Scaffolding Informal Learning in Science Museums: How Much Is Too Much?

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ABSTRACT: This research follows on a previous study that investigated how digitally augmented devices and knowledge building could enhance learning in a science museum. In this study, we were interested in understanding which combination of scaffolds could be used in conjunction with the unique characteristics of informal participation to increase conceptual and cognitive outcomes. Three hundred seven students from nine middle schools participated in the study. Six scaffolds were used in various combinations. The first was the digital augmentation. The next five were adaptations of knowledge-building scaffolds. Results demonstrated that digital augmentations, posted questions, and participation in collaborative groups may be the optimal design for improving conceptual learning (content knowledge) while preserving informal participation behaviors. However, our results also showed that obtaining deeper cognitive gains such as ability to theorize only occurred in the most highly scaffolded condition in which students demonstrated much decreased informal participation behaviors. We discuss the implications of our results with respect to the broader research on improving learning in informal science learning environments. © 2013 Wiley Periodicals, Inc. Sci Ed 97:848–877, 2013

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INTRODUCTION

Increasingly, informal science environments have been highlighted for their potential to improve science understanding and participation in daily science activities and scientific careers (Banks et al., 2007; National Research Council [NRC], 2009, 2011). There are many good reasons for this, which include engagement, fun, and self-directed learning (Falk & Dierking, 1992, 2000; Little, Wimer, & Weiss, 2008), qualities that often stand in contrast to traditional formal school experiences (NRC, 2009). However, these unique informal learning characteristics also, in part, pose challenges to developing a deeper understanding of science content and practices (McManus, 1994) due to learning that occurs in typically short, sporadic visits (NRC, 2009; Silverstein, Raue, Nyre, MacAllum, & Miyaoka, 2008). Thus, there has been growing emphasis on increasing the impact of these environments on conceptual (content) and cognitive (thinking processes) development through designing additional learning scaffolds such as postvisit Web activities and follow-up e-mail contact (NRC, 2009). Technological tools for enhancing learning and engagement in informal settings have also gained momentum (e.g., Falk & Dierking, 2008; Hall & Bannon, 2006) and can potentially serve the purpose of scaffolding extended experiences to improve short-term learning.

Over the past 3 years, our research team has conducted a series of studies that investigates how digitally augmented devices and knowledge-building scaffolds (Scardamalia, 2002; Scardamalia & Bereiter, 2006) can enhance science learning in a science museum (Wang, Yoon, Elinich, & Van Schooneveld, 2012; Yoon, Elinich, Wang, Steinmeier, & Van Schooneveld, 2012; Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012; Yoon & Wang, 2013; Yoon, Quintana, Lyons, Perry, Osterweil, & Lindgren, 2013). In the series, we use a quasiexperimental design in which students in multiple conditions interact with a museum device using digitally augmented information and various arrangements of knowledge scaffolds. Results thus far have suggested that digital augmentations can help in conceptual development and that students’ abilities to interpret information about a phenomenon using knowledge-building scaffolds can improve cognitive understanding in some conditions (Yoon, Elinich, Wang, Steinmeier, & Van Schooneveld, 2012; Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012). However, one major concern that emerged in our observations of student interactions in the more highly scaffolded conditions is what we called “overformalization” of the learning experience that appeared to be needed to achieve those results (Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012). Specifically, when students were asked to use learning scaffolds that were presented through, for example, student response sheets with knowledge prompts, students appeared to be less explorative and referred to the scaffolds to dictate their next steps in the exploration. Students in less formally structured conditions appeared to experiment more and asked their own questions to direct their own learning—much like students would normally do in museum exhibits during a school field trip. These observations, however, were anecdotal and did not result from a systematic investigation of how student behaviors and interactions differed with the device and different scaffolds. Given that benefits from informal participation are centrally contingent on the freedom and flexibility that visitors experience, understanding conditions that enable the preservation of informal behavior while improving learning outcomes is a prudent next step in our research.

In this study, we aim to investigate the issue of overformalization. Specifically, the research question we seek to answer is, Which combination of learning scaffolds can optimally be used in a science museum taking into consideration the unique characteristics of informal participation to increase learning outcomes?
THEORETICAL CONSIDERATIONS

In this section, we review some of the important educational literature that frames our understanding of the application of augmented reality (AR) as scaffolds to improve learning in informal environments, core features of knowledge-building scaffolds that we interpret for informal settings, and characteristics of informal learning environments and participation that may be impacted by the addition of different learning scaffolds.

Augmented Reality as a Scaffold for Learning

In the most recent Horizon Report, the New Media Consortium (2012) discusses the enormous potential AR capabilities have on learning and assessment in enabling people to construct new understanding. AR experiences layer digital displays over three-dimensional real-world environments (New Media Consortium, 2012), thereby providing access to normally hidden data that users can use to develop deeper knowledge about a phenomenon or take a different immersive perspective to broaden their understanding. In the past decade, practical uses of AR have emerged in fields such as games, marketing and advertising, films, navigation, and for medical and military applications (El Sayad, Zayed, & Sharawy, 2011). Although newer in education, over the past few years, there have been studies that illustrate AR’s potential for learning, particularly in the field of science education. For example, Dunleavy and colleagues (2009) document high student engagement influenced by the ability to collaboratively problem solve and collect data in the real world in their Alien Contact! handheld AR environment. Squire and Klopfer (2007) detail the impact of their AR game Environmental Detectives on accessing student prior knowledge by connecting academic content to physical spaces that students are familiar with. In Outbreak @ The Institute, Rosenbaum and colleagues (2007) document the affordance of their AR game play, which included authentic scientific inquiry to understanding the dynamic nature of system interactions. In these studies, the indirect correlates of student learning, that is, engagement, prior knowledge, and processes in scientific practice, are important outcomes of the research and provide valuable impetus for pursuing further studies on what and how students learn in terms of scientific knowledge.

AR technologies have also been incorporated in museums to enhance visitors’ experience by improving their interest, engagement, and access to information (Baber et al., 2001; Damala, Cubaud, Batino, Houlier, & Marchal, 2008; Hall & Bannon, 2006). For example, Szymanski and colleagues (2008) examined how two different electronic guidebook prototypes affected visitors’ social interaction. As visitors toured a historic house, the guidebooks provided information about the historic artifacts that the visitors encountered. Results indicated that these guidebooks led visitors to engage in more content-rich discussions with each other. Furthermore, their exploration of the room and its objects was enhanced (Szymanski et al., 2008). Similarly, Baber et al. (2001), in testing three different AR platforms in an art museum, discovered that different devices elicited various lengths of visitor viewing times and visitor preferences. Damala et al. (2008) also tested an AR-enabled mobile multimedia museum guide in a fine arts museum and found that visitors enjoyed the playful content presentation that the museum guide enabled. Finally, Hall and Bannon (2006) investigated the effects of a digitally augmented exhibit on children. When children were given radio-frequency identification (RFID) sensors that could detect exhibit locations and unlock virtual information, their interest and engagement increased. Collectively, these studies demonstrate the impact that AR can have on visitors in a museum setting in terms of increasing engagement, interest, and access to information through scaffolded experiences.
Encouraged by this previous research, we envisioned the use of AR as scaffolds for knowledge improvement in museum learning environments. The study presented here addresses the real need for learning research (NRC, 2009) in informal environments by using knowledge-building scaffolds in a science exhibit to see whether the well-documented benefits of scaffolding might transfer accordingly. In the next section, we describe our rationale for using scaffolds and discuss, in particular, the use of knowledge-building scaffolds to improve learning.

