Not a Magic Bullet: The Effect of Scaffolding on Knowledge and Attitudes in Online Simulations

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Abstract: Common wisdom and prior research suggest that students with low prior knowledge are in greater need for scaffolding. However, some forms of scaffolding may overload novice-students' cognitive capacity or short-circuit productive exploration of the problem space. Hence, we evaluate the effectiveness of scaffolding in a virtual simulation in physics, considering students' attitudes and prior knowledge. 100 undergraduate students completed either a scaffolded or a relatively unstructured activity, followed by another unstructured activity. While the given scaffolding was beneficial for students with high prior knowledge, it did not assist students with low prior knowledge. Furthermore, the scaffolded activity increased students' attitudes towards memory-and-recall in a way that transferred to the later unsupported activity, where these goals were no longer appropriate. Last, prior knowledge did not contribute to learning outcomes in the presence of intuitive grounded feedback. We explain these results in terms of productive failure and cognitive load.

Introduction

The desired level of assistance in online exploratory learning environments has been the focus of an intensive debate. In general terms, proponents of high level of guidance suggest that novice learners learn better in situations where direct and comprehensive instructional guidance is provided (e.g., Kirschner, Sweller, & Clark, 2006). However, others assert that students should be given more agency over their learning processes within the supported environment (Hmelo-Silver, Duncan, & Chinn, 2007). It is increasingly clear that rather than asking how much support, a more viable question is what timing and forms of support are most appropriate (Koedinger & Aleven, 2007; Wise & O'Neill, 2009).

Many studies of inquiry learning have evaluated the effect of support on learning (e.g., de Jong & van Joolingen, 1998; Manlove, Lazonder, & de Jong, 2007) and motivation (e.g., Butler, 1998; Horner & Gaither, 2006). However, the integration of student characteristics such as incoming attitudes, prior knowledge, and expectations, in the context of inquiry learning, has not yet received much attention. This study adds to the assistance debate by investigating the relationship between level of scaffolding and student prior knowledge and motivation, in the context of an online physics simulation.

The Interaction between Prior Knowledge and Support

Students' prior knowledge and experiences have been long recognized as a critical factors in their learning processes and outcomes. Tuovinen and Sweller (1999) suggest that novice learners can benefit from higher levels of guidance, compared with more experienced learners, because guidance acts as a substitute for missing schemas. Thus, the scaffolding helps novices by minimizing working memory load. Experienced learners, on the other hand, are less likely to need additional instructional guidance as they already possess schemas that support the construction of mental representations. Kalyuga (2007) refers to this phenomenon as the "expertise reversal effect", where guidance becomes redundant and thus, ineffective for experienced learners.

Somewhat contrary to these results, a second strand of studies indicates that novice learners may find difficulties in interpreting the provided assistance. Instead, novice learners may benefit more from engaging in solution attempts, albeit failed ones, before they can comprehend and make use of the provided guidance. For example, we have previusly found that novices may learn from their own explorations more than from using hints, even though the hints led them to quicker solutions (Roll, Baker, Aleven, & Koedinger, 2014). In another example, Vollmeyer, Burns, and Holyoak (1996) found that learners benefit more from answering their own questions, compared to being given scaffolding in the form of specific sub-goals. These lines of work highlight the distinction between *successful engagement* (that is, completing the task without errors), and *productive engagement* (that is, performing better on delayed measures of learning; Kapur, 2008; Schwartz & Martin, 2004; Roll, Aleven, & Koedinger, 2009). Letting novices explore the problem space also helps them acquire more flexible knowledge (Rittle-Johnson, Star, & Durkin, 2012). It seems that scaffolding the learning process by providing students with seemingly useful sub goals may put students in an "answer hunting" mode which may be counterproductive (Miller, Lehman, & Koedinger, 1999; Sweller, Mawer, & Ward, 1988).

