

Synergistic Scaffolding of Technologically-Enhanced STEM Learning in Informal Institutions

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Abstract: Scaffolding is often strongly associated with the structure of classroom educational software (Quintana et al., 2004), despite originally not involving classrooms or technology (Wood et al., 2007). Tabak argued that scaffolding can be productively distributed across a learning environment's varied educational resources, proposing a "synergistic scaffolding" design pattern: "different supports that augment each other; they interact and work in concert to guide a single performance of a task or goal" (Tabak, 2004). This symposium argues that synergistic scaffolding is particularly apt for informal learning environments like museums, where visitors draw on a diverse array of technological, social, and physical resources while learning. Examples spanning collaborative data exploration, multi-context inquiry learning, mixed-reality simulations, and augmented reality exhibits are presented. Each details the educational resources either intentionally designed into the environments or appropriated by visitors as they learn. These examples highlight how designers can enhance informal learning by looking for potential synergies.

Introduction

Informal science education shares many of the same aims as inquiry-based science education in classrooms, but is subject to a number of unique challenges not present in classrooms, like: the need to support learners with diverse experiences and knowledge, the demand that the activity be designed to fit within a short single-visit timeframe, and the requirement that the activity be able to attract the participation of learners embedded in a free-choice environment. At the same time, informal science institutions are home to a number of social and material resources not often present in classrooms, which, if properly employed, could support learning. In her conceptualization of synergistic scaffolding, Tabak (2004) proposes the framing as "an important conceptual tool in understanding how different constituents [in distributed scaffolding] interact to produce support that is greater than the sum of the constituents."

This session will delve into how the multiple learning resources available to visitors in informal science institutions can be intentionally coordinated (and sometimes unintentionally appropriated) to form synergistic supports for learning, and the implicit and explicit roles technology can play in that coordination. Papers in this session will discuss the nature of the learning performance that is being supported, and how the activity can be designed to intentionally incorporate scaffolding resources like peers, more-expert companions, interpreters, physical artifacts, digital artifacts, ancillary repositories of knowledge, and cultural tools (both the practices of the visitors as well as the practices of the target learning domain). The papers will also describe how these resources can be marshaled to perform the traditional scaffolding functions like inspiring interest in the task, reinforcing adherence to task requirements, reducing the degrees of freedom within the task, and providing feedback and repair functions.

Each presentation will cover a very different type of informal learning experience, each in different stages of development: Lyons & Roberts describe how visitors drew on each other and the exhibit space itself to support joint explorations in a whole-body interaction exhibit on data visualization; Quintana reflects on the challenges faced deploying a mobile tool for bridging formal and informal inquiry learning experiences; Tscholl & Lindgren describe how the addition of a monitoring station for adults to a mixed-reality simulation exhibit activated parents as resources for guiding their children's learning within the exhibit; and Yoon, Wang, & Anderson describe how the conceptual and social learning at traditional hands-on exhibits can be transformed by the addition of augmented reality scaffolds that visualize invisible aspects of physics phenomena. Discussant Iris Tabak will lead a reflection on the array of potential informal learning resources revealed by these projects, and where appropriate, draw contrasts with the goals and designs of formal scaffolding.

Scaffolding the Collaborative Interpretation of Data in a Museum Exhibit

Leilah Lyons, New York Hall of Science and the University of Illinois at Chicago

Jessica Roberts, University of Illinois at Chicago

Museums are cultural ambassadors – introducing learners to both new disciplines of knowledge and the ways-of-knowing that are privileged within those disciplines. Historically, science museums have allowed visitors to come face-to-face with the artifacts and practices of science (Conn, 1998). With our project, we address the challenge of what museums can exhibit when so much of the “stuff” of modern science is collections of organized information. How can museums present data to visitors in an accessible and engaging fashion, and how can they also inculcate a disciplinarily appropriate perspective towards data in visitors?



Figure 1. Left, diagram of pilot exhibit installation at the New York Hall of Science. Where visitors stand controls the appearance and the selection of the data set(s) being visualized. Right, visitors using the pilot *CoCensus* exhibit. The visitor is standing in the marked “1990” spot on the floor.