Learning Through Knowledge-Building Scaffolds

The use of scaffolds in educational technology applications has been researched fairly extensively to support scientific inquiry and cognitive tasks (e.g., Quintana et al., 2004). In particular, a long-standing program of research in the learning sciences that is premised on designing learning environments through the intentional application of technological and pedagogical scaffolds is knowledge building (Bereiter, 2002; Scardamalia, 2002; Scardamalia & Bereiter, 2006; Yoon, 2008). This approach is centrally focused on the goal of improving ideas in the same way that knowledge work is done by experts in real-world contexts (Scardamalia & Bereiter, 2006). Primarily applied in school classrooms, knowledge-building studies have been shown to increase student scientific abilities in explanation, interpreting and evaluating information, and knowledge advancement (van Aalst, 2009). Students also acquire deep theoretical understanding of scientific phenomenon through collective sustained inquiry and research on problems that can range from what causes leaves to change color in the fall in a Grade 1 classroom (Scardamalia, 2002) to the complex influences on genetic engineering research with middle and high school students (Yoon, 2008; 2011).

The technological application knowledge forum 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, and peer evaluation. 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, students can create a “rise above” note, enabled by an archived database of peer exchanges. This is a synthesis of an idea or theory from a collection of previous peer exchanges that provide students with opportunities to think across diverse perspectives and to arrive at conclusions about how the collective learning community views a scientific issue (Yoon, 2008).

Collaboration also factors prominently into the knowledge-building approach. By working with others discursively to solve problems, evaluate evidence, and identify important shared understanding, students are able to reflect more deeply on what they know rather than learning independently or learning through textual modes. This decentralized, public, and distributed participation promotes what Scardamalia (2002) calls collective cognitive responsibility, where the impetus for learning is generated by consensus within the community rather than by the teacher.

From this set of theoretical and pedagogical descriptions, our series of studies uses various degrees of what we refer to collectively as knowledge-building scaffolds. These include sentence-starter knowledge prompts, a bank of peer ideas, working in collaborative groups, instructions for generating consensus, and response sheets for recording shared understanding. However, because knowledge building requires the development of a community with shared understanding, language, and goals, learning events evolve over longer periods of time than informal environments may allow. Van Aalst (2009) characterizes learning experiences that are less focused on the community as knowledge construction.
in which students may collaborate in small groups on tasks that require less synthesis and reflection on the knowledge advancement process. We have understood the limitation of our informal setting and population in terms of achieving a true knowledge-building community in previous studies (e.g., Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012) but have nevertheless attempted to investigate how aspects of knowledge-building pedagogy can be applied in informal environments given its success in formal classrooms. The issue of overformalizing the experience was a phenomenon that emerged as an important context-dependent factor in considering how informal learning takes place (Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012), which is the subject of this study. In the next section, we describe the distinct features of learning in informal environments.

Features of Informal Learning Environments

Learning in informal spaces is fluid, sporadic, social, and participant driven—characteristics that contrast the highly structured formal classroom experience (Honey & Hilton, 2011; NRC, 2009). Activities are often conducted with little to no direct facilitation from museum staff and are highly influenced by the visitors’ personal choice, interests, and agenda (NRC, 2009). McManus (1994) has characterized typical visitors as demonstrating scouting behaviors within museum exhibits, where they roam around, encounter devices, and act quickly to discover the intended information. Thus, more systematic learning studies are difficult to design. However, science museum exhibit developers do intentionally design learning spaces that mix a variety of supports for learning. For example, exhibit devices (individual interactive kiosks within the larger exhibit) are deliberately grouped and arranged to encourage progressive engagement with topics (Grinell, 2006) in support of the exhibit’s overall learning objective. Most devices are also accompanied by posted graphic panels that provide printed content to support the interpretation of scientific phenomena (Serrell, 1998, 2006). These graphic panels frequently include questions that encourage users to probe the phenomenon more fully. Finally, visitors often encounter exhibit educators (Serrell, 2006), who are skilled at facilitating learning in social groups around exhibit devices. They spark conversation, notice ideas, and encourage theorizing. We see parallels between these aspects of the informal learning environment and the structure of effective knowledge building in classroom settings.

For this study, we deliberately constructed conditions that probe these parallels. Using six different conditions with increasingly scaffolded rigidity, we compared student learning and informal behavior outcomes to investigate what level of scaffolding would be optimal to use in informal learning environments.

METHODS

Participants and Context

The study took place at a well-established science museum in a large urban center in the northeast part of the United States. For our study population, we recruited students by leveraging our existing relationships with teachers who are known users of the museum and its programs. In total, 307 students (52% female, 48% male) from nine local middle schools (Grades 6–8) participated in the study. The schools’ demographics were representative of the larger urban context. For example, six of the nine schools in the study had more than 80% of their students on free or reduce-priced lunch and two of the nine schools had just more than 50%. The study engaged students in learning about the topic of electrical conductivity. We recruited students in this grade band because by Grade 6, all students would have
encountered the topic in their classrooms, as dictated by the local standardized curriculum. This provided a common ground for the participants, which increased the chances that all students would have similar prior knowledge.

The teachers brought their students to the museum for a daylong field trip on a weekday during the school year. The teachers were responsible for arranging transportation, but there were no admission costs for the field trip. Participation in the research took approximately 45 minutes. The teachers were free to arrange the rest of their time as they would any field trip to a museum. Each chaperone was assigned a time at which to arrive at the testing location within the museum. The chaperone’s students were randomly grouped into threesomes for testing. Although the students were unable to select the peers with whom they would use the device, the fact that they were with the same chaperone tended to ensure that there was an existing comfort level within the threesomes. The teachers and chaperones were told that they were welcome to observe the testing, but not obligated to do so. They played no other role in the testing. While in the testing area, the students were always accompanied by at least one member of the research team, with a lead researcher always present to observe the intervention with the device.

