Learning Science through Knowledge-Building and Augmented Reality in Museums

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Abstract: Although learning science in non-school settings has shown great promise in terms of increasing interest and engagement, few studies have systematically investigated and produced evidence of improved cognitive gains and higher order inquiry skills. Furthermore, little is known about what and how students learn through the digital technologies that are increasingly being used in these non-school settings. Through an experimental design, this study compared four conditions for learning science concepts with augmented reality technologies in a science museum. Using knowledge-building scaffolds known to be successful in formal classrooms, we hypothesized that students would show greater cognitive gains and higher order inquiry skills than when scaffolds were not used. Through the use of digital augmentations, the study also provided information about how such technologies impact learning in informal environments.

Introduction

The issue of declining participation by America's youth in science, technology, engineering, and math (STEM) education and careers has received a great deal of attention over the last few years from industry, government, and education sectors (Business Roundtable, 2005; Domestic Policy Council, 2006; U.S. Department of Education, 2007). Experts predict that the availability of STEM jobs will continue to increase such that, by 2012, the number of positions in science and engineering will have outpaced the number of qualified people to fill them by 26% and 15% respectively (NSF, 2006). Additional pressures on workforce development exist with the emphasis on 21st century skills (Partnership for 21st Century Skills, 2007) by which learning from and using digital technologies both for developing conceptual knowledge and process skills must figure prominently in education. As new scientific and technological developments continue to impact people's lives, there is further interest in providing educational opportunities that will increase general levels of scientific and technological literacy. Given this enormous need, there is increasing recognition that STEM education can no longer be the sole responsibility of formal schooling. The recent National Research Council (NRC) report on learning science in informal environments (Bell et al., 2009) examines the potential that non-school settings such as zoos, aquaria, and museums have for engaging large portions of the population in real-world scientific investigation. Furthermore, the report notes, where NCLB requirements have limited the amount of in-school science instructional time, informal programs actually serve as essential venues for learning. However, the report and others (Rennie et al., 2003) also highlight the need for systematic studies of learning designs in order to realize the potential for the field of informal science to contribute to STEM education and career development.

This study investigated three related critical gaps in understanding of informal learning, as outlined in the NRC report. First, while there is ample evidence of increased levels of interest and engagement, evidence for improved cognitive gains is less convincing. This is partially due to the free choice, episodic structure of activities characteristic of informal environments. Second, as more educational technologies are being used to assist in the development of conceptual knowledge, little is known about how digital platforms improve the learning experience in these settings. Finally, while designed interactive activities have been shown to increase important scientific skills—such as manipulating and observing—higher order inquiry skills—such as reflection, making predictions, drawing conclusions, constructing generalizations, and argumentation—are less frequently demonstrated. This study considered these critical gaps together by investigating the effects of digital platforms in an informal environment on cognitive gains, with particular emphasis on higher order inquiry skills. Using knowledge-building scaffolds for peer-to-peer discursive interaction and collective knowledge construction (Scardamalia, 2002), the study aimed to determine whether and how learning through digital platforms might be enhanced through a knowledge-building design, which had not previously been applied in informal environments. The research was conducted at a premiere science museum in a large urban city in northeast USA using augmented reality visualization technologies. The specific questions investigated were: 1) In what ways do digitally augmented visualizations of scientific phenomena assist learners in developing conceptual understanding in a museum environment? 2) To what extent do knowledge-building scaffolds added to visualizations improve higher order inquiry skills? and 3) How can knowledge-building scaffolds, that are highly successful in sustained and continuous classroom activities, be adapted to support single-visit episodic and free choice engagement in museums?

