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Interactivity of Question Prompts and Feedback on Secondary Students' Science Knowledge Acquisition and Cognitive Load

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ABSTRACT

This study investigated how question prompts and feedback influenced knowledge acquisition and cognitive load when learning Newtonian mechanics within a web-based multimedia module. Participants were one hundred eighteen 9th grade students who were randomly assigned to one of four experimental conditions, forming a 2 x 2 factorial design with the presence or absence of question prompts as one factor and types of instructional feedback as the other. With regard to knowledge acquisition, the findings revealed a significant main effect of question prompts and a significant interaction between question prompts and feedback. With regard to cognitive load, the results found a significant interaction between question prompts and feedback. Students who received problem-solving question prompts and corrective feedback achieved better performance and perceived less cognitive load. Implications for designing web-based science learning are discussed.

Keywords

Question prompts, Scaffolding, Problem solving, Feedback, Science learning, Cognitive load, Web-based learning

Introduction

Problem solving is an essential 21st century skill (Trilling & Fadel, 2009), and is continuously incorporated as an integral part of school curricula (Barron, 2000; Barrows & Tamblyn, 1980; Qin, Johnson, & Johnson, 1995). As web-based learning becomes the mainstream in many educational settings, it is increasingly important to adopt research-based guidelines to design effective web-based instruction for problem solving. Two research foci have become prominent: scaffolding and cognitive load. Scaffolding research focuses on designing tools and strategies that provide learners with optimal support as they work on learning tasks. A large body of research investigated the scaffolding of open-ended or ill-structured problem solving (e.g., Chen, 2010; Davis, 2000). Closely related to scaffolding is the provision of feedback to students' performance as a way to support learning (e.g., Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Corbalan, Kester, & van Merriënboer, 2009).

Cognitive load theories approach the design of web-based learning from a different angle. Focusing on making optimal use of humans' limited working memory, cognitive load theorists have identified design principles and guidelines that minimize extraneous cognitive load while focusing learners' cognitive resources on tasks directly related to learning (Sweller, 2010; Sweller, Ayres & Kalyuga, 2011).

While the two lines of research relate to each other, they do not intersect much in the research literature. Presumably, scaffolding which is intended to support problem solving should help to streamline learners' cognitive processes and facilitate schema construction. Yet existing research appears to cast some doubts on such a presumption (e.g., Chen, Wu, & Jen, 2013; Ge, Chen, & Davis, 2005; Hwang, Kuo, Chen, & Ho, 2014). Therefore, this study set out to implement scaffolding and feedback in a web-based learning environment to support students' problem solving in science, for the purpose of examining how scaffolding and feedback impact learners' cognitive load as well as knowledge acquisition.

Theoretical framework

Scaffolding problem solving in science

Solving problems is an essential practice in the disciplines of science. Polya (1957) proposed an influential model to characterize a four-step process in problem solving: understanding the problem, planning a solution, executing the

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plan, and checking the result. In the context of solving a science problem, the process involves identifying relevant information in the problem, determining known and unknown concepts, selecting rules or principles applicable to the problem, applying rules or principles, and ensuring that a satisfactory solution is reached (Jonassen, 2000; Simon, 1978). In other words, learners are in on the active construction, manipulation, and testing of mental models of the problem (Jonassen, 2011).

While problem-solving processes are known to researchers and intuitive to skillful problem solvers, students are often not strategic in their problem-solving approaches. Instead of taking time to comprehend a problem and build a conceptual model of it, learners often jump quickly to solutions (Bransford, Brown, & Cocking, 1999). As such, researchers have employed various strategies to scaffold students through the problem-solving process (Arnau, Arevalillo-Herráez, Puig, & González-Calero, 2013; Fund, 2007; Palinscar, 1986; Rosenshine & Meister, 1992; Rosenshine, Meister, & Chapman, 1996; van Merriënboer, Kirschner, & Kester, 2003). Question prompting is a frequently used approach to scaffolding learners' problem solving (e.g., Chen, 2010; Ge, Chen, & Davis, 2005; Saye & Brush, 2002). By presenting questions to students, question prompts focus students' attention on relevant aspects of problem solving and guide them through the process. Numerous studies have found the effectiveness of question prompts in promoting problem solving, knowledge acquisition, and metacognition (Davis, 2000; Rae, Schellens, Wever, & Vanderhoven, 2012; Zydney, 2010). For example, Ge and Land (2003, 2004) used question prompts to support ill-structured problem solving, and found that the prompts led to better performance in all the major problem-solving processes. In science education, a recent systematic review has identified question prompts to be the most effective scaffolds to regulate student cognition (Devolder, van Braak, & Tondeur, 2012).