While the debate around scaffolding is framed mainly in terms of given and withheld information (Koedinger & Aleven, 2007), students may be given implicit scaffolding in the form of grounded feedback (Nathan, 1998). Environments that offer grounded feedback support learning by showing the outcomes of students' actions in an alternative, familiar, representation. One family of simulations that supports learning using grounded feedback is PhET Simulations (Wieman, Adams, & Perkins, 2008). Overall, PhET simulations are used over 45,000,000 times a year. Figure 1 shows the D/C Circuit Construction Kit, one of the more popular simulations of the PhET family (http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc). In this specific simulation, students explore basic properties of D/C circuits by connecting wires, light bulbs, resistors, switches, and measurement instruments, on a virtual test bed. Grounded feedback in the simulation is given, for example, by matching the light intensity of the light bulbs to their current and voltage. In other cases, when the power is too high, elements in the circuit may catch on fire. In addition, students can see the speed in which electrons "travel" through the wires. This feedback gives students intuitive understanding on the outcomes of their actions. Other features of the simulation require more domain-level expertise, such as measuring using the voltmeter, shown in the bottom-left corner of all screenshots in Figure 1.

Figure 1. The D/C Circuit Construction Kit simulation. Grounded feedback is given in the form of light intensity, electron speed, and fire.

The Interaction between Attitudes and Support

The role of scaffolding in learning may be explored in further detail through an examination of motivation as measured through success attributions and self-efficacy. Success attributions are factors that students recognize as being the determinants of success in a particular context (Graham & Williams, 2009). They are important in helping learners understand what is required from them in order to succeed. Thus, success attribution should match the learning situation. For example, while students in a highly scaffolded environment can learn by answering questions, this strategy may be less appropriate for a less scaffolded environment, where students should determine their own sub-goals. Self-efficacy describes an individual's perceived capabilities and competencies for learning or acting in context (Bandura, 1997; Schunk & Pajares, 2009). Research suggests that students' perception of their ability is often inaccurate. In particular, novices often have unrealistic expectations for their own successes when confronted with novel tasks, as they are unaware of their personal knowledge gaps (Kruger & Dunning, 1999; Roll, Aleven, & Koedinger, 2011). Students tend to be more productive if they feel that success can be achieved, they think that they know what they need to do to be successful, and they possess the skills to do it (Butler & Cartier, 2004). Success attributions and self-efficacy research indicate a connection between these motivational attitudes and increased achievement (Bandura, 1997; Wilson & Linville, 1982). Understanding students' waxing and waning success attributions and self-efficacy can give us key insights into the role of scaffolding in the learning process and help us structure scholastic activities more strategically.

Similar to prior knowledge, students' attitudes coming into the learning environment may show a differentiated effect for different forms and levels of scaffolding. For example, Belenky and Nokes-Malackh (2013) found that students who enter a learning situation with low levels of mastery goals are more likely to benefit from low levels of scaffolding (in the form of explicit instruction), compared with students with high levels of mastery goals.

Research Questions

The current study explores how learning gains and attitudes, and in particular, students' expectations, change over time and in relationship to learners' prior knowledge and level of assistance provided. Specifically, we are interested in investigating the following questions:

(i) What is the effect of scaffolding on learning, contingent on prior knowledge?

(ii) How do students' expectations change with time, based on given scaffolding, and contingent on prior knowledge?

Method

One hundred post-secondary students from first-year physics classes in a large Canadian university participated in the study on the topic of D/C circuits. Data collection occurred in two waves: once during the school year as an add-on to the physics class, and again in the summer as a more integrated part of the physics course content.

The study procedure had five steps (see Figure 2): (i) Students first completed a 5-minute pre-test (assessing content knowledge) and pre-survey (assessing attitudes). (ii) Students then completed a 25-minute activity on light bulbs using the online simulation. Students were randomly assigned to one of two conditions with high- or low-levels of scaffolding, as described below. (iii) Following the learning activity, students were given a short break, and then completed a mid-survey which was identical to the pre-survey. (iv) A transfer inquiry activity on the topic of resistors was then administered for 25 minutes. Students from both groups received only low level of scaffolding in this activity. The activity used the same simulation that was used in the light bulb activity. (v) Last, a post-test of learning outcomes from both activities and a third survey of attitudes were administered.