CoCensus is an exhibit that presents geographically-plotted U.S. Census data on a large shared display. Georeferenced census data is useful to work with because it speaks to phenomena (where people live, what people earn, etc.) that are familiar to visitors without them needing any specialized scientific knowledge. To engage visitors interactively with the data, the exhibit allows visitors to control the visualization through embodied, whole-body interaction (Cafaro et al, 2013). Where visitors stand in the exhibit gallery affects what data are shown and how they are visualized, essentially making use of the visitors and the space within the exhibit as parts of the user interface (see Figure 1). This serves two purposes: (1) it allows visitors to establish personalized connections to the data, and (2) it makes the current “state” of control immediately visible to both participating and spectating visitors. In this presentation, we use two cases to describe how users exploited two types of resources, the presence of other visitors and the space of the exhibit itself, to support the interpretations they were making of the data visualization. The cases are from observational studies in two museums: Chicago’s Jane Addams Hull House Museum (a small urban history museum), and the New York Hall of Science (NySci, a large interactive science center).

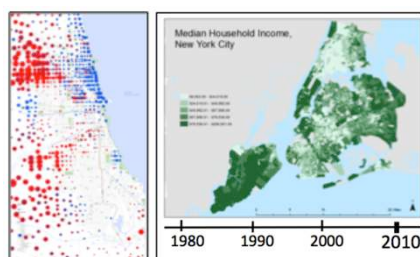


Figure 2. Left, a scaled centroid map showing the distribution of British-born (blue, embodied by Belle) and Polish-born (red, embodied by Peg) residents of Chicago. Users cause their data set to become more opaque (closer to the display) or transparent (farther away) by moving perpendicular to the display (see blue arrow on Figure 1, left). Right, a choropleth map of median household income data represented as five quantiles in New York. Moving across the marked timeline on the floor changed the decade (see red arrow on Figure 1, left).

Tabak highlights “coconstitution” as an important part of synergistic scaffolds, wherein: “different constituents interact to produce support that is greater than the sum of the constituents” (Tabak, 2004). With *CoCensus*, each visitor uses a kiosk to fill out an abbreviated US Census form, and their responses are then associated with a Radio Frequency ID (RFID) badge they wear in the exhibit. This allows the exhibit to display the data subsets relevant to each user in the exhibit, and thus the exhibit’s appearance depends on the number and chosen identities of the visitors present (Roberts, Lyons, & Radinsky, 2012). Some visitors took advantage of the co-presence of data to engage in reasoning that would never have occurred with a single data set. For

example, in one trial two adult women (“Belle” and “Peg”) assumed control of the British-born and Polish-born residents of Chicago, respectively (Figure 2, left). After moving backward and forward to reveal each others’ data sets, they very quickly noted the difference in the sets’ distribution:

Belle: It looks like I'm along the lake.
Peg: And I'm not. ((laughter)). Polish are inland. We're farming folk!
Belle: We're sailors!

The juxtaposition of the two sets caused the women to notice a difference in the distributions, and to begin generating playful hypotheses about why. They proposed other possible differences:

Peg: You're right, you're sailors!... So right, we have no idea... that's... if you're in the, if you're in the upscale? ((laughs))
Belle: I would think so...
Peg: I think so too. You're by the water. It's more expensive.

The women incorporated prior assumptions about how geography intersects with property values and made further playful inferences about what this might mean about the lifestyles of the residents depicted on the map:

Peg: So you're partying and I'm there in the fields.
Belle: Right, I'm having (all the fun).

While these women lacked the expertise to have made the same hypotheses that, say, sociologists would, their *process* of making these hypotheses isn’t so far from what an expert might do: (1) first notice a pattern in the data, (2) draw upon their prior knowledge to hypothesize about possible reasons for the patterns, and (3) make inferences about what impact the observed patterns might have on the lives of the represented people. The coconstitution of the women’s respective data sets was what made this fanciful exploration of the data patterns possible. What was missing from the exhibit was support for the visitors to test their hypotheses. Ongoing design iterations of CoCensus have incorporated additional data sets such as vocational information, income data, and household size. .