Theoretical Considerations

The following three areas of research in STEM education and the learning sciences informed the study's goals. *Digital Augmentations and Visualizations*: Augmented reality applications or digital augmentations of real-world phenomena have increased in formal education and other knowledge domains such as medicine over the last few years (John & Lim, 2007; Klopfer & Squire, 2008). Digital projections are programmed to enhance an object or environment in order to simulate or visualize information that is not normally observed. For example, in one game called *Environmental Detectives*, students can access virtual underground water sources to determine impacts of a toxic spill (Klopfer & Squire, 2008). Visualization tools in science education research have been found to produce positive learning gains such as challenging and correcting misconceptions (Tasker & Dalton, 2008), concretizing abstract theories (Dori & Belcher, 2005), and understanding scale of agents within systems (Sengupta & Wilensky, 2009). Although one group of researchers found positive outcomes in terms of interest and engagement when using augmented reality devices in a museum setting (Waite et al., 2004), little is known about cognitive impacts. *Knowledge Building and Scaffolds*: With respect to improving conceptual understanding and promoting higher order inquiry skills, one pioneering program of research in the learning sciences involves computer-supported intentional learning environments (Hewitt & Scardamalia, 1998; Scardamalia & Bereiter, 1994). Both the technological application and associated pedagogy use educational scaffolds to enable public, collective contributions that shape the knowledge constructed in the learning community. Such scaffolds include prompts for consensus building, generalizations, differentiation between evidence and theories, peer evaluation, and argumentation. For example, a prompt such as "*My theory is...*" encourages students to use evidence to construct a more general understanding of a class of scientific phenomena. Similarly, the act of creating a "rise above" note provides students with opportunities to think across diverse ideas and to offer conclusions about how the collective community views a scientific issue such as the benefits of genetic engineering (Yoon, 2008). *Learning in Informal Environments*: As noted in the NRC report, learning in informal spaces is fluid, sporadic, and participant driven—characteristics that are thought to increase engagement over highly structured formal classroom experiences. Often learning activities occur in single-visit episodes (Falk & Dierking, 1992) where individuals learn on their own with little follow-up or reflection. To date, knowledge-building programs have been used in formal classroom environments where there are opportunities for extended, recurring investigations—opportunities that informal environments generally lack. However, there is some evidence from museum visitor studies, that significantly greater cognitive gains can be achieved when objects are accompanied by interpretive labels (a simple form of scaffolding) than when there is no structure provided (Allen, 1997; Borun & Miller, 1980), suggesting that common ground between the two environments may exist. These results, and the positive impact of knowledge-building activities when coupled with computational tools, provide the rationale for undertaking this study.

Methodology

Participants and Context

Study participants were recruited from 6th and 7th grade classes who attended the museum on a field trip. This grade band was chosen deliberately. By middle school, most children are developmentally able to theorize about scientific phenomena. Furthermore, the study's scientific content was electricity, which local standardized curriculum covers in grade 4. Thus, all students would have some prior knowledge to access. The classes came from three schools within a high needs urban school district with an average of 92% of students qualifying for free or reduced price lunch. 119 students participated, with a gender ratio of 55% female to 45% male. While this was not the first time these students had visited the museum, it was the first time they had been invited to participate in learning research with the museum's educators.

The study leveraged a currently funded large scale National Science Foundation informal science education project in which the central goal is to design, integrate, and increase the use of educational technologies within the museum experience. Several tools are under construction including digitally augmented exhibit devices. While the larger project focuses on the viability of using digital technologies in informal settings, the present study extended this focus by investigating what and how scientific concepts were learned through such applications. The investigation used a prototype exhibit device called "Be the Path" that illustrated electrical conductivity and circuits (see Figure 1). The students had no previous access to this device which consisted of two metal spheres on a table, approximately one foot apart, with one connected by a wire to a battery and the other connected to a light bulb. The students attempted different configurations to complete the circuit and light the bulb by touching the balls. Once the circuit was completed, a projected visualization of electrons flowing around the complete loop appeared. The instructions on the device provided little direction, simply suggesting "try to complete the circuit."