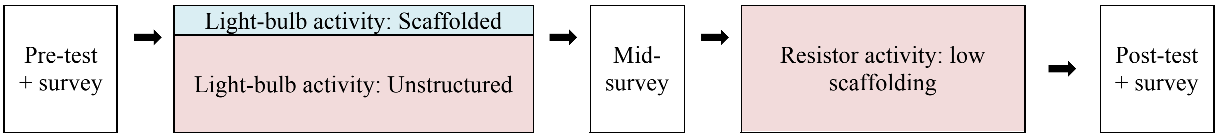

Figure 2. The study procedure.

Materials

All students used the D/C Circuit Construction Kit (shown in Figure 1) throughout the study. For the first activity, students in both conditions received the same learning goal and some advice for their exploration: "*Use the DC Circuit PhET simulation to explore how voltage, current, and the brightness of light bulbs depend on the number of light bulbs in a circuit and the arrangement of light bulbs in a circuit. For example, what happens when several light bulbs are connected in a line? What happens when light bulbs are sitting on different loops in the same circuit, and when electrons are moving through different loops? What happens when you use several batteries and switches*?" Half of the students were assigned to the Scaffolded condition. In addition to the elaborated learning goal, students in this condition received a worksheet that guided their exploration of these topics. The activity was adapted from recommended activities by the designers of the simulation, using inputs from the instructor of the course in which data was collected. The activity included diagrams that showed students which circuits to build, tables for students to fill in their measurements, and propmts that asked students to compare and contrast their measurements for the different experimental set-ups (see Figure 3a). The rest of the students received only the elaborated learning goals, without the additional worksheet. Even though students in this condition were supported by the learning goal and its recommendations, for simplicity, we refer to this condition as Unstructured.

During the second activity, on the topic of resistors, all students received an (Unstructured) learning goal with no worksheet. Notably, this activity was much harder, as the topic of resistors is less intuitive than light bulbs. Also, the grounded feedback was less relevant in this activity: when working with light bulbs, light intensity offers useful information. However, when working with resistors, students should use the measurement instruments (voltmeter, ammeter) and interpret numeric values.

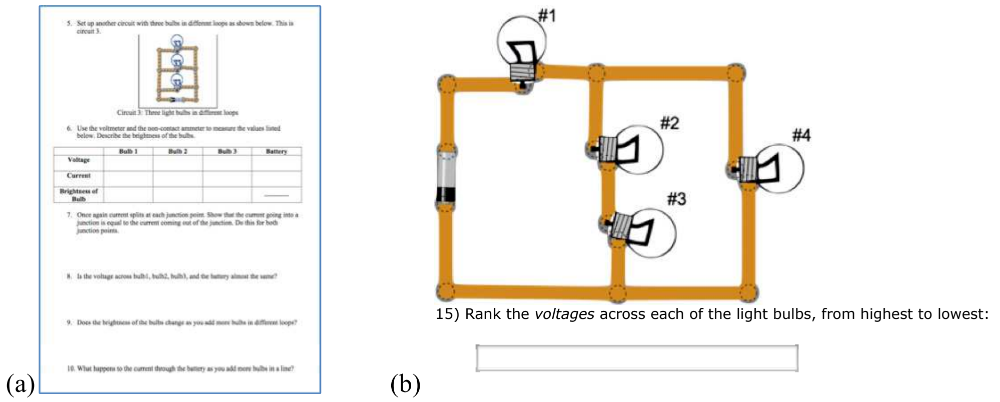

Figure 3. An example from the worksheet of the Scaffolded group (a) and an example of a post-test item (b).

The post-test covered both topics (light bulbs and resistors) and was administered online. All items in the test were conceptual and required no calculations (see Figure 3b). The post-test was a reliable measure of students' knowledge, with Cronbach $\alpha = 0.75$. The pre-test included a subset of the post-test items. Only items that had no diagrams in the post-test appeared also in the pre-test, in order to prevent a bias in students' inquiry towards regenerating pre-test questions. Three students had a perfect score on the pre-test and thus were removed from the analysis.

The attitudinal survey of success attributions and efficacy was adapted from Butler and Cartier (2004), and included ten Likert-scale items with two stems: 'I think that I can do a good job of…' and 'I think that I will succeed if I…' (see examples below). The same survey items were used before the first activity (pre-survey), between activities (mid-survey), and after the second activity (post-survey).