“The principled design of distributed scaffolding should include an attempt to create cohesion and direct interaction between the elements of the scaffolding system” (Tabak, 2004). With formal scaffolding, this recommendation often bears literal design implications, like using the same semiotics across different learning resources. With *CoCensus*, we see interacting visitors bring in spectating visitors to support their data explorations, and the spectators in turn use their observations of the position of the interacting visitors to shape their contributions. The space of the exhibit itself is thus playing an active, cohering role, as illustrated in the following case. A college-aged daughter, Kim, was interacting with the timeline of the choropleth income map (see Figure 2) when she noticed a phenomenon of interest and engaged her parents (Julie and Ken):

Kim: ... Dad, do you know what area that is?
Ken: Which?
Kim: That area that's turning from white to middle green? Right there?
Ken: Um, let's see. The bottom note. No, no wait. I'm sure that's Queens, but I'm not sure ((Really)) if that's near us or not. I don't think it is.
Julie: And it went back to white!
Kim: Interesting.
Julie: In twenty years
Kim: Ten. Well, within the space of twenty years, it has uh, from white to green to white again. That's what I mean. Um. Uh, from white to green to white again.

Here, the mother, Julie, is not just observing the change in the data visualization highlighted by Kim (“And it went back to white!”); she has also clearly been attending to how far along the timeline on the floor her daughter had been moving (“In twenty years”). This contribution added to Kim’s interpretation of what duration of time was needed to truly characterize the interesting change in the data. Kim had been thinking of it as a 10-year change, but the point her mother made forced her to realize that 20 years was needed for the odd pattern (low-then high-then low) to emerge. Julie’s attention to Kim’s movements on the timeline illustrates that the exhibit space helped the “scaffolding elements” (the visitors) cohere into unified support for data exploration.

These cases show how informal learning environments can make creative use of two oft-overlooked features (the presence of other visitors, and the space of the exhibit) to support the engagement with and joint exploration of data visualizations. We are currently exploring how to give visitors a more disciplinary

perspective by engaging them in critically challenging what data can tell them, and conversely, letting their assumptions be challenged by the data, paralleling work in classrooms (Radinsky, Melendez, & Roberts, 2012).

The Issue of “Fit” between Formal and Informal Contexts to Facilitate Synergistic Scaffolding

Chris Quintana, University of Michigan

The Zydeco project is exploring how mobile and cloud technologies can support middle/high school scientific practices and inquiry activity spanning across formal classroom and informal out-of-class contexts (Quintana, 2012). The Zydeco system includes an app for iOS devices, along with a corresponding web application to provide scaffolded workspaces that support different scientific practices, including: (1) A *planning workspace* to set up a project with investigation questions and sub-questions, possible hypotheses, and labels or tags to describe and organize data, (2) a *data collection workspace* to collect different kinds of data, information and observations in the form of photos, videos, audio notes or text notes, (3) a *review workspace* to access and review the different items that have been collected, and (4) an *explanation workspace* to develop an explanation by using a “claim-evidence-reasoning” model (McNeill & Krajcik, 2011). The goal is to explore the notion of “cross-context inquiry” that broadens the settings, supports, and resources available to students so they can integrate different experiences and information into their inquiry activity. The notion of cross-context inquiry provides a setting to consider the potential synergies between the formal and informal contexts where students are undertaking their scientific inquiry. Closer integration of the formal and informal contexts is facilitated by the mobile and cloud technologies in Zydeco, which increase the *contextual permeability*, allowing students to engage in different scientific practices in and draw from resources in the different contexts, and *contextual transference*, allowing students to transfer different aspects of their inquiry activity between contexts (Quintana, 2012).

While such tools can open up larger, richer settings for inquiry projects in multiple contexts, students still face different challenges and issues. Many of the challenges that have been previously identified for students engaging in inquiry activity still apply, such as the challenges for managing the inquiry process, making sense of different ideas and information, and reflecting on and articulating different information about the inquiry activity (Quintana et al., 2004). In some respects, expanding student inquiry to span formal and informal contexts may exacerbate these challenges because students are now working in contexts that each have different goals, levels of support, and cultures. As we continue to explore cross-context inquiry, we see additional challenges in terms of the “fit” between formal and informal contexts (Quintana, 2013). For example, there are issues of (1) “cultural fit”, or the challenges arising from the potential mismatch between the goals and cultures of different formal and informal sites, (2) “resource fit”, or the challenges faced in making sure that the resources available in a given informal site fit the curricula, goals, and projects being developed in the formal classroom context, and (3) “supportive fit”, or the challenges of identifying the scaffolding needed to support not only the different aspects of the scientific practices students are engaging in, but also the resources that students may encounter in the different contexts.