An exhibit device called “Be the Path” was used in the study (see Figure 1). The device consisted of two metal spheres on a table, approximately 1 foot apart, with one connected by a wire to a battery and the other connected to a light bulb. The instructions on the device provided little direction, simply suggesting “try to complete the circuit.” The students attempted different configurations to complete the circuit and light the bulb. When students completed the circuit to light the bulb, a projected animation (of moving electrons) would appear from overhead and map onto the flow of current through the circuit through the device and the students’ bodies. A more complete description of the technological platform and how we developed it can be found in Yoon, Elinich, Wang, Steinmeier, and Tucker (2012).

Six scaffolds were used in various combinations. The first was the digital augmentation. The next five were adaptations of knowledge-building scaffolds, which included the following:

a. Collaborative groups;
b. Student response sheets with questions directing student attention to relevant information:
   - What happened when you touched both metal spheres?
   - What happened when you only touched 1 metal sphere?
What happened to make the bulb light up?
What does the projection show?
What are you supposed to learn by using this device?
c. Directions on how to reach consensus within their groups:
Write down your answer only after your group has come to agreement on it.
Be clear about the difference between what you actually observe happening and what you think about it.
It is important that you listen to each other.
For each question:
  Brainstorm possible answers.
  Give reasons to support your answers.
  Compare your answers and the reasons behind them.
  Decide on the best possible answer.
d. Embedded knowledge-building prompts on the student response sheets:
  Our hypothesis is . . .
  Our theory is . . .
  Others have said . . .
  We agree/disagree with them because . . .
e. A bank of student responses.

Table 1 presents a detailed description of the six study conditions and how many students participated in each. Students were randomly assigned to one condition, constructed to represent the increasing use of scaffolds. **Condition 1** (C1: device only) served as the control group with no scaffolds. **Condition 2** (C2: digital augmentation) represented the digitally augmented device with no additional scaffolds. **Condition 3** (C3: posted questions) was the same as C2 with the addition of posted student response sheet questions. Although students in all conditions attended to the device in groups of three, students in C1–C3 were not explicitly asked to work with their peers and they individually completed their response sheets afterward. **Condition 4** (C4: collaborative groups) students were told to explore the device with their group members, with posted response sheet questions, but completed their response sheets individually after the experience. C4 was meant to represent typical informal learning participation in which small groups of students encounter posted labels with questions about devices. **Condition 5** (C5: posted knowledge building) students had the same treatment as C4 students with additional knowledge-building scaffolds and the bank of answers posted. They completed the student response sheet collaboratively after the experience, with one sheet per group. **Condition 6** (C6: recorded knowledge building) students had the same treatment as C5 except the response sheet was placed on a clipboard and completed collectively during the experience.

**Learning Task**

We designed the learning environment to probe the application of various levels and combinations of scaffolding. Students entered the testing area in groups of three. We oriented the students to the environment, explaining each condition’s scaffold(s) using a scripted introduction. For example, when the condition included posted questions, we first directed their attention to the poster and read the questions aloud to the students before

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1In some cases throughout the article, we have included a representative label in addition to the number of each condition to provide semantic support when interpreting results.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Student Number</th>
<th>Description</th>
<th>Visual of Scaffold Configuration</th>
<th>Condition</th>
<th>Student Number</th>
<th>Description</th>
<th>Visual of Scaffold Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Device only</td>
<td>30</td>
<td>• Control condition&lt;br&gt;• Device with no scaffolds&lt;br&gt;• Student response sheet completed individually afterward</td>
<td><img src="image1.png" alt="Diagram" /></td>
<td>Four Collaborative Groups</td>
<td>Twenty-four groups of three (72)</td>
<td>• C3 scaffolds plus addition of directions on how to work in collaborative groups&lt;br&gt;• Student response sheet completed individually afterward</td>
<td><img src="image2.png" alt="Diagram" /></td>
</tr>
<tr>
<td>2: Digital augmentation</td>
<td>31</td>
<td>• Addition of augmented reality scaffold&lt;br&gt;• Student response sheet completed individually afterward</td>
<td><img src="image3.png" alt="Diagram" /></td>
<td>Five posted knowledge building</td>
<td>Twenty-three groups of three, one group of two (71)</td>
<td>• C4 scaffolds plus addition of posted knowledge-building scaffolds&lt;br&gt;• Student response sheet completed collaboratively afterward</td>
<td><img src="image4.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

(Continued)
### TABLE 1
Continued

<table>
<thead>
<tr>
<th>Condition</th>
<th>Student Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3: Posted questions</td>
<td>31</td>
<td>• C2 scaffolds plus addition of posted questions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Student response sheet completed individually afterward</td>
</tr>
<tr>
<td>Six Recorded Knowledge Building</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twenty-two groups of three, three groups of two (72)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• C5 scaffolds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Student response sheet completed collaboratively while students interact with the device</td>
</tr>
</tbody>
</table>

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*“Be the Path” interactive device.*

*Digital augmentation—computer with overhead camera/projection system.*

*Posted questions that mirror the worksheets for recording shared understanding.*

*Posted instructions for collaborative group work.*

*Posted bank of peer ideas.*

*Clipboard with worksheet that includes the knowledge prompts.*
they were allowed to begin. Although having information read aloud to students may not consistently occur during a natural field trip learning experience, we felt it was essential to do so to counteract the possibility that some students might lack the ability to read the postings. Because we were bringing a broad and diverse sample of students from several different schools, we wanted to ensure a common baseline of awareness of the posted information. Without knowing the literacy level of each individual student, reading the posted scaffolds aloud was the only way to ensure equitable access to the information. Good chaperones, of course, do tend to read signage aloud to students, and peers are often observed reading aloud to one another, so the applicability of our results is still quite broad for the field of informal learning. Likewise, when the collaborative group scaffold was added, instructions for how to work together to come to consensus were posted on the wall and read aloud to the students. When the bank of peer ideas was present, students were urged to consult it before they began interacting with the device. In all cases, we followed a script to orient the students to the environment and to provide common, consistent guidelines for how to make use of the scaffolds that were present in their condition.

Data Sources and Analyses

Four data sources were analyzed through a quasiexperimental mixed-methods approach: videotaped student small-group interactions with the device, conceptual knowledge surveys, student-response sheets, and postintervention interviews. Each data source is detailed below.

Student Small-Group Interactions With the Device. Student small-group interactions with each other and with the device were videotaped. In all conditions, most students entered the testing area in groups of three (there were also a few groups of two and one group of three) and were instructed to work as a group depending on their condition. Students were not explicitly told to refrain from working as a group in conditions where the collaborative group was not an intentional scaffold. The numbers of groups used in the video analysis differed slightly in some conditions from the numbers of students and groups reported in Table 1 due to technology glitches or interruptions with the video recording that made the video difficult to transcribe. This impacted one group in Condition 1 and three groups in Conditions 5. The total number of groups analyzed in the video data was 100 broken down by condition in Table 2.