Analysis

Students were split to high- and low-prior knowledge groups, based on pre-test performance. The effects of condition and prior knowledge were evaluated using a MANOVA with light bulb and resistor scores from the post-test as the dependant variables and condition and prior knowledge (median split) as factors. Since there were two waves of data collection, and there were slight differences in the light bulb post-test items between the two waves, we use normalized z-scores throughout the analysis.

To analyze the attitudinal surveys, a factor analysis was run on each of the three time periods (pre-, mid-, and post-). The factors obtained in the post-survey were used to indicate which items can be averaged together to create summary scores for each student*time*factor. The factors from the final time period were used because they represent the final structure of the students' attitudes, and they are highly interpretable. This method allows us to see how students' answers to the items across the final factors changed over time, and to explore what variables might be influencing that change. Post-survey results indicated three, clear factors: The first factor, success expectations, includes items about students' expectations for success, such as '*Before I begin a PhET sim activity, I think that I will succeed if... I try hard'*. This factor included six items. The second factor, scientific reasoning, with two items, includes '*When I work on a PhET sim like the one in the example I think that I can do a good job of ...testing my ideas and theories'* and '*…exploring the topic'*. The last factor, memory and recall, also consists of two items: '*I think that I can do a good job of ...memorizing information about circuits'* and '*…answering given questions'*. Student scores on the items within each factor were averaged to give a summary score for each student on each of the three factors on the pre-, mid-, and post-survey. The summary scores for each of the time periods were then used as the repeated measures in a mixed design MANOVA, with prior knowledge and condition entered as independent variables, each with two levels.

An alpha level of 0.05 is used throughout the analysis.

Results

No significant differences were found between the Saffolded and Unstructred conditions on the pre-test, $t_{(95)} = -.12$, $p = .91$. Identical items between pre- and post-test show significant learning. Mean (SD): Pre: 0.47 (0.17); post: 0.62 (0.23); $t_{(96)} = 6.1$, $p < 0.0005$. Analysis of learning by prior knowledge shows that students with low prior knowledge learned more than students with high prior knowledge, though learning for both groups was significant: Low prior knowledge: from 0.33 (0.78) to 0.57 (0.22), $t_{(44)} = 6.5$, $p < 0.0005$; High prior knowledge: from 0.59 (0.13) to 0.67 (0.24), $t_{(51)} = 0.015$.

Learning as a Function of Prior Knowledge and Condition

A MANOVA with normalized performance on the light bulb and resistor tests, as a function of condition and prior knowledge, found a marginally significant condition*prior knowledge interaction, motivating further analysis of the two separate ANOVAs: Wilks' $\lambda = .952$, $F_{(2, 92)} = 2.3$, $p = .10$. Descriptive statistics of students' z-scores on both post-test sections are listed in Table 1.

Table 1: Normalized mean (SD) of learning outcomes by condition

(a) Light bulb post-test

	Unstructured	Scaffolded
Low Prior Knowledge	-.09 (1.11)	-.53 (.76)
High Prior Knowledge [a]	.07 (1.01)	.41 (.87) [b]

(b) Resistor post-test (notably, support levels refer to the previous activity, as all students worked with Unstructured activity in this activity.)

	Unstructured	Scaffolded
Low Prior Knowledge	-.33 (1)	-.30 (.74)
High Prior Knowledge [a]	20 (.92)	.33 (1.12)

[a] Main effect for prior knowledge, $p < 0.01$; [b] effect for prior knowledge within Scaffolded condition, $p < 0.05$.

The ANOVA for the light bulb post-test showed a significant interaction effect for prior knowledge*condition, $F_{(1,93)} = 4.0$, $p < .05$, $\eta^2_p = .041$. Planned contrasts indicated that within the Scaffolded condition, students with high prior knowledge significantly outperformed students with low prior knowledge: $t_{(93)} = 3.42$, $p = .001$. The same difference was not found within the Unstructured condition: $t_{(93)} = -.59$, $p = .56$. The ANOVA for the resistor post-test found a significant main effect for prior knowledge, $F_{(1,93)} = 8.71$, $p < .05$, $\eta^2_p = .086$.