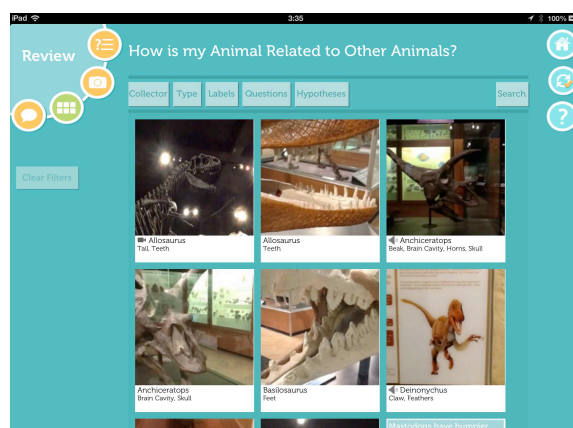


Figure 3: The Zydeco Review workspace allows students to review the data they have collected in their investigation to see what they may use as evidence in their investigation.

Students can filter their data. and also view their peers' data in certain cases.

A potential benefit of cross-context inquiry is that there are conceivably more resources available to students to support their work, especially in different informal settings that can include museums, nature parks, etc. There are also supportive resources available to students, which can range from teacher and peer support in

formal settings, to signage and docent support in informal settings, to technology-based support in tools like Zydeco that aim to include supportive features that can be used in both the formal and informal settings. This collection of resources provides a potential for more synergistic scaffolding for students (Tabak, 2004)—if these different resources can be marshaled to work together, then students could potentially benefit from more cohesive supports targeted to work together to support the inquiry aims of the student and teacher in all the settings where the inquiry activity is taking place.

However, the potential synergies between these various supportive resources can be hampered because of these issues of “fit” that emerge from mismatches between formal and informal settings. For example, in a recent Zydeco trial that spanned an academic year in a Detroit middle school, our teacher was devising an inquiry project around energy. The goal was to use engines as artifacts to study different ideas about energy transformation. The potential synergies here would include classroom discussions about energy and engines, a museum visit for information gathering in exhibits on engines and automobiles, and a set of tags or labels in Zydeco describing energy concepts so students could focus on and annotate their observations and collected data about the energy projects. However, this potential synergistic trio lacked cohesiveness: exhibit signage was aimed at a general audience and there were concerns from the teacher that it would not be helpful to students, the classroom discussion did not always mesh with the material in the museum, and the student use of Zydeco labels that may not always be consistent. This episode led the team to consider ways of adjusting these activities and supports to operate in a more synergistic way. For example, we have begun to employ “mini museums” in the classroom to augment the classroom discussion with engine models that prepare students for the more complex museum exhibits they will visit. We are also considering how to better incorporate data labels within Zydeco so they go beyond an organizational tagging aid, but also reflect important aspects of the classroom discussion to serve as a reflective support that can guide data collection. And our teacher even asked whether an augmented reality approach would be feasible at the museum so that students could their mobile devices as “viewers” to gain additional, dynamic information about how engines work when they visit the static engine models, again to augment the classroom discussion in ways that concretely illustrate the energy concepts being discussed.

These ideas point to the issues about the fit between the formal and informal context, and how trying to improve that fit could facilitate more synergistic supports between contexts. How can we improve the fit between the inquiry questions and plans in the classroom and the resources in a given museum so that the resources complement and augment the ideas and discussions in the classroom? How can we augment the signage and information in a museum with additional scaffolding to help students with sensemaking activity at the exhibits in ways that connect with their inquiry goals? Ultimately, the promise of effective cross-context inquiry is contingent on effective scaffolding across those contexts, and given the differences between formal and informal contexts, and the challenges that arise because of these differences, addressing these issues of fit may be necessary to develop a more cohesive, synergistic approach to supporting students and educators.

