-solving report a contribution to the literature on scaffolding problem-solving processes. Past literature only pointed out that an expert could provide modeling, coaching, and scaffolding in a learning environment characterized by cognitive apprenticeship, but it was not clear how providing an expert's problem-solving report as an expert modeling strategy and support mechanism would impact students' reasoning and problem solving. In future studies, we would like to follow up on what students will learn from expert modeling, how they are going to transfer the knowledge and skills they have learned from the expert to a novel problem-solving situation, and whether there are differences among students who process the information they gain from the expert comparison at different metacognitive levels.

In conclusion, we recognize some limitations of this study in both system design and research design. For instance, the existing cognitive system did not have a space for individuals in the treatment group to make comments after viewing peers' responses. In future investigations, we will add the peer interaction function to enable students to provide feedback and suggestions to each other and facilitate their revisions. Another limitation is the small size grouping of 3-4 students. Although we agree that group sizes of 6-10 are ideal for PBL, we had limited the group size so that students would have a manageable size to write a paper together for the course in which they were enrolled and for the treatment group students not to be overwhelmed with too many peer reviews. Lastly, due to the research design, the control group students did not have the benefit of working in groups.

For future research, in addition to investigating the transfer effect of expert modeling through providing an expert's problem-solving report, we plan to increase the number of interventions with additional cases over a longer period. Moreover, the study should be designed in stages to allow the withdrawal of scaffolding and to encourage transfer of problem solving skills and strategies, with more question prompting at the beginning, less question prompting towards the end, and more peer interactions and self-reflections in the middle stage. The gradual withdrawal of scaffolding based on Vygotsky's (1978) sociocultural theory is consistent with the PBL approach, which suggests a shift from tutor guidance at the beginning, to shared guidance between the student and the tutor later on, to complete student guidance at the end (Dolmans, De Grave, Wolfhagen, & van der Vleuten, 2005). It is hoped that students can work confidently and independently as competent problem solvers in a variety of problem situations towards the end of the PBL process as scaffolds are gradually withdrawn. As Salomon (1993a) argued, the ultimate goal of scaffolding is to improve a learner's performance and to leave a transferable cognitive residue in the form of improved competencies.

Acknowledgments

The authors thank Stephanie Barud, PharmD, and Winter Smith, PharmD, for their assistance as raters. They also thank Jeannine Rainbolt College of Education at the University of Oklahoma for its support through a summer research grant awarded to the first author. Lastly, the authors appreciate the editor's and the three anonymous reviewers' critical feedback and constructive suggestions, which helped to improve the quality of this article.

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Appendix 1

Problem-Solving Question Prompts

1. Identify the problematic situation.
 - What *facts* from this case suggest a problem?
 - Is there a standard for comparing these facts? If so, what is (are) the standard(s)?
 - Are the facts out of line? Why or why not?
2. Define the problem.
 - What do you already know about the problem?
 - Do you need additional facts to define the cause(s) of the problem?
 - What is (are) the probable cause(s) of the problem?
3. List and evaluate alternative solutions.
 - List at least two alternatives to solve the problem.
 - Evaluate each alternative by describing its advantages and disadvantages, including relevant patient and provider perspectives.
4. Choose, justify, and implement a plan.
 - Which option will you implement as a plan?
 - Why is this plan the best choice?
 - How will you implement this plan?
5. Evaluate the plan.
 - How and when will you monitor the implementation of the plan?
 - How will you know if the problem is solved, alleviated, or is getting worse?
 - What secondary problems should you watch out for, and how would you do that?

Appendix 2

A Sample of Problem-Solving Scoring Rubric

Step 3. Lists and Evaluates Solution Options

Competency	Outstanding Performance	Meets Expectations	Needs Improvement	Unsatisfactory Performance
<p>States at least two options to solve the problem</p> <p>3 points</p> <p>Points earned _____</p>	<p>☐ (3 points)</p> <ul style="list-style-type: none"> Clearly describes at least two options to solve the problem <p>AND</p> <ul style="list-style-type: none"> All options will address a probable cause of the problem 	<p>☐ (2 points)</p> <ul style="list-style-type: none"> Clearly describes at least two options to solve the problem, but only some options will address a probable cause of the problem <p>OR</p> <ul style="list-style-type: none"> Describes at least two options to solve the problem, but descriptions are unclear or incomplete 	<p>☐ (1 point)</p> <ul style="list-style-type: none"> Clearly describes one option to solve the problem <p>AND</p> <ul style="list-style-type: none"> Option will address a probable cause of the problem 	<p>☐ (0 points)</p> <ul style="list-style-type: none"> Describes one option to solve the problem, but description is unclear or incomplete <p>OR</p> <ul style="list-style-type: none"> None of the options described will address a probable cause of the problem <p>OR</p> <ul style="list-style-type: none"> Does not describe any options to solve the problem
<p>Evaluates each option by describing its advantages and disadvantages, including relevant patient and health provider perspectives</p> <p>3 points</p> <p>Points earned _____</p>	<p>☐ (3 points)</p> <ul style="list-style-type: none"> Clearly describes one or more relevant advantage and disadvantage per option <p>AND</p> <ul style="list-style-type: none"> Advantages and disadvantages include relevant patient or health provider perspectives 	<p>☐ (2 points)</p> <ul style="list-style-type: none"> Describes one or more relevant advantage and disadvantage per option, but at least one description is unclear <p>AND</p> <ul style="list-style-type: none"> Advantages and disadvantages include relevant patient or health provider perspectives 	<p>☐ (1 point)</p> <ul style="list-style-type: none"> Describes one or more advantage and disadvantage per option, but at least one is irrelevant <p>OR</p> <ul style="list-style-type: none"> Describes at least one relevant advantage or disadvantage per option <p>OR</p> <ul style="list-style-type: none"> Neither advantages nor disadvantages include relevant patient or health provider perspectives 	<p>☐ (0 points)</p> <ul style="list-style-type: none"> Does not describe any relevant advantages or disadvantages <p>OR</p> <ul style="list-style-type: none"> Does not describe any advantages or disadvantages