Attitudes as a Function of Prior Knowledge and Condition

A repeated measures MANOVA with the three factors as dependent measures found that time*condition*prior knowledge was significant, supporting a further exploration with the independent repeated measures ANOVAs. Wilks' $\lambda = .850$, $F_{(6, 88)} = 2.58$, $p = .024$. Table 2 shows the results for the three attitudinal factors.

Table 2: M (SD) for factor summary-scores by prior knowledge and condition for pre-, mid-, and post-survey

(a) Memory and Recall

	Unstructured	Scaffolded [b]
Low	2.63(.63)	2.67(.62)
Prior	2.73(.61)	2.98(.56)
	2.42(.46)	2.79(.51)
High	2.71(.62)	2.41(.49)
Prior [a]	2.79(.64)	2.77(.44)
	2.85(.65)	2.79(.53)

(b) Scientific Reasoning

	Unstructured	Scaffolded
Low	2.82(.55)	2.79(.64)
Prior	3.06(.62)	3.11(.76)
	2.92(.76)	2.97(.76)
High	2.90(.55)	2.79(.49)
Prior	3.25(.56)	2.95(.49)
	3.15(.46)	3.14(.49)

(c) Success Expectations

	Unstructured	Scaffolded
Low	3.02(.46)	3.02(.51)
Prior	3.03(.47)	3.10(.70)
	2.98(.50)	2.88(.70)
High	2.95(.55)	2.79(.55)
Prior [a]	3.11(.62)	2.97(.49)
	3.08(.55)	2.98(.50)

[a] A significant time * prior-knowledge interaction, $p < 0.05$; [b] a significant time * condition interaction, $p < 0.05$

With regard to *memory and recall*, a repeated-measures analysis revealed significant interaction for time*condition: $F_{(2,186)} = 3.20$, $p = .038$, $\eta^2_p = .033$, and for time*prior-knowledge: $F_{(2,186)} = 4.19$, $p = .032$, $\eta^2_p = .043$. As seen in Figure 4a, students in the Scaffolded condition associated success with memory and recall during the mid-survey, that is, right after completing the activity that required them to answer questions. Interestingly, their increased attitudes towards memory and recall remained high also after the second activity, which was Unstructured for all students.

With regard to *success expectations*, the repeated measures ANOVA found a significant time*prior knowledge interaction, $F_{(1.79,166)} = 4.94$, $p = .022$, $\eta^2_p = .05$. As seen in Figures 4b,c, students with low prior knowledge began the study much more certain of their ability. However, their confidence dropped after the resistor activity. Students with high prior knowledge showed the exact opposite trend, gaining confidence from pre- to post-survey.

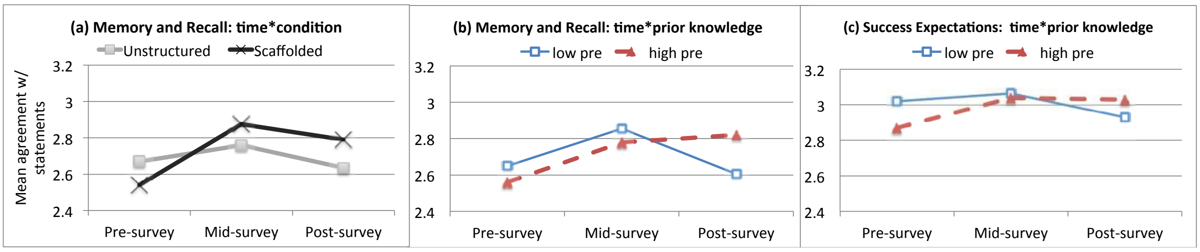

Figure 4. Significant interactions in the attitudinal data

No significant interactions were found with regard to the *scientific reasoning* factor. However, there was a significant main effect for time, $F_{(2,186)} = 13.64$, $p < .05$, $\eta^2_p = .13$.

Discussion

Our first research question focuses on the relationship between learning, prior knowledge, and scaffolding. In addition to finding a main effect for prior knowledge on learning outcomes, results show a somewhat surprising interaction of prior knowledge with condition. In the light-bulb section of the post-test, prior knowledge was very helpful for students who worked with the Scaffolded activity, but had no effect on performance among students working with the Unstructured activity. In fact, for students with low prior knowledge, performance on the Scaffolded condition was *lower* than the Unstructured condition. This result raises two questions: Why did the scaffolding help only students with high prior knowledge? And why did prior knowledge help students only in the Scaffolded condition?