The video data were analyzed for informal behaviors. The coding was completed through a modified method of interaction analysis (IA). This involves analysis of video and/or audio clips by a group of researchers to examine the details of social interactions (Jordan &

<table>
<thead>
<tr>
<th>Condition</th>
<th>Groups Analyzed</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
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<tr>
<td>3</td>
<td>11</td>
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<tr>
<td>4</td>
<td>24</td>
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<tr>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

Henderson, 1995). The basic goal of IA is to understand what people are doing in social or discursive activity. The analysis is normally performed in collaborative work groups that are assembled for particular projects. Codes and categories in IA are meant to emerge from ongoing and deepening understanding that occurs through multiple replays of, in our case, video data and the negotiation of group member data interpretations. This qualitative collaborative form of analysis mitigates individual researcher bias and enables mutual construction of meaning (Jordan & Henderson, 1995).

In our study, we were interested in understanding how participation in conditions with different kinds of scaffolds impacted their informal behaviors. Four members of the research team participated in the development of the IA protocol. We first reviewed numerous informal education studies and, in particular, scholarship that discussed typical behaviors in science museums. We watched several of the video clips to investigate which behaviors were discernable in our situated context. For example, although we know that informal learning often occurs through sporadic or episodic experiences, we would not be able to code for this in our data. We were able to eventually settle on two categories of informal behaviors, experimentation, and self-directed exploration in the form of student-generated questions.

Next, we needed to construct codes that would show the variability of informal behaviors between groups and conditions. All four members of the research team independently ranked 10 randomly selected groups on both categories without knowing the group’s condition. To do this, each video excerpt of the entire group’s interaction with the device was coded first for the category of experimentation and then the same excerpt was coded for the category of student-generated questions. We then discussed our rankings to see whether we could identify boundaries around behaviors that more or less reflected informal participation in each category. The categorization manual was simultaneously constructed, refined, and applied to 10 more randomly selected groups. The codes were discussed until the team was confident in their ability to complete the analysis with few discrepancies. Each category was coded on a scale of low (1), medium (2), or high (3), using category and scale descriptions found in Table 3. This process of category and code generation and validation took several sessions of 1.5–2 hours each. Three members of the research team coded the remaining 80 groups. Scores in each category were added together to obtain a total for informal behavior per group out of a possible score of six, and an average score for each condition was calculated. A univariate analysis of variance (ANOVA) and a post hoc Tukey HSD were conducted on the coded data set to see whether there were significant differences between the conditions in their informal behaviors and to identify where the greatest differences were located.

**Conceptual-Knowledge Surveys.** A conceptual-knowledge survey was administered to students in each group before and after the intervention to measure knowledge gains. The survey posed five general multiple-choice content questions related to the scientific topic of electrical conductivity and circuits. Each was valued at one point. The five questions were as follows:

1. Lightning is a discharge of ( ____ ).
2. Which class of elements best conducts electricity?
3. ( ____ ) is an example of a good conductor.
4. ( ____ ) is an example of a good insulator.
5. Which of these is the best definition of an insulator?
### TABLE 3
Video Data Analysis Category and Scale Descriptions

<table>
<thead>
<tr>
<th>Category and Description</th>
<th>Low (1)</th>
<th>Medium (2)</th>
<th>High (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refers to the level of interaction that the individual and group have with the exhibit. In particular this is looking at how the group or individual experiments with the exhibit. Are the students experimenting with how to complete the circuit? Do they try out different configurations and arrangements? Is there some joy in the interaction with the exhibit? Is the whole group involved in the experimentation or just an individual?</td>
<td>Students complete the circuit by simply placing each hand on the metal balls. There is no experimentation.</td>
<td>Students complete the circuit initially by placing each hand on the metal balls but then start to experiment with how to complete the circuit. One or two students are experimenting. There is little to no interaction in experimentation with the other individuals in their group.</td>
<td>Students complete the circuit and then continue to experiment with how to complete the circuit. Students try different body parts (fingers, elbows) or different configurations of holding the balls. Students involve other members of their group in the experimentation. For example, students talk about and then create different patterns of holding the balls or holding onto hands and try to complete the circuit using more than one body for the electricity to go through. The whole group is involved in the experimentation.</td>
</tr>
<tr>
<td>Refers the level of self-directed exploration in the form of the kinds of questions and actions that emerge from interaction with the device and others in the group. Do students articulate questions of their own or do questions come from those that are already posed to them? Do students propose actions to be taken by themselves or other members of the group or do they only follow the actions already dictated to them in the instructions?</td>
<td>One or no questions are self-generated. Students only ask questions that they have been given to answer. There is little to no proposed actions in terms of how to interact with the device other than what they have been asked to do.</td>
<td>At least two questions are self-generated. One or two members of the group propose actions to self-directed questions. There is no clear conversation happening between group members about questions or actions generated.</td>
<td>More than two questions are self-generated. All members of the group generate questions or propose actions. All members of the group are involved in doing the actions or in trying to answer the questions being proposed. A conversation or flow of ideas happens between group members.</td>
</tr>
</tbody>
</table>
An additional open-ended question on the survey also solicited responses that demonstrated knowledge directly related to the device experience, that is, “Think about an electric circuit that supplies electricity to a light bulb. What parts make it work so that the bulb lights up?” Responses to this question were coded on a five-point Likert-scale from no understanding (0) to complete understanding (4). To establish the coding scheme, the data set was reviewed qualitatively by members of the research team in a series of data analysis sessions during which responses were compared to the answer in the Full Option Science System (FOSS, n.d.) teacher’s manual from which the question was originally sourced. We also consulted a physicist on staff at the museum to help the team design the scoring rubric. Once codes were established, a categorization manual was constructed. Refer to Table 4 for a description of the levels of understanding and the coding rubric. Two graduate students, who were not otherwise familiar with the research project, were trained on the coding scheme, and interrater reliability was obtained on 20% of the data with greater than 90% agreement.

In total, the highest possible score on the conceptual knowledge survey was nine points—five points from the multiple-choice section plus four points from the open-ended question. A paired-samples t test was conducted to determine statistical significance in conceptual knowledge gain within each condition after treatment. A between-subjects analysis of covariance (ANCOVA), using condition pretest scores as covariate, was conducted to determine whether the main condition effect was significant.

**Student Response Sheets.** A student response sheet was used to gather additional knowledge data from participating students in all conditions. Students in Conditions 1–4 completed their responses individually immediately after they finished interacting with the device. They moved away from the device and were seated at tables for the task. Students in Condition 5 also moved away from the device and were seated for the task, but completed their responses collectively with just one sheet for each trio. Students in Condition 6 completed their collective responses during the group activity while standing around the device with a single sheet on a clipboard. Groups were allowed to negotiate the collaborative process for themselves. For example, some elected a single scribe, whereas others passed the sheet around to share the scribe duties.