Scaffolding Productive Learning Conversations around Mixed Reality Simulation Technologies in Informal Spaces

Michael Tscholl and Robb Lindgren, University of Illinois, Urbana-Champaign

Michael Carney, University of Central Florida

There is a recognized potential for furthering learning through social interaction in informal environments, particularly parent-child guided participation (Ash, 2003; Zimmerman, Reeve & Bell, 2009). Augmented reality (AR) and mixed reality (MR) technologies, which are increasingly being used in informal spaces such as science centers, have the ability to enhance social interactions that can lead to powerful learning experiences (Dunleavy, Dede, & Mitchell, 2009; Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012a). How to most effectively facilitate productive learning conversations that both leverage the visual affordances of AR and MR technology, as well as the epistemic supports offered by accompanying parents and other adult visitors is a question that requires further examination. To investigate this area of learning design and attempt to create instances of ‘synergistic scaffolding’ (Tabak, 2004), we placed an interactive and immersive simulation into a science center and configured the spatial setup and access to information so as to create knowledge dependencies between a child—directly interacting with the simulation—and parents positioned as active observers. The objective was to understand how our configuration and similar socio-technical designs support everyday interaction, as well as elicit forms of conversational interaction recognized as being particularly effective for generating learning.

The MR simulation environment utilized in our research is called *MEteor*, a full-body immersive simulation of planetary astronomy designed to help children learn about gravity and how objects move in space. Due to its significant footprint in the museum exhibit hall (a 30 by 10 foot interactive floor space) and vivid sound and visual effects, the simulation attracted considerable attention, and middle-school aged children who visited the science center with their families were invited to participate for approximately 15 minutes. The participating child was asked to carry out a set of 4 interrelated tasks that required an understanding of the effect

of gravity on the trajectory of a launched asteroid (see Figure 4a). For example, in one of *MEteor*'s levels the child was asked to hit a target located behind a planet. This required understanding and leveraging the planet's gravity to bend the asteroid's trajectory around the planet. The simulation was set up to resemble a space exploration control station with the child playing as the asteroid inside the simulation and parents and visitors situated at the sidelines invited to help. The objective was to create knowledge dependencies that would elicit conversations pertaining to the child's strategies inside the simulation and the important science concepts that dictate the behavior of the simulation. To this end we made 3 display screens visible only to the onlooking parents (see Figure 4b) that provided 1) explanations about physics principles related to gravity and orbits, 2) a replay of the just-completed launch showing the trajectory of the asteroid and the child, and 3) text giving suggestions for how to prompt the child in particular ways. The child interacting in the simulation is given a first-person perspective on the action as they launch the asteroid, but there is the potential for their performance to benefit from the knowledge and supports that can be provided by the parents.

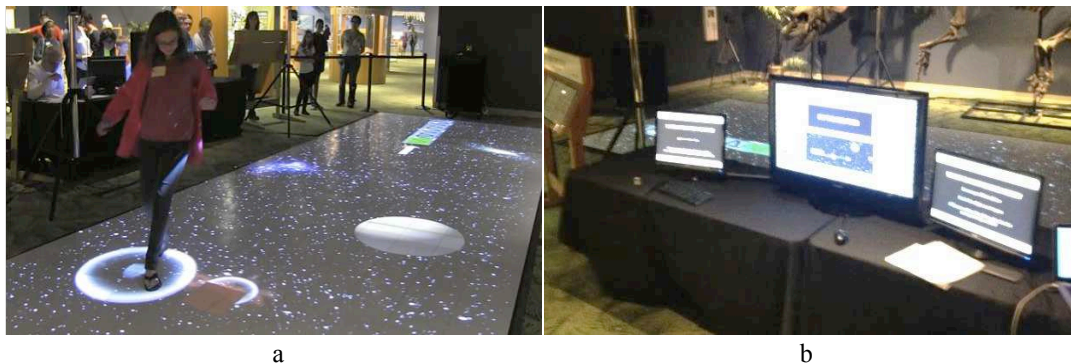


Figure 4. (a) A child using her body to launch an asteroid into a target given the presence of a strong gravitation force (i.e. a planet). (b) A series of display screens visible only to observing parents and other visitors giving replay and other supplemental information about the child's performance.