With regard to the first question, only students with high prior knowledge benefited from the given scaffolding, suggesting that they were better able to infer relationships and generalize scientific rules based on the questions and diagrams they were given. Rather than limiting their inquiry, the scaffolding was used by high-prior students to engage in inquiry with better data. Novice learners, on the other hand, may have been cognitively overloaded by answering questions or filling-in tables so that they did not engage in the higher-order thinking that the worksheet had charted for them. In this case, it seems that the high scaffolding gave students with low prior knowledge a false sense of progress, as they could find values without understanding the patterns. This result highlights the tension between *successful behaviours* (i.e., completing the task), and *productive behaviours* (i.e., causing learning). While the high-level of scaffolding allowed students with low prior knowledge to engage in more sophisticated experimentation, it did not support learning. We previously found similar results in learning in a problem solving environment, where hints helped students with low prior knowledge to complete the given problems, but did not improve their chances of succeeding on future problems (Roll et al., 2014). Another clue for the negative (yet insigificant) effect of scaffolding on novice students in the light-bulb activity may be found in their use of intuitive knowledge. As mentioned above, students could have made significant use of grounded feedback (light intensity, electron movement, etc). However, the scaffolding required students to use more formal physics and measurement instruments. Thus, pushing students towards formal notaion and practices may pull them away from their intuitive ideas, and subseuently, hurts their learning. This is similar to the effect of equations vs. story problems among novice learners (Koedinger & Nathan, 2004).

Interestingly, these results are at odds with the expertise reversal effect (Kalyuga, 2007). While we found that students with high prior knowledge benefit more from high levels of scaffolding, the expertise reversal effect shows the opposite trend. One explanation for this difference is the given support. Our support gave students *more* responsibilities in terms of collecting data and running virtual experiments. Thus, the scaffolding that we used may have led to an increase in students' cognitive load. Kalyuga (2007), on the other hand, used worked examples. Thus, that scaffolding reduced students' cognitive load. Both forms of scaffolding can be useful – but apparently, for different populations.

The second finding shows that prior knowledge did not improve learning on the light bulb post-test for those in the Unstructured condition. It is possible that the prior knowledge of the high-prior students was too narrow and did not prepare them to conduct productive inquiry during this activity. While prior knowledge did not play a role in the light-bulb activity, it was a significant determinant of learning in the second activity. Given that both tasks were isomorphic for the Unstructured condition, why did prior knowledge improve learning in the resistor activity, but not in the light bulb activity? Notably, the resistor activity requires much better domain knowledge. Thus, the effect of prior knowledge on learning is not surprising. In the light bulb activity, grounded feedback may have helped low-prior students to overcome their lack of formal disciplinary knowledge.

Effect of Condition and Prior Knowledge on Attitudes

Our second research question focuses on the relationship between scaffolding, knowledge, and attitudes. The repeated-measures MANOVA found that all three attitudinal factors changed over time, supporting the notion that these motivational components are sensitive to contextual features. Interestingly, changes in attitudes generally tended to peak at the mid-survey, suggesting that students felt they knew what they needed to do to be successful based on their first activity. Perhaps this confidence was fostered by the grounded feedback from the PhET simulation on this activity, as the light bulb activity is much more intuitive than the measurement-intensive resistor activity.

Divergent patterns of success expectations based on prior knowledge can be noted from figures 4b-c. In the beginning, students with low prior knowledge tended to feel that they could navigate a path to success, whereas students with higher prior knowledge were not so confident. This difference in starting points may be due to a greater familiarity with the content or task demands by more expert students, while students with low prior knowledge may have suffered the dual burden of being unskilled and unaware (Kruger & Dunning, 1999; Roll et al., 2011). Students in both groups tended to peak at the mid-survey, and then switch trends: students with high prior knowledge maintained confidence, whereas more novice students saw a sharp decrease. This interaction may be interpreted as a realignment of success expectations where novice students have now gained the experience to adjust success expectations based on a more realistic understanding of the task and their abilities within the task. Although initial success expectations were not realistic, judging by performance on pre-test, students' expectations at the end of the study seem to reflect their actual knowledge.