While previous studies have mostly focused on the use of question prompts to support ill-structured problem solving, few have examined their use to help students solve conceptual, application problems in science, in which students have to identify the relationships among variables and apply relevant rules and principles to solve them. Research in science education has long established that while students are good at plugging in numbers and using formulas to solve a problem, their conceptual understanding is often lacking and plagued with misconceptions (Hestenes, Wells, & Swackhamer, 1992; Vosniadou & Brewer, 1992). Therefore, in this study, we investigated whether question prompts could help improve students' performance in solving application problems in the domain of physics.

Because application problems in science are often well structured, having convergent answers and a preferred or prescribed solution process (Jonassen, 2011), question prompts that guide students' problem solution can take the form of multiple-choice questions, instead of the open-ended question format often seen in studies. By drawing students' attention to relevant information in a problem, guiding them to understand the problem, and providing them with multiple plausible answers along the process, multiple-choice question prompts offer several advantages. First, they force students to engage in the thinking process and make a specific choice for a given question. Further, the multiple-choice format makes it possible to provide targeted feedback to learners based on their answers, which can be beneficial to web-based learning. In the next section, we review the use of feedback in problem solving.

Feedback during problem solving

Feedback is a critical part of learning. Effective feedback not only helps learners to understand the subject being studied but also gives them clear guidance on how to improve learning. Studies have shown feedback to be strongly and consistently related to achievement regardless of grade, socioeconomic status, race, or school settings (e.g., Corbalan, Kester, & van Merriënboer, 2009; Lee, Lim, & Grabowski, 2010; van der Kleij, Eggen, Timmers, & Veldkamp, 2012). Feedback can be provided immediately upon students' completion of certain tasks, or after a period of time. Immediate feedback appears to positively influence learning (Arnau et al., 2013; Corbalan, Paas, & Cuypers, 2010). In teaching science problem solving, immediate feedback was found to be an effective way to correct students' misconceptions or incorrect connections (Kornell, Hays, & Bjork, 2009; Taconis, Ferguson-Hessler, & Broekkamp, 2001; Vaughn & Rawson, 2012).

Two types of feedback are often provided to students in web-based learning: *knowledge of results (KR)* and *knowledge of correct response (KCR)*. After learners respond to a question, KR simply informs them whether or not the response is correct; for example, "Your answer is correct." (Dempsey, Driscoll, & Swindell, 1993). In comparison, KCR provides the same information as KR about the correctness of a response, but additionally specifies the correct answer; for example, "Your answer is incorrect. The correct answer is *increase*." (Jaehnig &

Miller, 2007). While KR has an impact on learning (Wulf & Shea, 2004), Lantz and Stawiski (2014) observed that KCR improved students' ability to retain information and led to deep cognitive processing. In addition, KCR was found to accelerate learners' conscious construction of schema and reduce random problem-solving attempts (Mealor & Dienes, 2013; Scott & Dienes, 2008). From the students' perspective, they perceived great utility in immediate KCR, and exhibited positive attitudes toward it (Timmers & Veldkamp, 2011; van der Kleij et al., 2012).

Studies comparing different types of feedback generally agree that KCR produced more positive learning outcomes than KR (e.g., Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Jaehning & Miller, 2007; van der Kleij, Eggen, Timmers, & Veldkamp, 2012). However, in past studies, feedback was often provided after students had performed certain problem-solving tasks. Few have examined the use of feedback in conjunction with question prompts that are intended to help students understand a problem before attempting to solve it. That is, feedback is not only provided after students solve a problem, but also during the mental thinking and reasoning processes that lead to problem solution. In such a context, would the two types of feedback, KR and KCR, achieve similar effects as they do in other studies? Further, would question prompts affect science problem solving differently, depending on the type of feedback students receive? Conversely, would the effect of feedback vary depending upon the presence or absence of question prompts scaffolding? The current study intended to address these questions.