Students were grouped into four conditions such that each of the three participating schools had some students encountering each of the four conditions so that each condition analyzed below includes students from three schools. The conditions were constructed to represent increasing use of scaffolds for learning through digital augmentations and knowledge-building structures. Condition 1 (C1) served as the control group with no digital augmentations or knowledge-building structures. Condition 2 (C2) represented the device with the digital augmentation but no other scaffolding. This condition was designed to represent the average museum visitor who participates mainly through hands-on sensory experiences or trial and error (Bell et al., 2009). Condition 1 and 2 also directly address the first research question, which is to understand the impact of digital augmentation on conceptual understanding. Condition 3 (C3) featured some scaffolding in which the equivalent of labels in the form of directed questions were posted in the room for participants to reference. This condition was designed to represent the ideal scenario for exhibit designers as they provide labels, signs, and explanations with the expectation that visitors will read them. The posted questions were: What happens when you touched both metal spheres? When you touched only one? What happened to make the light bulb light up? What does the projection show? What are you supposed to learn by using this device? Condition 4 (C4) represented the condition in which both digital augmentation and knowledge-building applications were used. Students were instructed to work as a group of three. Each group was given the same questions as students in condition 3 and additionally asked to brainstorm possible answers, give reasons for each, decide as a group, and write their collective response on a worksheet. These directions were listed in a small box at the top of the worksheet. Other knowledge-building scaffolds were added to the worksheet questions in the form of directed prompts such as "*Our hypothesis is...*" and "*Our theory is...*" Students also had access to a bank of completed worksheets which were posted on the wall in order to evaluate their own ideas against others through two more knowledge-building scaffolds: "*Others have said...*" and "*We agree/disagree with them because...*" Conditions 3 and 4 were constructed to respond directly to the second two research questions, which investigated whether knowledge-building scaffolds increased higher order thinking and how a knowledge-building process might be adapted to informal environments. Students in conditions 1, 2, and 3 completed the worksheet individually after they finished playing with the device while students in condition 4 actually completed the worksheet during the experience.

Figure 1. Be the Path Device with Digital Augmentation.

Students were randomly assigned to each condition. As the study was embedded in a whole class trip to the museum, we wanted all students to participate in the activity. However, logistical factors subsequently caused variation in the number of participants analyzed in each condition. Some students lacked authorized consent to participate forms. Other students were absent for the pre-test data collection. See Table 1 for the number of participants in each condition.

Table 1: Number of participants in each condition.

Condition	Number of Participants
1	18
2	22
3	31
4	16 groups of 3 (48)

Data Sources and Analyses

Four data sets were collected and analyzed through a mixed-methods approach.

1. A conceptual knowledge survey was administered to students in each group before and after the intervention. The survey posed five general multiple choice questions related to the scientific topic of electrical conductivity and circuits such as, "Which class of elements best conducts electricity?" An open-ended question on the survey also solicited responses that demonstrated knowledge directly related to the device experience, i.e., "Think about an electric circuit that supplies electricity to a light bulb. What parts

make it work so that the bulb lights up?" These responses were coded on a five point Likert-scale from no understanding (0) to complete understanding (4). Collectively, the highest possible score on the conceptual knowledge survey was nine. A paired-samples t-test was conducted to determine whether there was a statistically significant gain in conceptual knowledge within each condition. A repeated measures ANOVA was conducted on the data set to determine whether there was a statistically significant difference between the mean gains.

2. With respect to worksheet responses, the last question, "What are you supposed to learn by using this device?" was intended to elicit responses that demonstrated generalized higher-order thinking, i.e., understanding of electrical circuits and how the human body functioned as a conductor in the device experience. Responses were scored on a four point Likert-scale from no understanding (0) to complete understanding (3). A response that demonstrated complete understanding satisfied the following criteria:

   Level 3 Description:
   - Student identified that the human body can complete a circuit to conduct electricity.
   - Student identified both concepts (completed circuit and conductivity).
   - Student demonstrated accurate understanding of both concepts, even if the terms "circuit" or "conduct" are not explicitly used.
   - Student correctly used simile or metaphor to explain concepts.
   - Even if student identified all components, if a part of the answer is wrong or contains a misconception, it cannot count as complete understanding.

   An ANOVA was conducted on the data set to determine whether there was a statistically significant difference in responses between the conditions and a post-hoc Tukey analysis was conducted to determine the source of the difference.
3. In order to investigate how knowledge-building scaffolds impacted the nature of the museum visit, 10 groups (30 students) in condition 4 were randomly selected for short interviews. Questions solicited responses from students to determine the utility of worksheet questions and the knowledge-building scaffolds in helping them learn about the scientific topic. Responses were summarized and used to identify which scaffolds were more or less effective. Responses of scaffold helpfulness were tallied and a chi-square test was conducted on the frequencies in each scaffold category.
4. The last data source integrated observation field notes and anecdotal reflections from the five researchers. These notes and reflections were used to triangulate findings from the other data sources and also to provide plausible rationales and further hypotheses that might explain the results we obtained.