The setup creates multiple overlapping—and ideally synergistic—spaces within which activities conducive for learning can occur. The child's natural body movements are placed within a simulation scaffolding the development of new intuitions about how objects move in space through visual and auditory feedback. Parents observe the child's activities and can infer her strategies and her thinking, which enables them to give timely and contingent feedback on her performance. Parents themselves are scaffolded by the visual displays providing more formal information about laws of physics and gravity. They are further encouraged to prompt the child to maintain a higher-level perspective on the game activities, specifically to think about the relationship between how the asteroid was launched (position, velocity, etc) and its subsequent trajectory. With this configuration parents have the unique opportunity to make the child's thinking and activity meaningful in relation to scientific terminology and underlying principles.

We developed a coding scheme aligned with current informal learning research (Tare, French, Frazier, Diamond, & Evans, 2010; Crowley, Callanan, Jipson, Galco, Topping, & Shrager, 2001) that was used by our researchers to annotate the talk and action while on site. We found that the parent-child interactions can be distinguished into 2 broad categories:

1. *didactic interaction* (coaching) of the child with the child carrying out the instructions
2. *dialogic interaction* between child and parents that included valuable conversational moves such as explanation, and invitations for reflection

Primarily didactic interaction occurred in 46 sessions out of 85 where parents participated in some form (54%), while in 33 (39%) sessions some conversational moves typical for dialogic interaction were identified (in 6 sessions parents participated only through encouragement or affective comments). Interactions placed in this latter category included requests for explanations ("what do you think happened here?"), offering causal explanations in scientific terms ("your asteroid got pulled by gravity"), or descriptions of what happened in the simulation in scientific terms ("did you see? There is gravity"). Often parents would engage in lengthy exchanges aimed to elicit children's knowledge, reasoning and planning, as exemplified in the following excerpt:

Dad: Tom, do you see the planet?
 Tom: Yes"
 Dad: What do planets do?

Tom: They attract things
 Dad: Correct. So, do you see what is going on here?
 Tom: I have to shoot it this way ((curving gesture))

In contrast, the ‘coaching’ type of engagement typically focused on how the child had to set the spring (“pull back more”) or the child herself (“run faster”). Prediction and reasoning were, in the didactic situations, done by the parents, with only the action of the manipulation delegated to the child. Through this first analysis, it became evident that dialogic exchanges consisted primarily of parents ‘eliciting explanations’ from children and ‘providing explanations’ themselves. Providing explanations was more prominent and occurred in all 33 ‘dialogic’ sessions; in 26 of these sessions parents in addition asked the child to provide explanations and reflect.

Our analysis suggest that when digital technologies are used in informal learning environments—even MR or AR technology that embeds a learner within an immersive simulation—parents actively work to create learning opportunities for children, guiding their attention and engaging them in critical concepts relevant for understanding the simulation. The various strategies that parents employ include elicitation of explanations or requests for knowledge. Parents model problem solving strategies, a form of scaffolding that has been linked to children’s development of metacognitive competencies (Klahr, 2000; Zimmermann, 2000). We have shown, however, that parents’ contributions to digital interactions do not only convey explanatory or descriptive knowledge, the kinds of conversational acts typically identified by studies of “static” exhibits (e.g., Tare et al., 2010; Crowley et al., 2001). The parental interventions in our study frequently aimed instead to create a space for the children to think and reflect – a space that they are left to fill on their own.

Using Augmented Reality to Scaffold Learning about Conceptually Challenging Science Content in a Science Museum

Susan Yoon, Joyce Wang, and Emma Anderson, University of Pennsylvania
 Karen Elinich, The Franklin Institute Science Museum

Increasingly, informal science environments have been characterized as important venues for learning science and influencing participation in science activities and careers (NRC, 2009). Questions that have arisen from this focus include the extent to which visitors can learn the science, what supports are needed, and how technology can aid in the learning (NRC, 2009). At the same time, augmented reality (AR) technologies have been highlighted for their enormous potential to enable people to construct new understanding (New Media Consortium, 2012). By layering digital images over real world environments, the hybrid display of phenomena provide scaffolds for users to experience and perceive virtual elements as part of their present world, making normally invisible things visible. In informal museum spaces, a number of studies have shown that AR can enhance visitor exploration of objects (Szymanski et al., 2008), increase visitor collaborative interactions (Asai et al., 2010), and improve interest in the content of museum exhibits (Hall & Bannon, 2006).