The student response sheet listed the steps on how to work with the device, knowledge-building prompts, and an open-ended question: “What are you supposed to learn by using this device?” This question was intended to elicit responses that demonstrated ability to theorize from the interaction with the device, that is, understanding of electrical circuits and how the human body functioned as a conductor. The construct of ability to theorize was distilled from a set of sociocognitive determinants of knowledge-building communities in Scardamalia (2002) that signal learners’ abilities to apply high-order thinking skills such as developing coherent arguments, higher level formulations and articulations of knowledge, and collective knowledge construction. We distinguish this construct as cognitive development (higher order thinking skills) rather than conceptual development (content or declarative knowledge), as gleaned from the conceptual knowledge survey described above, to understand the kind of learning that is enabled through participation in our intervention. We coded responses to this question only as a measure of the group’s collective cognitive skills. Responses were coded on four levels from no understanding (0) to complete understanding (4). Answers that correctly identified the parts and process of lighting up the bulb, recognized that human bodies could close a circuit and conduct electricity, and were free of common misconceptions (e.g., the sink model, the attenuation model, the clashing current...
TABLE 4
Levels of Understanding on Conceptual Knowledge Survey

<table>
<thead>
<tr>
<th>Level of Understanding</th>
<th>Description</th>
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</thead>
</table>
| **Level 4: Complete understanding (+4 points)** | • Student identifies all the major components of a complete circuit including the power source, the method of transfer, and the output.  
• Student identifies the power source as a battery. (Potentially could be a power plant, but would have to demonstrate a loop or complete circuit.)  
• Student identifies a complete loop or circuit composed of a conductive material such as wires, cords, or human body.  
• Student indicates an accurate flow of current from the battery to the bulb.  
• Student identifies the output as the bulb lighting up or demonstrates that electricity has achieved its intended use. |
| **Level 3: Partial understanding (+3 points)** | • Student identifies all the major components of a complete circuit including the power source, the method of transfer, and the output.  
• Student identifies a power source as a battery, power plant, or an outlet/socket.  
• Student identifies a circuit (thought it may not be a complete or closed loop) composed of a conductive material such as wires, cords, or human body.  
• Student identifies the output as the bulb lighting up or demonstrates that electricity has achieved its intended use. |
| **Level 2: Emergent understanding (+2 points)** | • Student identifies that there are multiple components of a circuit and that there is a process or system in place to make the bulb light up. Something is transferred from a power source to make the bulb light up. Answers may neglect components of a complete circuit and may contain misconceptions. |
| **Level 1: Little understanding (+1 point)** | • Student identifies that something works to make the bulb light up. The power source may include a “magic” switch in which the student recognizes that a switch turns on the bulb but does not have an understanding of a circuit. There may be too much emphasis on only one specific component that makes the bulb light such as the switch or the wires. Answers are missing major components of a complete circuit and contain major misconceptions. |
| **Level 0: No understanding (no points)** | • Student does not answer, identifies that they do not know the answer, or does not provide evidence that connects the illustration and the description to the key words. |

model; Pesman & Eryilmaz, 2010) were coded as the highest level of understanding. Refer to Table 5 for a description of the levels of understanding, sample student responses, and the coding rubric. An ANOVA was conducted on the student response sheet data set to determine whether there was a statistically significant difference in responses between the conditions, and a post hoc Tukey HSD comparison was conducted to determine the source of the difference. We were unable to conduct a multilevel analysis due to the small sample size, but we are aware of the nonindependence issues that can potentially impact results. Cress (2008) discusses two important nonindependence factors that pertain to our study: *common fate,*
<table>
<thead>
<tr>
<th>Level of Understanding</th>
<th>Description</th>
<th>Sample Response</th>
</tr>
</thead>
</table>
| Level 4: Complete understanding (+4 points) | - Student identifies in detail that the human body can complete a circuit AND can conduct electricity.  
- The terms flow, conductivity, circuit, runs through, transfer, or current must be used in the explanation. If the student does not use these terms, there must be enough information provided to be sure that they are demonstrating the concept.  
- Student must describe the process of lighting up the bulb in an attempt to explain the concepts.  
- Even if a student identifies all components, if part of the answer is wrong or contains a misconception, it cannot be counted as complete understanding. Pictures must be labeled or accompanied by an explanation, but an explanation may not necessarily be accompanied by a picture.  
- That electricity traveled through your body like a wire and a circuit when you touched the metal sphere causing the bulb to lit (sic). That a wire causes an electrical circuit which causes the bulb to lit up (sic).  
- It shows the electrical current running through your body and back into the wires, batteries, and light bulb. That you need something to connect the electrical currents flowing from the wires. |  
| Level 3: Partial understanding (+3 points) | - Student identifies that the human body can complete a circuit AND can conduct electricity.  
- The terms: flow, conductivity, circuit, runs through, transfer, or current must be used in the explanation or the student correctly uses simile or metaphor to explain the concepts.  
- Student may describe the process of lighting up the bulb in an attempt to explain the concepts.  
- The answer must be free of misconceptions, though it may not necessarily include all the criteria for fully understanding the concepts. Pictures must be accompanied by an explanation.  
- That your body works as a circuit. Your body also conducts electricity.  
- That sometimes your body can complete the circuit if both hands are touching 2 different things, and make something work. |  
| Level 2: Emergent understanding (+2 points) | - Student identifies that the human body can complete a circuit OR conduct electricity.  
- The terms: flow, conductivity, circuit, runs through, transfer, or current must be used in the explanation or the student correctly uses simile or metaphor to explain the concepts.  
- You are supposed to learn that electricity goes through the body.  
- Currents go through your body into it. |  

(Continued)
which is the tendency to become similar over time due to only being exposed to the same group, and reciprocal influence, which has to do with group members being strongly influenced by other group members. As Cress (2008) also notes, computer-supported collaborative learning environments are designed to be influenced by group interactions and we intentionally designed the conditions to probe the impact of learning scaffolds—one of which is group interaction.

**Postintervention Interviews.** To investigate how knowledge-building scaffolds impacted the nature of the intervention, 66 students (~20% of the population) from C5 and C6 were randomly selected for short audiotaped interviews following their interaction with the device. Interviews were transcribed and coded by two research team members independently. A code of 0 (not helpful) or 1 (helpful) was assigned to responses for interview Questions 1–5. And a code of 1 was assigned to each scaffold identified as the most helpful for Question 6. Coders compared responses with greater than 98% agreement, after which codes for each question were tallied. Table 6 lists the interview questions and sample student responses.

We asked students to evaluate each of the scaffolds they encountered to understand which were more or less helpful in enabling them to learn the science content instantiated in the device.

**RESULTS**

Analyses of the four data sources yielded important results in investigating which combination of learning scaffolds could be optimally used to increase learning outcomes while preserving the unique characteristics of participation in informal environments. We present first the results from the IA of student informal participation (experimentation and student-generated questions) and then the results from the learning outcomes and interview analyses.