For the open-ended questions on the conceptual knowledge survey and the worksheet, the data were qualitatively and systematically mined by the researchers (Strauss & Corbin, 1998). Codes were established, a categorization manual was constructed, two external graduate students were trained on the coding scheme, and inter-rater reliability was obtained on 20% of the data (35 mixed pre- and post-intervention open-ended responses and 18 worksheet responses). In both cases, greater than 90 percent agreement was obtained.

Analysis

Conceptual Knowledge Survey

Figure 2 shows the mean raw scores obtained for pre- and post-intervention conceptual knowledge surveys in all four conditions. Over all, across pre- and post-intervention surveys, the means were low, ranging between 2.6250 to 3.6818. Students in C2 (the condition with just the digital augmentation) had the greatest gains and the highest raw score on the survey.

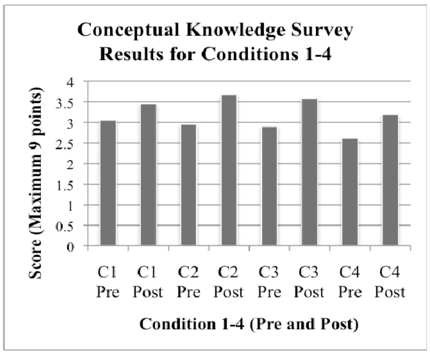

Figure 2. Means of Raw Scores for Pre- and Post-Intervention
Conceptual Knowledge Surveys for Conditions 1-4.

Table 2 shows the results of paired-samples t-test conducted within each condition. The table shows that gains in all conditions except C1 were statistically significant. However, the repeated measures ANOVA showed no significant differences between the mean gains. From the observation field notes and anecdotal reflections, researchers identified some difficulties students had in referring to and completing the worksheet questions and the post-surveys in C3 and C4. These students wanted to rush through the activity in order to participate in the rest of the field trip and appeared to put less effort into the post-intervention surveys.

Table 2: Results of paired-samples T-Test comparing means within conditions.

Condition	Mean Difference	SD	t	df	Sig. (2-tailed)
1	.38889	1.81947	.907	17	.377
2	.72727	1.07711	3.167	21	.005*
3	.67742	1.83280	2.058	30	.048*
4	.56250	1.41280	2.758	47	.008*

* $p<0.05$

Worksheet Responses

The analysis of worksheet responses that evaluated students' abilities to generalize about electrical circuits and conductivity yielded some positive results toward understanding the impact of the different study conditions. Figure 3 shows an increasing trend from C1 to C4 in the means obtained of generalized higher-order thinking. Out of a possible score of 3—which indicated a complete understanding—students in C4 scored the highest with a mean score of 2 (representing the category of Partial Understanding) while students in the remaining conditions scored between 1 (Little Understanding) and 1.5.

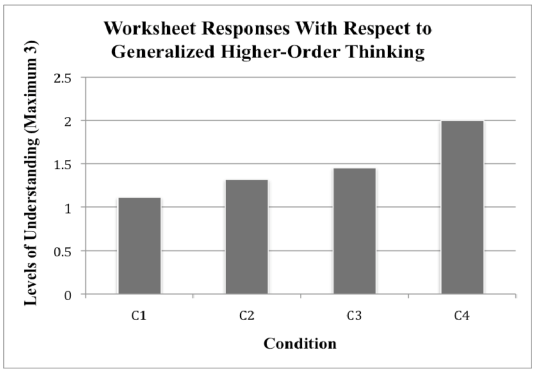

Figure 3. Mean Scores of the Generalized Higher-Order Thinking Analysis for Conditions 1-4.

An ANOVA showed a significant difference between the means of the four conditions, *F*(3)=4.560, *p*=.005. A post-hoc Tukey analysis showed that the difference was attributable to the higher mean of C4 which was significantly higher than C1 (*p*=.004) and C2 (*p*=.028), and marginally higher than C3 (*p*=.077). Sample responses from students in C4 along with their codes compared to responses from students in other conditions illustrated these results:

Student 1 (C4):	I learn the body can act like wires to connect stuff and there are electric charges in the body. (score = 3)
Student 2 (C4):	How our body transported electricity through the circuit into the metal spheres to make the bulb and images appear. (score = 3)
Student 3 (C2):	You have electrical currents in your body. (score = 1)
Student 4 (C3):	How energy flows through your body. (score = 2)