Cognitive load

Cognitive load theory views learning as the construction and automation of schemas based on limited working memory capacity (Sweller, 1994). The research literature has examined how different instructional activities influence students' cognitive load, particularly within technology-enhanced learning environments (Boucheix & Guignard, 2005; Cierniak, Scheiter, & Gerjets, 2009; Schnotz & Kürschner, 2007; Serge, Priest, Durlach, & Johnson, 2013). Three types of cognitive load have been identified: (a) intrinsic cognitive load, which has to do with the complexity of the learning material, (b) germane cognitive load, which are cognitive resources directly contributed to learning, and (c) extraneous cognitive load, which refers to information or activities that are irrelevant to the learning task (Paas, Renkl, & Sweller, 2004). To achieve successful construction of schemas, extraneous load should be kept at a minimum while most cognitive resources should be allocated to germane cognitive activities (Chandler & Sweller, 1991; Paas & van Gog, 2006).

In web-based learning, when novice learners attempt to solve problems without guidance or instruction, they may find the task overwhelming. Supposedly, both scaffolding and feedback provide a way to reduce cognitive load in problem solving, because both mechanisms are intended to provide support so that learners' working memory is not overwhelmed by the demand of problem solving. Indeed, scaffolding has been argued to reduce cognitive load in problem-based and inquiry learning (e.g., Hmelo-Silver, Duncan, & Chinn, 2007). Yet cognitive load theory casts doubts on the universally positive effect of scaffolding. For example, the expertise reversal effect argues that the effects of instructional guidance vary according to learners' expertise level. As expertise increases, too much support may actually have a reversal effect on learning (Kalyuga, 2007; Kalyuga, Ayres, Chandler, & Sweller, 2003). Within the empirical literature, few studies have investigated how scaffolding, particularly question prompts, impacts cognitive load in problem solving. Some studies, while not directly measuring cognitive load, appear to suggest that scaffolding can be intrusive and may ultimately obstruct learning (Adams & Clark, 2014; Chen, Wu, & Jen, 2013; Ge et al., 2005). Further, a recent study by Hwang and colleagues (2014) found that a concept-mapping task intended to scaffold web-based problem solving produced high cognitive load within students. Thus, a clear conclusion about the effect of scaffolding on cognitive load cannot be drawn from the existing studies.

On the other hand, research appears to have produced more unequivocal findings about the effect of feedback on cognitive load. For instance, Yeh et al. (2012) found that feedback reduced 10^{th} grade students' cognitive load when they learned science from animation-based instruction. Moreno (2004) confirmed that explanatory feedback reduced cognitive load in inquiry learning. Yet to the authors' knowledge, no study has compared the effects of KR and KCR on cognitive load in the context of science problem solving. Would KCR produce less cognitive load than KR in such a context? Would the combination of KCR and question prompts provide optimal problem-solving support, thereby producing minimal cognitive load? These questions remain to be answered.

Research questions

Built on the existing literature, this study examined the use of question prompts and feedback to support science problem solving in web-based learning. The study intended to answer the following questions:

- How does the presence of problem-solving question prompts affect students' knowledge acquisition and cognitive load?
- How does the type of instructional feedback affect students' knowledge acquisition and cognitive load?
- How do problem-solving question prompts interact with the type of feedback to impact students' knowledge acquisition and cognitive load?

Methodology

Design and participants

This study employed a pretest-posttest, 2 × 2 factorial research design. The first factor was the presence or absence of problem-solving question prompts (PS or noPS), and the second factor was the type of feedback provided to learners (KR or KCR). One hundred eighteen 9^{th} grade students from four classes were recruited from middle schools in central Taiwan (57 females and 61 males; 14 to 15 years of age). The four intact classes were each randomly assigned to one of the four treatment groups: (a) PS/KR (n = 27), (b) noPS/KR (n = 30), (c) PS/KCR (n = 30), or (d) noPS/KCR (n = 31). The four classes were equivalent in student characteristics and academic ability.

Materials

The e-learning environment for this study was a web application written in the Hypertext Preprocessor (PHP) web-scripting language. A database connected to the e-learning environment hosted all the materials used in the study, including instructional presentations, problem-solving tasks and interventions, a knowledge acquisition test, and a cognitive load measure.

Web-based instructional presentations

The instructional presentations consisted of five modules: (a) force and acceleration, (b) the definition of Newton's Second Law of Motion, (c) the unit and solution strategies in Newton's Second Law of Motion, (d) the graphics in Newton's Second Law of Motion, and (e) application examples of Newton's Second Law of Motion. As shown in Figures 1 and 2, the five modules were represented by the five buttons at the top of the web interface. Each module addressed specific learning objectives.