### TABLE 6
Interview Questions and Sample Responses

<table>
<thead>
<tr>
<th>Interview Question</th>
<th>Sample Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Did the questions on the worksheet help you think about what you are supposed to be learning?</td>
<td>• It got us to think about things that we learned before like electricity and energy and how it works and stuff.</td>
</tr>
<tr>
<td>(2) Did working in a group help you think about these questions?</td>
<td>• More cause everybody had different opinions and when we all put our opinions together, we have a big conclusion.</td>
</tr>
<tr>
<td>• If so, how did it help you?</td>
<td>• By telling us what to do or how to answer.</td>
</tr>
<tr>
<td>• If not, why didn’t it help you?</td>
<td>• It was kind of like an explanation. Explanation on our theories and hypotheses.</td>
</tr>
<tr>
<td>(3) At the top of the worksheet there was a box with directions. Did you follow the instructions?</td>
<td>• Like one said that energy flows through our body and stuff. And then we kinda used it, some of it.</td>
</tr>
<tr>
<td>• If so, how did the instructions help you?</td>
<td>• Working in a group because if you’re working by yourself, if you want to go to other people for help . . . based on all of our opinions, we could work it out ourselves</td>
</tr>
<tr>
<td>• If not, why not</td>
<td></td>
</tr>
<tr>
<td>(4) There were also words in italics after each question that was supposed to be prompts. Were the italicized words helpful in answering the questions?</td>
<td></td>
</tr>
<tr>
<td>• If so, how so?</td>
<td></td>
</tr>
<tr>
<td>• If not, why not</td>
<td></td>
</tr>
<tr>
<td>(5) Recall the bank of other students’ answers that were posted. Were these helpful in answering the questions?</td>
<td></td>
</tr>
<tr>
<td>• If so, how so?</td>
<td></td>
</tr>
<tr>
<td>• If not, why not</td>
<td></td>
</tr>
<tr>
<td>(6) Which of these supports (student response sheet, working in a group, the instructions in the box, the italicized sentence prompts, or bank of others’ answers):</td>
<td></td>
</tr>
<tr>
<td>• Was the most helpful? (Explain)</td>
<td></td>
</tr>
<tr>
<td>• Was the least helpful? (Explain)</td>
<td></td>
</tr>
<tr>
<td>• Were any of them equal? (Explain)</td>
<td></td>
</tr>
</tbody>
</table>

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**Informal Participation Outcomes**

The IA results in the combined informal behavior categories of experimentation and student-generated questions varied across conditions. Means and standard errors are reported in Figure 2.
A univariate ANOVA revealed significant differences between conditions in their behaviors, $R^2 = .26$, $F(5, 94) = 6.612$, $p = .001$. A post hoc Tukey HSD analysis showed the significance to be largely attributable to differences found between C3 and C4 ($p = .002$) and between C6 and C1, ($p = .043$), C4 ($p = .001$), and C5 ($p = .028$). All other differences were not significant. Two large trends may be discerned from the figure. In the first three conditions, where students were not explicitly instructed to work in collaborative groups, we see a decreasing trend in informal behaviors with increased scaffolding. However, the introduction of collaborative groups in C4 appears to have mitigated the effects of the other scaffolds, yielding the greatest amount of informal behaviors of all the conditions. With the addition of the posted knowledge-building scaffolds in C5, and then requiring students to record their collective knowledge-building responses during the activity in C6, we again see a decrease in informal behaviors. The difference in means obtained for C3 and C6 was statistically indistinguishable ($p = 1.000$).

These results suggest several things. First, overall, as scaffolds were added to the learning environment, informal behaviors tended to decrease. Second, working in collaborative groups appeared to influence informal behaviors in a positive way. Finally, when students were asked to record their ideas, even when working in collaborative groups, informal behaviors were significantly negatively affected.

From the video footage, we see further qualitative evidence of the impact of collaborative groups and increasing scaffolds. The following series of discourse interactions and screen shots illustrates how two groups of students interacted differently with themselves and the device. The first excerpt of students in C4 (collaborative groups) shows a high amount of experimentation and self-generated questions. In the following video transcript and screen shots, the girl with the light hair on the left of the
frame is G1. The girl in the middle with glasses is G2 and the girl on the right side of the frame with long hair is G3. After being introduced to the device, students begin exploring.

Excerpt 1: Group 4 Condition 4 (38:43-42:38)

1. G2: ((Completes the circuit.))
2. G3: ((Smiles at seeing the projection light up. Walks over to the right-hand side of the device and completes the circuit.))
3. G2: ((Looks up at the projection.)) Oooh ((Giggles))
4. G3: Let go. ((All of the group members take their hands off of the silver balls.))
5. G1: ((Touches one silver ball on the left side and one on the right side not completing the circuit.))
6. G2: No, only if you do these two. ((Indicating to G1 that to complete the circuit it has to be the two balls in front of her.))
7. G1: It has to be both of your hands.
8. G2: Why? ((Takes her hands off of the silver balls and looks at her palms.)) Hmm. Light bulb glows when you put your hands on the spheres.
9. G1: ((Reaches over to touch the silver balls on G2’s side of the device.))
10. G2: Wait, put your hand on there. ((Directs G1 to place her hand on one of the silver balls.))
11. G1: It has to be both of yours. ((Places her other hand, on the other silver ball, to complete the circuit.))
12. G2: Oh so you have to be like, wait, do it again. ((G1 completes the circuit.))
13. G2: Oh snap! So, I am guessing it can tell your hands from a different person’s?
14. ((All three students try different configurations of holding the silver balls, crisscrossing over the device.))

(10)
15. G2: Hmm, strange. How can it tell what shape your hands are? I’m thinking about that.


17. G2: Wait. ((Begins to experiment again with different ways of touching the silver balls to complete the circuit.))

(10)

18. G2: By touching the balls your body acts as a wire.

19. G1: [Oooh.]

20. G2: [So the energy,]

21. G1: Wait, watch G3 when she touches them. It lights up. ((Gestures to the digitally augmented projection of electrons across G3’s body)).

22. G2: Ooooh, because she is part of that. ((Gestures to the light projection across G3’s body.)) So, is that like . . .

23. G3: So, come over here. ((G3 has G2 come to her side of the device.))

24. G2: Because, so um, so every time you be touching the light bulb comes on, that comes on. Oh, snap! If you put your hands on it plus my two hands.

25. G3: ((Inaudible))

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26. G2: So, technically there is a way to do it, but need my hands and a different person’s hands. But it has to be both [of your hands and my hands.]

27. G3: [And the other persons hands.]

28. ((The whole group experiments with how to complete the circuit.))

29. G2: This bulb is brighter (Talking about the bulb on the left side of the device.)


31. G2: If I put my hand on and you put your hand on it. ((All of the group members put their hands on the same two silver balls.))