Interview Responses

In the small group interviews, condition 4 students were asked to provide responses about whether they believed the following five categories of worksheet and knowledge-building scaffolds were helpful: worksheet questions; directions on how to work in a collaborative group listed at the top of the worksheet; collaborating in a group; knowledge-building prompts; and a bank of answers from other groups. Figure 4 shows a graph of student responses in each of the categories. There was unanimous agreement that collaborating in a small group was helpful while the directions at the top of the worksheet were least often identified as helpful. Greater than 50 percent of the students said that the remaining three categories of scaffolds were helpful. When asked what they thought was the most and least helpful scaffold, 100 percent of the students identified collaborating in a group as most helpful. The least helpful scaffolds were identified as the knowledge-building prompts (57 percent) and the directions (37 percent). However, there is some evidence to suggest that students had difficulties understanding why the prompts were included. For example, one student said, "We didn't even know what they was about, like, but we just put an answer that others have said, like on the board." When students did understand the rationale behind including the prompts, their helpfulness increased. For example, one student answered, "Because we knew what we was supposed to give. Like the hypothesis, what we believe it is, and the theory is what we think it is." Other students said that they weren't accustomed to answering questions like that. Thus, responses to whether or not students felt the knowledge-building prompts were helpful appeared to be influenced by their familiarity or understanding of the prompt vocabulary such as "hypothesis" and "theory." Similarly, with the directions, some students stated that they didn't read them because they were just focused on answering the questions. The following interviewer and group exchange illustrated this point:

> Interviewer: Alright, remember these directions in the box. OK? Did these directions help you figure out how to come up with the best answer?
> Student #1: Didn't read them.
> Interviewer: You didn't read them?
> Student #1: Nope.
> Student #2: I didn't see it.
> Interviewer: What about you?
> Student #3: I didn't read nothing.
> Interviewer: You didn't read them. OK. So why did you guys not read this?
> Student #1: I don't know, it's just like...
> Student #2: 'Cause we was studying. We was focused on the questions.

Comments in the researcher field notes and anecdotal reflections support this finding. After a longer interaction with the device than the other three conditions, some students appeared to be anxious to complete the worksheets and had a "just get it done" disposition. Still, considering students in condition 4 showed greater ability to generalize from the experience (Figure 3), the worksheet and knowledge-building scaffolds seemed to provide some utility in terms of learning the content. A chi-squared analysis revealed a statistically significant difference between the frequencies found in the five categories, $x^2 = 9.96$, p=.0411.

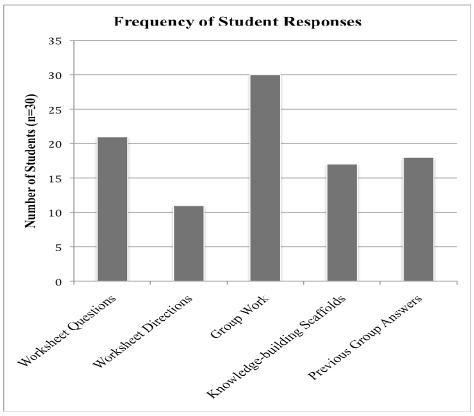

Figure 4. Frequency of Student Responses Indicating Helpfulness of Categories of Worksheet and Knowledge-Building Scaffolds.

Discussion

The explanation and implication of study findings are discussed in order of the three research questions.

1) In what ways do digitally augmented visualizations of scientific phenomena assist learners in developing conceptual understanding in a museum environment?

The results of the conceptual knowledge survey that tested for increases in general knowledge of electrical conductivity and circuits showed that only students in condition 1 (no digital augmentation) did not demonstrate a significant increase in their understanding after manipulating the device. This finding suggests that the digital augmentation did have an impact on conceptual knowledge. The fact that students had the greatest gains in condition 2 (just digital augmentation and no other scaffolds) suggests that other scaffolds may not have been necessary to increase learning of these general concepts. However, the results found an increased higher order thinking from students in condition 4, suggesting that scaffolds might be necessary to reach more advanced learning. Both findings are consistent with other research. For example, Klopfer and Squire (2008) found that students were basically able to solve the simple problem, but required additional teacher supports to resolve more complex issues. Similarly, John and Lim (2007) found that although students learned from the medical training augmentations, the learning gains were enhanced when combined with pedagogical scaffolds. There are other plausible explanations for why differences in learning outcomes between the conditions were found in the conceptual knowledge survey. In research meetings, one researcher on the team discussed the idea that the scaffolds may have overly formalized what was supposed to be an informal experience, e.g., reading worksheets, following directions, and filling them in. This researcher was the main observation field note taker. She recalled that the feeling in the room was markedly different between the conditions. Students in condition 2 were generally more playful and experimenting on their own—much like students would normally behave on the museum floor. Students in conditions 3 and 4, however, were more serious and referred to the questions to dictate their next steps thereby missing the important concepts—much like traditional classroom instruction. Another explanation that may be related to this over-formalization is the fact that students in conditions 3 and 4 spent more time with the device and the post-intervention survey questions were the last thing standing in the way of running off to participate in other nearby museum exhibits such as the Sports Challenge. Thus, their rushed responses may not be an accurate indication of what they learned.