Figure 1. A sample of web-based instructional presentation

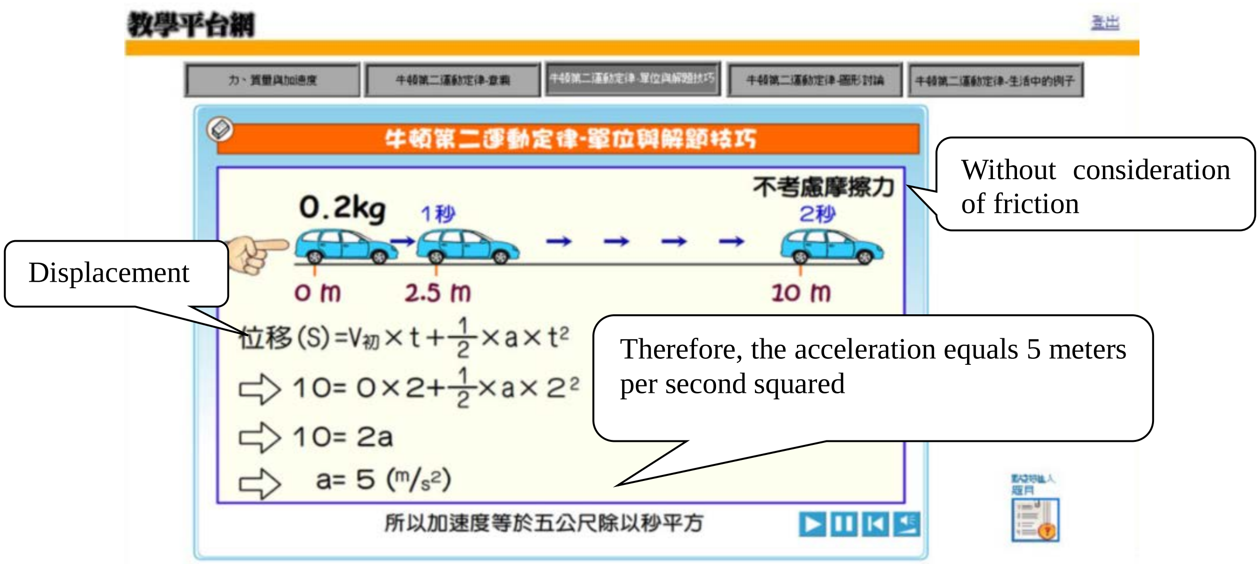

Figure 2. A sample of web-based instructional presentation

For example, upon completing Module 3, students were expected to: (a) indicate that when the overall external force acting on an object is not zero, the object must have an acceleration, (b) understand that when the mass is fixed, the greater the acceleration, the greater the force, (c) understand that when the force is fixed, the greater the mass, the smaller the acceleration, and (d) explain Newton's Second Law of Motion and apply the formula $F = ma$ to solve problems. All the modules were produced using Adobe Flash CS3 which incorporated multimedia elements such as text, audios, animations and videos. Students were able to control the presentation by pressing stop, pause, continue, or volume on/off buttons. Figures 1 and 2 demonstrate two sample interfaces of the modules.

Problem-solving tasks and interventions

After studying each module, two problem-solving tasks were presented to the students. For each task, students had to choose the best solution among four possible choices. An example problem-solving task was stated as follows, "An object is moving at a constant speed. Its mass is 500 kg. Now an external force is pushing the object in a direction that is opposite to the object's movement. As a result, the object stopped moving after five seconds. It is known that the amount of the external force is 2000 N. What was the speed of the object before it was pushed by the external force?" For the students in the PS/KR and PS/KCR groups, the system provided question prompts to scaffold their problem solving. The other two groups did not receive question prompts. Instead, they had to work on their own to solve each problem. The question prompts were designed by two science teachers and a researcher with expertise in problem solving. The questions were intended to guide students to strategically approach a problem instead of jumping quickly to solutions. The questions were based on the problem-solving processes identified in the literature, which include understanding the nature of a problem, planning a solution, and executing the plan (Jonassen, 2011; Polya, 1957). As an example, for the problem-solving task described above, three questions were asked: (a) What is the main purpose of this question? (c) In the problem, which of following do we already know? (b) Based on your answers to the two previous questions, which formula is applicable to the problem? Each of the questions had multiple answers for students to choose from.