Figure 5: Bernoulli Blower

Building from these bodies of research, over the last several years, our project entitled *Augmented Reality for Interpretive and Experiential Learning* (ARIEL) has investigated how augmented reality and various forms of learning scaffolds can improve visitor scientific knowledge in an informal science museum setting. To date, three pre-existing exhibit devices have been modified to include digital augmentations. We selected these devices because the same or similar ones are present in virtually all science museums and centers across the world. The first device, “Be The Path”, was augmented to show the flow of electricity when visitors complete an open circuit; the second device, “Magnetic Maps”, was augmented to visualize the magnetic field surrounding two bar magnets; and the third device, “Bernoulli Blower” (depicted in Figure 5), was augmented to feature the

interactions between two types of air to keep an object afloat. Results from quasi-experimental studies on the first two augmented devices demonstrate that AR can increase conceptual (content) understanding (Yoon et al., 2012a) and cognitive (theorizing) skills (Yoon et al., 2012b). We have also shown that this learning is largely influenced by collaboration between peers and the AR device (Yoon et al., 2012b), dynamic visualization affordances (Yoon & Wang, in press), and preservation of informal participation such as self-directed experimentation (Yoon et al., 2013).

In this study, we investigate learning affordances of the third device “Bernoulli Blower” to scaffold learning about a conceptually challenging scientific concept. The exhibit features a plastic ball that is able to float in midair because it is caught between the fast moving air that is being blown out of a blower attached to the exhibit device and the normal, slow-moving air in the room. Although the normal room air moves at a lower speed than the faster moving tube air, it exerts greater pressure onto the ball and is therefore able to keep the ball floating in the stream of fast-moving air instead of being blown away. This idea – that speed and pressure of a moving fluid are inversely proportional – is extremely counterintuitive to learners. Studies have shown that most people believe that pressure should be high where speed is high (Faulkner & Ytreberg, 2011). Considering common daily experiences, such as observing how wind moves objects around in proportion to how strong the wind blows, this belief is not surprising. Furthermore, literature reveals that children often recognize air pressure by its movement (Sere, 1982). Where there is no perceptible movement, they think that pressure does not exist (Basca & Grotzer, 2001). In standard K12 science curricula, Bernoulli’s Principle is also often not taught by physics teachers who either lack a clear understanding of the concept themselves and/or find it too difficult to explain to students (Hewitt, 2004). Given these teaching and learning difficulties, we were interested in investigating how digital augmentations could support the learning of highly challenging science concepts. We hypothesized that the addition of AR could help students visualize the behavior of air and air pressure, which would provide a valuable scaffold for students to build better knowledge of the science behind the floating ball.

We tested this hypothesis with 58 middle school science students who visited the museum on a field trip. Students were randomly placed in one of two conditions: condition 1 (device with no augmentation); or condition 2 (device with augmentation). Through interviews conducted with students after they interacted with the device, we measured student content knowledge of the Bernoulli Principle by asking the question, “What were you supposed to learn from this device?” Responses were measured on a five point Likert-Scale ranging generally from limited understanding (1) to complete understanding (5). An independent samples t-test was conducted to compare the amount of content knowledge gained in the two conditions. Results showed that there was a significant difference in the knowledge scores of students in condition 1 ($M = 2.66$, $SD = 0.55$) and condition 2 ($M = 3.1$, $SD = 0.77$); $t(56) = -2.543$, $p = .014$. In condition 1, 38% of the students had a level 2 understanding (defined as providing simple observations or listing objects or concepts presented) and 59% had a level 3 understanding (defined as identifying a relationship between two of three variables – air speed, air pressure, and the floating ball). Only 2% reached a level 4 understanding (defined as identifying a relationship of both air speed and pressure and the floating ball). In contrast, in condition 2, only 17% had a level 2 understanding. Although there was a similar frequency of level 3 responses, 21% reached a level 4 or 5 understanding (defined as recognizing a relationship between varying air speeds and pressures and the floating ball). These results suggest that the digital augmentation had an effect on students’ content knowledge.