2) To what extent do knowledge-building scaffolds added to visualizations improve higher order inquiry skills?

As noted earlier, while there appeared to be no significant effect of the worksheet and knowledge-building scaffolds on increasing learning of concepts, students' abilities to generalize from their hands-on experiences, which we have interpreted as a higher order inquiry skill, showed differences across the conditions. The increasing trend in Figure 3 appears to be related to the number and kinds of scaffolds students were exposed to while manipulating the device. Students in condition 4 (with all scaffolds available) were better able to generalize their understanding than the other condition participants and the ability to generalize also appeared to relate to the presence of scaffolds. This finding is relevant to the field of informal science learning in that we provide some evidence that indicates that a modified knowledge-building approach may be useful in helping students learn science beyond simply manipulating and observing phenomena (NRC, 2009). Furthermore, through our investigation of a kind of learning design, we believe that this study responds to the call for more systematic research that identifies how learning science in informal science environments can impact the broader goals of STEM education (Rennie, 2003).

3) How can knowledge-building scaffolds, that are highly successful in sustained and continuous classroom activities, be adapted to support single-visit episodic and free choice engagement in museums?

Although the results for question #2 were encouraging, we were also interested in identifying which scaffolds were most helpful in terms of learning science in the museum. From the interview data analysis, it appears that the findings were mixed. Overall, students identified the ability to collaborate with each other as the most helpful scaffold, which is consistent with other knowledge-building studies (e.g., Yoon, 2008) and studies on collaborative learning (Dillenbourg & Schneider, 1995; O'Donnell & O'Kelly, 1994). One of the important design constraints that challenged the research team during construction of the condition activities was the notion of deep investigation over an extended period of time that is characteristic of successful knowledge-building classrooms (Scardamalia, 2002). We were concerned that the single-visit episodic nature of museum learning experiences would greatly inhibit the ability for students to knowledge build. To be clear, we are not claiming to have achieved knowledge building in this study. Rather, we are addressing the ability to use knowledge-building scaffolds to promote learning in informal environments. Those scaffolds were represented by the directions to collaborate, the collaboration itself, knowledge-building prompts, and the bank of other group responses intended to simulate the use of "rise aboves." From the interview data, there is evidence to suggest that there is some utility when students are familiar with the terms and processes. However, to ensure that all students receive the intended learning benefits of knowledge building, more time needs to be devoted to learning the terms and processes which would take longer than one activity during a single visit affords. This constraint in addition to our hunches about the over-formalization of informal activities and the increased higher order skills in the last condition has led the team to conclude that further investigation is warranted.

Conclusions and Future Research

Results of the study suggest that digital augmentations can help in conceptual development of science content. They also suggest that higher order thinking with respect to being able to generalize from the museum experience can be improved through the use of worksheets and knowledge-building scaffolds. While students unanimously said that collaborating in small groups was helpful and a majority of students said that the worksheets were helpful, the utility of the other scaffolds is inconclusive. Preparations for another study are underway with the following modifications. For C4, since it was not clear that students had actually read the directions, they will be read aloud. Rather than a suggestion, students will be required to consult the bank of previous answers before they construct their own. Students will also be instructed briefly about what the knowledge-building prompts mean and, finally, the post-intervention surveys will be administered the day after their museum visit rather than immediately after the activity. To address the issue of over-formalization, another condition will be added between conditions 3 and 4 in which we will post the worksheet questions but with the directions, knowledge-building prompts, and the bank of previous group answers added. In this condition, students will also work in small groups but will not be required to fill in the worksheet while they are interacting with the device.

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