32. G2: Whoever put their hand on it first is the one who is really making it light up.

33. ((The whole group continues to experiment with completing the circuit.))

(17)

34. Researcher: Okay, great. Thanks girls. That was wonderful.

In this excerpt, as the students explore the device, group members begin hypothesizing about what actions made the projection appear (lines 1–12). In terms of the informal behavior category of experimentation, it is evident that the students are interacting and experimenting with each other and trying out different configurations of the device. There is genuine interest in participating together (e.g., lines 4, 10, 23); the proposed actions are organically derived from within the group, spurred by a collective inquiry to understand the phenomenon. In lines 10–16, the students are intentionally working with each other trying to understand how different student’s hands impact their ability to turn on the device. After this experimentation, in line 17, G2 realizes that multiple combinations can in fact turn on the device and states in line 18 that the body (in any configuration) acts as a wire to close the circuit. G1 confirms her understanding by pointing to the projection across G3’s body in line 21, and the three students continue together testing out their hypotheses. Throughout the interaction, students are generating their own questions and hypotheses that dictate their emergent behaviors and all members of the group are involved in performing the actions. For example, after some testing, G2 wonders out loud in line 8, why their hands on the spheres make the light bulb light up.
By contrast, the following excerpt from a group in C6 (recorded knowledge building) shows how behaviors followed exactly what the scaffolds asked students to follow. This group received lows in both informal categories of experimentation and student-generated questions. In this excerpt, G1 refers to the girl on the right of the screen shot; G2 refers to the girl on the left, and B1 refers to the boy. Initially, the students walk in and begin to play with the silver balls. However about 20 seconds into the activity, the boy asks the girl on the right who is holding the clipboard, when they were going to begin answering the questions.

**Excerpt 2: Group 2 Condition 6 (11:37–17:10)**

1. B1: Aren’t you gonna read them?
2. G1: ((Takes up the clipboard and starts to read the first question out loud)) What happens when you touch both balls?
3. G2: ((touches both of the balls on the right.))
4. G1: The bulb lights up.
5. B1: ((Places hands on the balls on the right)) Try it at the same time.
6. G2: ((Walks around the table to try the other set of balls on the left.))
7. B1: They feel like a little warm.
8. G1: ((Writes down the answer to the question while other group members are waiting in silence.))
9. G1: ((Reading the next question out loud)) what happens when you only touch one?
10. ((G2 removes one hand off of one of the metal balls. B1 still has both hands on the metal balls. B1 removes one hand from one metal ball.))
12. G1: It doesn’t light up. ((G1 writes down the answer and the other two group members continue to touch the metal balls completing the circuit.))
13. G1: ((Reading the next question out loud)) so what happens to make the bulb light up?
14. G2: ((Inaudible))
15. G1: Why do you think that answer?
16. G2: ((inaudible)) “Cause the wire, I don’t know, the wire, somewhere in there near the edge ((gestures between the two metal balls when talking about the wire, giggles and points to B1)) Well he’s got to think.
17. G1: ((Reading the next question out loud)) What does the projection show?
18. G2: Digital squares. ((Quietly))
20. G1: ((Writes down the answer and then reads the next question the from the sheet))
   What are you suppose to learn by using this device? Our Theory is?
21. G2: ((Quietly reads the instructions on the table)) ((Inaudible))

(47)

22. G2: So, our body acts as a wire.
23. ((G1 writes down the answer. B1 and G2 touch the device again completing the circuit
   as they have done before. G2 stops interacting with the device and looks over G1’s
   shoulder who is writing on the clipboard. ))

(38)

24. G1: ((Reading from the student response sheet)) Others have said?
25. G2: Right there. ((Points to the poster of answers others have given. The group walks
   over to the poster))
26. G1: ((Reading from the sheet)) We disagree with them because ... ((G1 and G2 fill out the clipboard while B1 goes back to the device and touches the balls again to complete the circuit))

27. G2: ((Inaudible))

28. Researcher: Done?

29. G1: ((Asking the researcher)) Do we need to put down our names or no?

30. Researcher: Um ... just your first names. ((Collects the clipboard)) Thanks guys, that was great.

We can see that from the beginning of the interaction, the group’s behavior is dictated by the questions on the student response sheet and the expectation that they are to fill in the answers to complete the activity (lines 1, 2). In terms of the informal behavior category of experimentation, it is evident that there is little experimentation happening on the group’s own. The questions and directions are read out loud by G1 (e.g., lines 9, 13, 17), and students follow exactly what they are asked to do. When the knowledge-building prompt, “Our theory is ...” is read in line 20, rather than any discussion about what the group thinks, one student immediately looks for an answer, which is read out loud and then written down while interaction with the device stops. Then the group moves on to the next question to answer. There is little discussion between group members. For example, even when students are prompted to review what other groups have said (line 24), there is no discussion between group members about what they agree or disagree with, G1 and G2 in line 26 simply choose and answer and write their response on the clipboard while B1 continues to play with the device. In contrast to the previous group in Excerpt 1, there is little display of self-motivated interest or self-generated questions.

When comparing the two excerpts, we see how the increased scaffolds in Condition 6 served to impede the informal behaviors of experimentation and self-generated questions that are characteristic of interest and engagement in informal science environments. These two illustrative cases provide qualitative evidence supporting the means reported in Figure 2. In the next section, we present the results of the learning measures that show somewhat different outcomes.
Learning Outcomes

**Conceptual Knowledge.** Across the conditions, pre- and postsurvey means ranged between 2.90 (presurvey, C3) and 4.01 (postsurvey, C4) of a possible score of 9. Results of a paired-samples t test conducted within each condition showed that gains in all conditions except C1 were statistically significant. Students in C4 demonstrated the greatest gains, with students in C3 a close second. However, a between-subjects ANCOVA using the pretest scores as covariate showed that there was no significant difference in the outcomes between six groups, $F(5, 300) = 0.546, p = .741$. Figure 3 shows mean gains obtained for all conditions.

**Cognitive Understanding.** Students were asked, *What are you supposed to learn by using this device?* Response scores ranged from 2.233 (low emergent understanding) to 2.800 (nearly partial understanding). Figure 4 shows an increasing trend from C1 to C6 in the means for higher order reasoning as measured by ability to theorize.
An ANOVA comparing mean scores showed a significant difference in results, $R^2 = .05$, $F(5, 300) = 2.234$, $p = .052$. A post hoc Tukey HSD analysis attributed the difference to the higher mean of C6, which was marginally significantly higher than C1 ($p = .056$). Differences between all other conditions were statistically not significant.

**Impact of Knowledge-Building Scaffolds**

C5 and C6 students were asked which knowledge-building scaffolds were helpful in learning the science content. Figure 5 shows a graph of the frequency of student responses. Many students found both working in groups and the student response sheet helpful, whereas fewer than half found the directions on how to work together helpful. Greater than two thirds of students indicated that the knowledge-building prompts were helpful, and greater than half indicated that the bank of other students’ ideas was helpful.