Interestingly, students with high prior knowledge within the Unstructured condition did not perform as well on the light bulbs post-test, but did not seem to suffer much in terms of success expectations. Although this pattern may be explained by the pervasive influence of prior knowledge, it also seems to support the notion that students with high prior knowledge in the Unstructured condition had their content knowledge affirmed through the online simulation. Rather than pushing themselves to ask more advanced questions, these students appeared to be satisfied with their success and continued prospects for success, without actually making advancements in their knowledge about light bulbs.

Interactions were also noted in the memory and recall factor, where students predicted that they could be successful at memorizing information and answering questions. Figures 4a-b indicate significant interactions of time with condition and with prior knowledge. It is interesting to note that low ability students reported that they could be successful at memorizing information and answering questions, even though they did not seem to acquire much content knowledge by answering questions in the Scaffolded condition. Without basic conceptual understanding, merely filling in questions or memorizing facts is unlikely to support successful outcomes. This finding seems to support earlier suggestions that novice students, especially within the Scaffolded condition, may be more pre-occupied with answering questions than focusing on deeper relationships. In addition, an inquiry activity requires a different kind of thinking than that encouraged by focusing on memory and recall.

Last, the interaction between time and condition is especially interesting, as it transfers to the post-survey, when all students worked with the same activity. Simply put, the level of support on the first activity determined students' attitudes following both the first and the second activity. We can split graph 3a to two: First, in the mid-survey, students who worked with the Scaffolded activity were confident in their ability to remember facts and answer questions. This makes sense, as the activity asked students to do exactly that. The second component of the graph is more surprising. Scaffolded students trusted their ability to remember and answer also after the resistor activity, and even though that activity was Unstructured for all students. This result demonstrates the contextual nature of students' attitudes, and how attitudes are shaped by experiences and expectations. At the same time, it also shows some maladaptive behaviour, as Scaffolded students did not readjust their expectations to the unstructured resistor activity.

The study presented above has several limitations. First, the sample size is fairly small. Second, analysis of the attitudinal surveys showed different factors for the pre-, mid-, and post-survey. While we chose only to use the post-survey distribution to factors, understanding the shift in the factor analysis is of interest. Last, the study relies on self reports and test scores, and lacks process measures. Examining students' online behaviours and paper materials, and inferring their strategies form these data, would improve our understanding of the effect of scaffolding, prior knowledge, and attitudes on learning (Kardan, Roll, & Conati, 2014).

Summary and Implications

We describe a study with 100 post-secondary students using an online simulation for D/C circuits. During the first activity, half of the students received a high level of scaffolding (using an elaborate worksheet), while the other half received only learning goals. During the second activity, which was much harder, all students received only learning goals. Results show that the level of support in the first activity had an effect on students' attitudes in the second activity. Thus, it is important for instructors to realize the contextual nature of success attributions and efficacy, which can work in a cyclical manner to influence learning outcomes (Butler & Cartier, 2004).

Secondly, results show that while students who received a high level of support benefited from their prior knowledge, prior knowledge was not helpful in the Unstructured condition. Yet, this was the case only for the first activity. Learning in the second, and more challenging, activity, benefited significantly from prior knowledge. We hypothesize that students' intuition and grounded feedback play a role. In the light-bulb activity, students could engage in productive inquiry using situational cues (such as light intensity and electron speed). In the resistor activity, learning required the use of virtual measurement instruments, which was much harder for students with low prior knowledge.

Results also show that while the given scaffolding helped students with high prior knowledge, it was not effective for students with low prior knowledge. It seems that the scaffolding that we used, and which focused on giving students sub-goals and reflection questions, required more technical proficiencies from students, thus, increasing their cognitive load. Also, it may have focused students on values and formalities rather than intuitive ideas. As a reminder, this support was modeled after common classroom activities. Thus, intuitions about the utility of different support mechanisms may not be confirmed by data (Koedinger & Nathan, 2004). Rather than debating high versus low levels of support, it may be beneficial to identify which support, for what tasks, is useful for which learners.

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