Two types of feedback were provided to the participants as they worked on the problem-solving tasks. In the PS/KR and noPS/KR conditions, students received feedback about whether or not their answers were correct. Figure 3 illustrates an example feedback received by the PS/KR group. In the other two conditions (PS/KCR and noPS/KCR), students not only knew whether their answers were correct, but also knew the correct answer to each question. Figure 4 illustrates an example feedback received by the noPS/KCR group.

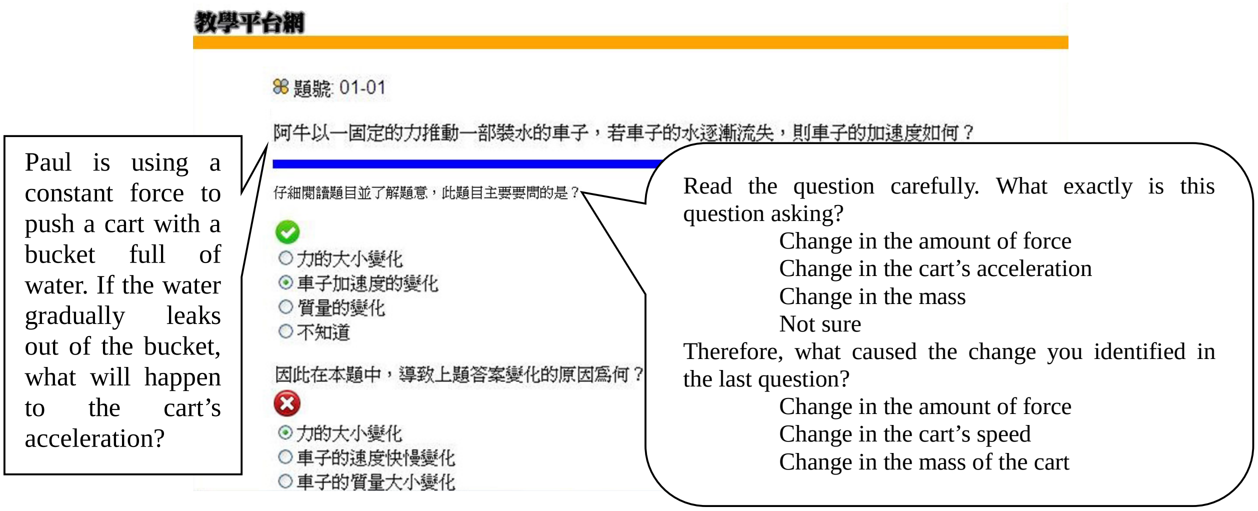

Figure 3. A sample of problem-solving task with question prompts and KR feedback (Note: Green mark indicates correct answer; red mark indicates incorrect answer)

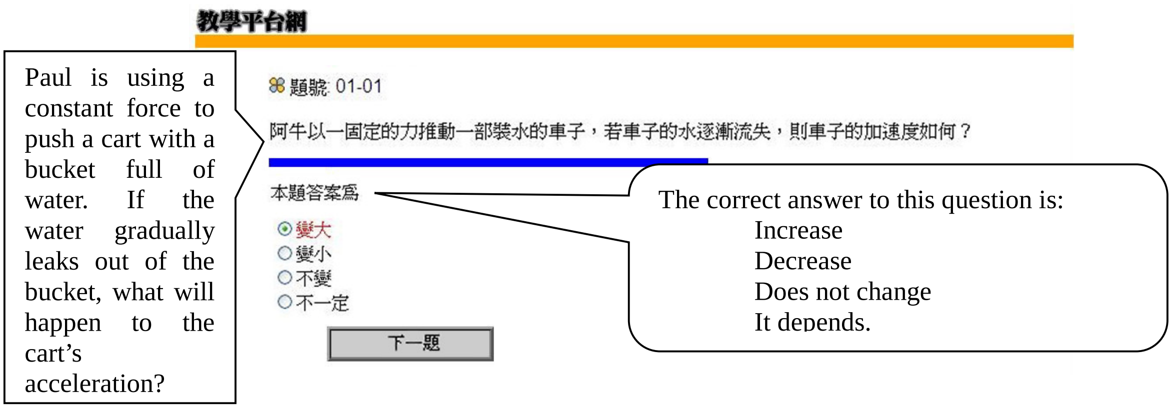

Figure 4. A sample of problem-solving task with KCR feedback

Knowledge acquisition test

The knowledge acquisition test was devised by two science instructors to ensure that the items adequately and appropriately assessed students' mastery of the content in the instruction. The test was administered twice as pretest and posttest. The test contained 23 multiple-choice questions. Students received one point for each correct answer, and could earn up to 23 total points. Cronbach's alphas for the pretest and posttest were .78 and .81, respectively, suggesting satisfactory reliability at each test time.