A perusal of student responses illustrates how the AR impacted their learning. One student (ID6) in condition 2 who scored a level 5 said, “It helped you see the air currents that was coming from the tube and it helped you see the high pressure air that was coming in from below and above. If air is moving quickly, it has low pressure. If it’s moving slowly, it has high pressure.” This student went on to explain that the activity was different from how they normally learned in school because of the screen and the display where she could “experience what it was instead of reading about it in a textbook”. She and two other girls also “tried to play a game” where they had to “get the ball to move around without completely cutting off the air current”. Here we can see that the student was able to build an accurate understanding of the phenomena while at the same time engaging in self-directed experimentation, which is an archetypal characteristic of informal participation. In the symposium, we will present additional data from the interviews that provide further illustration of how the AR provided other visualization scaffolding for students.

In this study, we examined whether and how augmented reality could be used as an effective scaffold to help visitors learn about difficult scientific concepts in the museum setting. Our findings showed positive gains as a result of student interaction with the digital scaffolds. However, similar to our other studies, we also found that there was room for even further growth in conceptual knowledge gains. Looking forward, we are considering additional ways to scaffold the experience to induce greater learning while at the same time preserving the informal experience. Designing for content understanding will inevitably require increased scaffolds, some of which are already common practices within museums such as grouping exhibits into clusters based upon conceptually related content and including advanced organizers (Falk, 1997). In our future work, we will investigate various aspects of multiple exhibit design with the addition of AR to understand how content learning and engagement can be maximally supported.

Conclusion

Traditional scaffolding functions like inspiring interest in the task, reinforcing adherence to task requirements, reducing the degrees of freedom within the task, and providing feedback and repair functions, take on a very different form outside of the usual formal classroom settings. The examples above all demonstrate the ways in which different resources were marshaled to support some or all of these features. For example, *CoCensus* and *MEteor* engage learners' interest by "personalizing" the exhibits in different ways: *CoCensus* allows visitors to see data that reflects "them" or their choices on a shared display, while *MEteor* allows visitors to "role play" as heavenly bodies. *Zydeco* helps learners adhere to task requirements by allowing visiting schoolchildren to quite literally carry a bit of their pre-visit planning with them, and pares away unnecessary degrees of task freedom with an interface structured to place the focus on the desired information gathering activities. The *ARIEL* exhibits show how coherence between visitor actions and visualizations of invisible forces can provide necessary feedback to visitors who would otherwise struggle with the exhibits, allowing them to adjust their interactions to hone in on the core content of the exhibits.

All of these examples have designed features that work to synergistically recruit and employ other people to support learning, bringing these examples of scaffolding closer to the original tutor-to-pupil definition of scaffolding (Wood, Bruner, & Ross, 1976). The large displays and material properties of the *ARIEL* exhibits, *MEteor* (along with the side display), and *CoCensus* (along with the use of the floor space) all allow spectators to develop richer understandings of what participating visitors are doing with interactive exhibits, so that they can provide counsel and guidance. With *Zydeco*, the guidance of the teacher's counsel gets somewhat reified within the software itself by the collection of pre-selected tags, so that the students carry the teacher's guidance with them.

Each of these projects also illustrates some of the challenges that are unique to scaffolding learning in informal learning environments. The challenges with using *Zydeco* highlight how museums, despite ostensibly being settings which support open-ended inquiry learning, often lacked the curricular fit needed to support the inquiry learning questions students would generate. *ARIEL* showed how conceptual learning could be improved with augmented reality visualizations, but Yoon et al. warn that attempts to add additional scaffolds to attain even greater learning gains must be balanced against not making the activities too highly-structured and school-like, lest students lose interest. *CoCensus* showed that visitors were surprisingly ready to engage in joint explorations of data visualizations, but might be too willing to accept shallow and naïve interpretations. *MEteor* hints that sometimes the best way to employ parents as learning resource is to (quite literally) get them to step out of the way. Synergy does not magically result by combining learning resources. Informal learning designers should be sure to take into account not just individual learning resources in their designs, but to consider how the alignment across the social, material, and cultural resources in informal settings to produce learning experiences that truly exceed the sum of their parts.

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