Collectively, the learning measures showed that students found the multiple scaffolds helpful for learning the science content. Working in collaborative groups was found to be helpful by all students, which was introduced in C4. This corresponds well with the highest mean obtained in terms of informal behaviors displayed. We saw clear benefits to learning the content as being accrued through participation in C6 where knowledge-building scaffolds were used and students were required to complete the response sheet during the activity. However, the results also show a significant decrease in informal behaviors. We discuss the overall results as they relate to the goal of the study in the following section.

**DISCUSSION**

In this study, we sought to answer the following research question: Which combination of learning scaffolds can optimally be used in a science museum taking into consideration the unique characteristics of informal participation to increase learning outcomes? This research was aimed at investigating the issue of formalizing an informal learning experience that emerged in our previous studies. The study’s central finding demonstrates an apparent tension, between efforts to increase science knowledge learning outcomes with more formalized scaffolds and the ability to preserve participation characteristics in informal environments that make them so attractive. From the observation data, we saw an inverse relationship between learning scaffolds and informal behaviors. That is, as scaffolds increased, informal behaviors decreased with the exception of collaborative groups.

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However, learning through various kinds and combinations of scaffolds did produce differential and beneficial learning outcomes. Based on the conceptual gains shown in Table 4, this study supports our previous findings (Yoon, Elinich, Wang, Steinmeier, & Van Schoneveld, 2012; Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012) that digital augmentations can serve as valuable scaffolds for conceptual learning, which we conclude based on nonsignificant learning gains in C1 (device only). Now in this third study supporting the validity and reliability of this finding, we believe that the idea of applying AR technologies on museum devices to increase conceptual gains is a solid contribution to the field of informal learning. As the use of AR technologies becomes more prominent in museum environments, it is important to understand the effects they have on visitors’ learning and their experiences. Although other studies have revealed that they have the potential to increase visitors’ exploration of objects (Szymanksi et al., 2008), increase children’s engagement and interest (Hall & Bannon, 2006), and increase collaborative interactions between parents and children (Asai et al., 2010), none have studied the effects on visitors’ conceptual understanding. Indeed, in a review of the current status of AR research in education, Wu and colleagues (2013) conclude that the field is still mainly focused on development, usability, and initial implementation of AR tools. We add to this growing literature base and suggest that AR can also enhance visitors’ understanding of important scientific concepts, ideas, and information—especially for physical science topics. The science museum, in which the study took place, has a strong focus in its exhibits on physical science topics where we find AR to be particularly effective for visualizing characteristics of phenomena that are not visible. Although our methodology has not yet been applied to topics in other scientific fields of study such as biology, we anticipate a similar learning benefit.

Another potential learning benefit of various uses of scaffolds was revealed in the conceptual learning gains found in the conditions where questions for participants to refer to were posted, that is, C3 and C4. Although the ANCOVA results were not significant, we did see an increase in the mean differences of C3 and C4 students on the response sheet questions. Here we may consider the posted questions as analogous to graphic panels or exhibit labels commonly used in museum settings (Serrell, 2006). They are frequently used in museums to stimulate participation and learning by inviting visitors to engage in a particular task or activity, and in the process, helping them anticipate and formulate new meanings (Serrell, 1996). We suggest that by stimulating visitors to ask their own open-ended questions (Hohenstein & Tran, 2007) and by encouraging them to offer explanations to each other (Atkins, Velez, Goudy, & Dunbar, 2009), questions in exhibit labels can also simultaneously improve conceptual understanding.

Yet a third claim that we could make supporting the use of scaffolds in informal learning environments comes from the interview data. When interviewed, C5 and C6 students said that working in groups to formulate their responses was the most helpful scaffold beside having the student response sheets, which suggests that the combination of collaborative groups and posted student response sheet questions can assist in learning science concepts. Thus, the results, at least for conceptual learning and informal behaviors, show that the scaffold configuration of Condition 4 (posted questions and collaborative groups) was the most beneficial. The literature on family visitors and school groups can offer some important insight into the importance of social interaction in museum learning. As a social group composed of multigenerational members, research reveals that families, through conversations, and personal and cooperative learning strategies, interact and negotiate with one another to construct meaning of their museum experiences (Ellenbogen, Luke, & Dierking, 2004). Similarly, social interactions between children in school-group visits are also an important element of museum learning. Studies have revealed that children can and do engage with their peers by sharing discoveries and experiences (as cited in DeWitt &
Stoksdieck, 2008; Griffin, 2004). Price and Hein (1991) have even advocated for having students work in small groups as it encourages more question asking and more hands-on work. Indeed, the opportunity to engage with peers to share information and explore together is an invaluable activity that encourages learning for everyone in the group. Although these studies have certainly ascertained the significance of social and collaborative engagements between visitors in terms of contributions to learning, there are no studies to our knowledge that investigate how these collaborative experiences can be scaffolded for deeper learning. Our study provides a step in that direction upon which future research should build.

Finally, in terms of cognitive skills, although both the knowledge-building prompts and the bank of other students’ ideas were selected fewer times as helpful scaffolds than working in groups and student response sheets, the fact that a good portion of the population endorsed these more formal scaffolds lends some support for their use. The result that C6 students had the highest score in ability to theorize also somewhat supports an argument for their continued use. This condition was designed to illustrate a typical school museum visit in which students are required to complete worksheets that are meant to ensure on-task, learning behavior. However, although the use of worksheets can be highly effective in promoting inquiry-style field trip experiences (Kisiel, 2005), studies have shown that structuring an informal experience through worksheets without room for children’s interests, motivations, and choices can dampen interest and result in less positive attitudes (as cited in DeWitt & Stoksdieck, 2008). This was demonstrated in the results of the interactional analyses. The obvious differences in participation revealed in the video transcript excerpts of students in C4 and C6 show that increased cognitive skills may come at the expense of informal behaviors. Therefore, if we want to preserve the kind of unique participation afforded in informal learning environments such as science museums, scaffolding for deeper level understanding in this way may not be possible.

This may not be a negative outcome of the study. Rather, we view our results as valuable information and a contribution toward the larger research discourse on the possibilities for designing for increased learning in informal educational settings (NRC, 2009). With the knowledge obtained from this study that digital augmentations, posted questions, and participation in collaborative groups may be the optimal design for conceptual learning that preserves informal behaviors, in the next steps of this research we may consider other possibilities for improving cognitive skills. For example, as offered by Grinell (2006), we may provide multiple experiences with different devices designed on the same topic of electrical conductivity. Students can gain more knowledge and ability to theorize about the science as they move from exhibit to exhibit throughout the course of a day. In our research series, we intend to continue in our efforts to explore other kinds and combinations of scaffolds that will elicit deeper learning outcomes while participating in informal learning environments.

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