Cognitive load measure

The cognitive load measure was translated from Lin, Atkinson, Christopherson, Joseph, and Harrison (2013), which had been previously described and adopted by Gerjets, Scheiter, and Catrambone (2004). The instrument included three subjective questions to assess students' cognitive load. Each question utilized a Likert-type rating scale from 1 (very low cognitive load) to 8 (very high cognitive load). The three questions were: (a) How difficult was the study? (b) How much mental effort did it take to learn from the materials? (c) How frustrated were you during the study? Students' ratings of the three questions were averaged to represent their level of cognitive load, with 8 being the highest. Cronbach's alpha for the measure was .85.

Procedure

In this study, after the students were assigned to the four treatment groups, each group participated in two 90-minute sessions per week for a period of two weeks. The study took place in computer labs with a teacher and three researchers present throughout the process. On the first day of the study, the participants were introduced to the research team, informed of the general purpose of the study, and then given a description of the procedure. After the orientation, students had approximately 20 minutes to individually complete the pretest.

Upon completion of the pretest, each student was given a unique username and password to access the e-learning environment and proceed with the learning modules. Depending on their treatment conditions, students had to solve problems with or without question prompts scaffolding, while receiving different types of feedback (KR or KCR). Upon their completion of all the five modules and problem-solving tasks, the students took the posttest and completed the cognitive load measure at the end of the second week.

Results

Table 1 shows the means and standard deviations of the knowledge acquisition pretest and posttest, as well as the cognitive load measure for the four treatment conditions. No statistical difference was found between the groups in the pretest, F (3, 114) = 1.48, $p > .05$, partial$\eta^2 = .04$. The posttest means ranged from 15.45 (noPS/KCR group) to 18.67 (PS/KCR group), suggesting that all the groups had some improvement from the pretest (ranged 10.00-11.00), but the scale was not very large. With regard to cognitive load, the means ranged from 3.30 (PS/KCR group) to 4.28 (noPS/KCR group), suggesting that the groups perceived low to medium levels of cognitive load.

Table 1. Means and standard deviations of knowledge acquisition and cognitive load

	Prompts Provided (PS)				No Prompts (noPS)			
	KR (*N* = 27)		KCR (*N* = 30)		KR (*N* = 30)		KCR (*N* = 30)	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Pretest	10.70	2.20	10.77	1.68	10.00	2.04	11.00	1.89
Posttest	16.15	4.00	18.67	3.19	15.63	3.71	15.45	3.56
CL	3.98	1.52	3.30	1.50	3.89	1.39	4.28	1.45

Effects on knowledge acquisition

A 2 x 2 ANCOVA was conducted to evaluate the effects of two question prompts conditions (PS and noPS) and two feedback types (KR and KCR) on students' performance in the knowledge acquisition posttest, with the pretest scores as the covariate. The results of the ANCOVA indicated a significant main effect of question prompts, $F(1, 113) = 7.32$, $p < .01$, partial $\eta^2 = .61$, and a significant effect of question prompts by feedback interaction, $F(1, 113) = 5.56$, $p = .02$, partial $\eta^2 = .05$. The main effect for the feedback type was not significant. Given the significant interaction, interpretations of main effects were set aside in favor of interpretation of the simple main effects of question prompts and feedback respectively. The simple main effect of the question prompts was found to be significant within the KCR condition, $F(1, 113) = 13.38$, $p < .001$, partial $\eta^2 = .11$, with the PS group outperforming the noPS group. Within the KR condition, there was no significant difference between the PS and noPS conditions. With regard to the simple main effect of feedback, there was a significant difference within the PS condition, $F(1, 113) = 7.06$, $p < .01$, partial $\eta^2 = .06$, with the KCR group outperforming the KR group. No significant difference was found between KR and KCR within the noPS condition. Figure 5 illustrates the four group's knowledge acquisition performance.

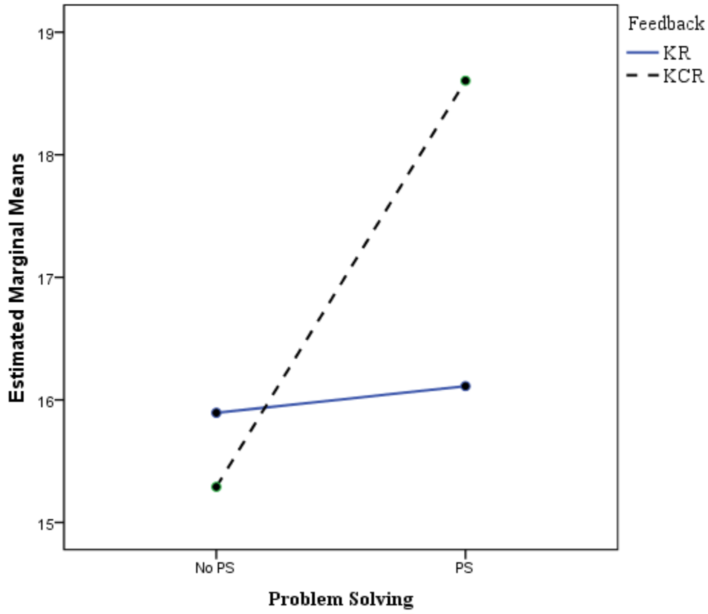

Figure 5. Estimated marginal means of knowledge acquisition posttest by groups

Effects on cognitive load

A 2 x 2 ANOVA was conducted to evaluate the effects of question prompts and feedback on students' perceived cognitive load. The results indicated a significant prompts by feedback interaction, $F(1, 114) = 3.93$, $p = .0498$, partial $\eta^2 = .033$. The main effects for both feedback and question prompts were not significant. This interaction effect was further investigated by conducting simple main effects of question prompts within each feedback condition. There was a significant difference within the KCR condition, $F(1, 114) = 6.72$, $p = .011$, partial $\eta^2 = .11$, with the PS group reporting lower cognitive load than the noPS group. The cognitive load of the four groups is illustrated in Figure 6.

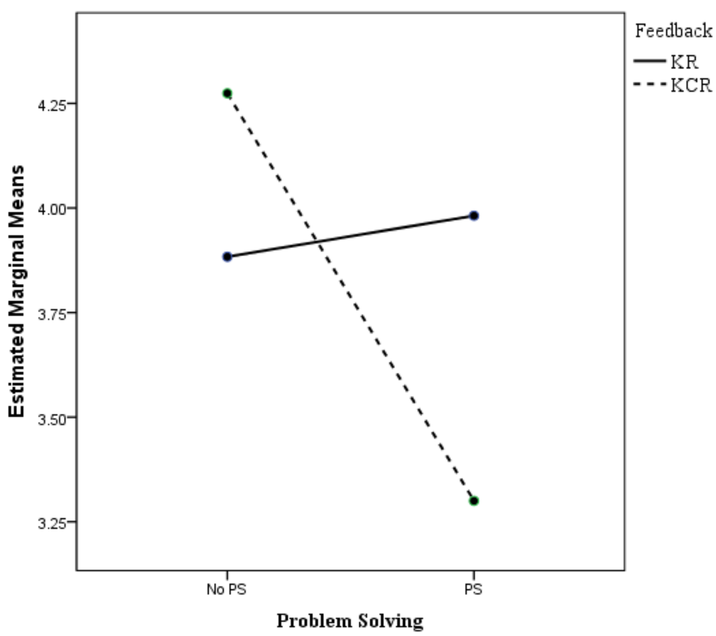

Figure 6. Estimated marginal means of cognitive load by groups

Discussion

This study investigated the effects of problem-solving question prompts and feedback on students' knowledge acquisition and perceived cognitive load as they studied a web-based module on Newtonian mechanics. A particular purpose of the study was to bring together two lines of research, scaffolding research and cognitive load theories. While both research areas are related to web-based multimedia learning, few studies have empirically examined the effects of scaffolding on cognitive load.

Question prompts, feedback, and knowledge acquisition

Aligned with the existing literature (e.g., Bulu & Pedersen, 2010; Ge et al., 2005; Kim & Hannafin, 2010; Raes, Schellens, Wever, & Vanderhoven, 2012), this study found that the problem-solving question prompts led to improved knowledge acquisition. Moreover, the effect of question prompts was more pronounced when combined with the KCR feedback. While past studies on scaffolding and question prompts examined their use to support ill-structured problem solving, this study implemented question prompts to support students' solution of conceptual, application problems that usually have convergent answers and preferred solution paths (Jonassen, 2000; 2011). When solving this type of problems, a human tutor in face-to-face settings can direct students' attention and guide them through the process. In web-based learning, however, such scaffolding is often not available. Students usually receive feedback after they solve a problem. The findings from this study suggest that question prompts can help students better understand a problem and plan for solutions to the problem, which can lead to improved knowledge acquisition. The strengths of question prompts can be further enhanced when combined with KCR feedback.

With regard to the use of the two types of feedback, KR and KCR, the findings are different from those in the past studies (Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Jaehning & Miller, 2007; van der Kleij et al., 2012). In the existing literature, feedback is often provided after students complete certain problem-solving tasks. This study took a different approach by integrating feedback with problem-solving question prompts prior to students' solution of problems. In such a context, this study found that the types of feedback did not make a significant difference on students' knowledge acquisition overall. However, the feedback did make a difference when problem-solving question prompts were available. That is, KCR can lead to better knowledge acquisition than KR when combined with problem-solving question prompts.

Question prompts, feedback, and cognitive load

In this study, neither question prompts nor the types of feedback had a general impact on students' cognitive load. With regard to the cognitive load of KR and KCR, while the comparison of the two feedback types was not previously studied in the problem-solving context, the findings indicate that the two types of feedback generally did not cause difference in cognitive load. Regarding the problem-solving question prompts' lack of impact on cognitive load, one possible explanation could be that, while the prompts might help to reduce extraneous load, students' germane cognitive load might have been increased as they attempted to answer the questions. The overall lack of difference in cognitive load among the four groups might be partially attributed to the students' relatively high level of prior knowledge which is shown in the knowledge acquisition pretest. With certain levels of prior knowledge, the students might not feel the study as taxing as might those with little prior knowledge, which could have led to the relatively low cognitive load and lack of difference among the treatment groups.

On the other hand, for the two groups that received corrective feedback, problem-solving question prompts did help to reduce cognitive load. It could be reasoned that for the students who did not receive question prompts, when they learned the correct answer to a problem following an incorrect response, they might have wondered why, even though they were not prompted to do so. Without previous question prompt scaffolding, such reasoning process might have taken this group of students extra mental effort and even caused frustration. The finding suggests that when learners take time to go over necessary problem-solving mental processes by responding to question prompts and receiving corrective feedback, they may be able to manage their cognitive resources more effectively, which also contributes to improved knowledge acquisition.

This study contributes to the cognitive load and scaffolding literature by providing empirical evidence against the intuitive assumption that scaffolding could reduce cognitive load during problem solving. It is possible that scaffolding, such as question prompts, does not help to reduce cognitive load in problem solving. While scaffolding in itself may not have an effect on cognitive load, it may have an effect when combined with other instructional interventions such as corrective feedback. Therefore, in examining the relationship between scaffolding and cognitive load, it is productive to go beyond a one-dimensional, universal-effect model to investigate how scaffolding influences cognitive load in different instructional contexts.

Conclusion and implications

Overall, the findings suggested that question prompts, when combined with corrective feedback, can provide an effective means of supporting problem solving and knowledge acquisition in web-based science learning. Moreover, such a combination can not only lead to improved knowledge acquisition, but also to reduced cognitive load which may further contribute to improved learning and reduced stress. The study offers several practical implications. First, when students' learn to apply principles and rules to solve science problems in web-based learning, feedback alone is not sufficient. Scaffolding such as question prompts is necessary to engage them in the thinking processes that lead to problem solution. Second, in the web-based learning context, use the combination of question prompts and KCR to provide optimal support for students' problem solving and maximize students' use of cognitive resources on tasks directly related to learning.

This study has a few limitations. First, the same knowledge acquisition test was administered twice as pretest and posttest. Although the two tests were two weeks apart, during which students studied five learning modules, the pretest could have still had a learning effect on the students in their study. Second, although the problem-solving question prompts and the actual problem-solving tasks were different content-wise, they both took a multiple-choice format. Therefore, the PS groups could have potentially gained more familiarity with multiple-choice questions than the noPS groups, which could have partially led to the PS groups' better performance and lower perceived cognitive load.

Future studies could use parallel forms for pretest and posttest, and adopt additional question format in measuring students' knowledge acquisition. In addition, future studies should examine the effects of question prompts and feedback on specific types of cognitive load (DeLeeuw & Mayer, 2008). Further, future studies can also incorporate elaborated feedback, another frequently used feedback type, to examine its impact on learning and cognitive load in web-based science problem solving. Finally, it is worthwhile to study how scaffolding interacts with other instructional interventions to impact cognitive load.

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