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How Augmented Reality Enables Conceptual Understanding of Challenging Science Content

Susan Yoon[1*], Emma Anderson[1], Joyce Lin[2] and Karen Elinich[3]
[1]Graduate School of Education University of Pennsylvania, Philadelphia PA, USA // [2]Knowles Science Teaching Foundation, Moorestown, NJ, USA // [3]The Franklin Institute, Philadelphia, PA, USA // yoonsa@gse.upenn.edu // emmaa@gse.upenn.edu // joyce.lin@kstf.org // kelinich@fi.edu
[*]Corresponding author

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ABSTRACT

Research on learning about science has revealed that students often hold robust misconceptions about a number of scientific ideas. Digital simulation and dynamic visualization tools have helped to ameliorate these learning challenges by providing scaffolding to understand various aspects of the phenomenon. In this study we hypothesize that students acquire a more accurate understanding of the Bernoulli's principle, a challenging science concept, by interacting with an augmented reality (AR) device. We show that even given a short period for investigation in a science museum, students in the AR condition demonstrate significantly greater gains in knowledge over students in the non-AR condition. Through interview responses, we further show that the AR affords greater ability to visualize details and hidden information to help students learn the science.

Keywords

Augmented reality, Challenging science content, Bernoulli's principle

Introduction

Research on learning about science has revealed that students often hold robust misconceptions or naïve conceptions about a number of scientific ideas (Chi, 2005; Bransford, Brown, & Cocking, 1999). For example, studies on student understanding of the Bernoulli's principle, which is the subject of our exploration, have shown that students find learning the content challenging due to, among other things, the counterintuitive experiences of pressure-related events observed in the real world (Stepans, 2003).

Digital simulation and dynamic visualization tools have helped to ameliorate these learning challenges by providing scaffolding (Honey & Hilton, 2011; Kim & Hannafin, 2011) to understand various aspects of phenomenon that may contribute to misconceptions. Related to this, a recent focus in the learning sciences has investigated how augmented reality (AR) tools can support science learning (Dunleavy, Dede, & Mitchell, 2009; Dunleavy & Dede, 2014; Klopfer & Squire, 2008). At its simplest, augmented reality describes systems that integrate computer-generated virtual elements or information (known as "digital augmentations") with the real world environment (Zhou et al., 2008). By superimposing virtual elements onto the real world environments, AR allows users to experience and perceive the newly incorporated information as part of their present world, thereby enhancing their perception of the real world (Kirkley & Kirkley, 2004; New Media Consortium, 2012). Everyday examples of AR include Google Effects in Hangouts, AR games for Nintendo 3DS, and Webcam Greeting cards from Hallmark.

Over the last 4 years, our project, Augmented Reality for Interpretive and Experiential Learning (ARIEL), has investigated optimal uses of AR in science museums (e.g., Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012a; Yoon, Elinich, Wang, Van Schooneveld, & Anderson, 2013; Yoon & Wang, 2014), where misconceptions about science are rarely addressed. In this study, we hypothesized that the use of AR, because it provides a visualization of the underlying causal mechanisms, can assist students in developing a more accurate conception of Bernoulli's principle. We found that after participating in brief, informal investigations of the principle at a science museum, students who interacted with an exhibit using AR were better able to understand the science than students in a non-AR condition. Findings from our interviews and surveys suggest that the tool supported students' learning by revealing typically invisible features of the phenomenon.

Theoretical considerations

Common misconceptions and challenges associated with understanding Bernoulli's principle

Bernoulli's principle states that "when an incompressible, smoothly flowing fluid gains speed, internal pressure in the fluid decreases, and vice versa" (Hewitt, 2004). In other words, there is an inversely proportional relationship between fluid speed and pressure. When the fluid's speed increases, the pressure drops. As it turns out, this is a conceptually challenging and counterintuitive idea to understand for students, who typically believe that when speed increases, so does the pressure (Faulkner & Ytreberg, 2011). Stepans (2003) explains,

> *Children learn from experience that when they blow on something – like a bubble or dandelion plume – it goes away. These experiences make it difficult to make sense of the fact that when you blow on a surface, it comes toward you, or that when you blow between things, they come together. These experiences make it difficult to accept the concept of Bernoulli's Principle.* (p. 46)

In a test given to private and public 6th, 7th, and 8th grade Turkish students on the outcomes of discrepant events related to Bernoulli's principle, Bulunuz, Jarrett, and Bulunuz (2009) found that the majority of students held incorrect conceptions of the phenomenon. Researchers gave a similar test to a group of pre-service elementary teachers, and results indicated that less than 50% of the teachers gave correct responses (Bulunuz & Jarrett, 2009). Even physics teachers claim to have unclear understandings of Bernoulli's principle and sometimes avoid teaching the concept altogether to their students (Hewitt, 2004).

In examining misconceptions of pressure-related concepts, Basca and Grotzer (2001) organize the conceptual challenges into four categories, two of which have important implications for our research. The first difficulty that children have is that they tend to reason using obvious, rather than nonobvious, variables when determining the causes of pressure-related events. For example, de Berg (1995) found that when a syringe was compressed, 17- and 18-year-old students felt, and accurately identified, that the pressure in the system increased. However, a majority of them also thought that the enclosed air did not exert any pressure if the syringe was not being compressed. In other words, children tend to associate pressure with movement; in the absence of detectable movement, they assume that there is also no pressure (Glough & Driver, 1985). Similarly, Séré (1982), found that 11- to 13-year-old children explained the movement of air in relation to another movement. Consequently if a system was at equilibrium, they believed that there were no forces being exerted. Séré (1982) concluded,

> *[Children] thus lack the knowledge of atmospheric pressure as a state of reference in order to understand that air—even when immobile—exists, is present, and acts. This state of reference is needed to recognize the effects of pressure and to attribute a pressure to any quantity of air, even when it is not in movement.* (p. 308)

The unobvious and undetectable nature of "stationary" air explains why students are not always aware that pressure contributes to an effect. Therefore, they turn to more obvious and concrete but inaccurate explanations (Kariotoglou & Psillos, 1993).

A second challenge that inhibits students' understanding of pressure-related concepts is that they tend to reason linearly rather than systemically and relationally (Basca & Grotzer, 2001). Children often attribute causes and effects to a linear, unidirectional model, instead of considering more complex variables, and the relationships between the variables, that might offer a better model of the scientific phenomenon (Grotzer & Tutwiler, 2014). For example, Glough and Driver (1985) found that 12- to 16-year-old children explained drinking through a straw as simply pulling or sucking rather than the result of a pressure differential between air pressure inside and outside of the straw. Oftentimes, relational causality, which refers to the interaction between causes and effects, more accurately explains scientific phenomena. As depicted in the second image of Figure 1, the cause of the floating ball is the result of the interaction of and relationship between the two air pressures—not one (or two) pressures acting disparately. Although a linear model is more conspicuous and accessible, it often does not fully explain the complexity of the phenomenon (Basca & Grotzer, 2001).

These prevailing misconceptions and challenges that prevent children and adults from accurately understanding pressure-related topics in the physical world motivate our study. Because Bernoulli's principle is illustrated in museums all over the world yet is a conceptually challenging topic to grasp, we hypothesized that the addition of AR could help visitors build better knowledge of the science behind the floating ball. In the following section, we describe previous studies of AR in science learning environments that show promising evidence to support its use in improving science content learning.

Augmented reality to scaffold science learning

Augmented reality (AR) technologies have been highlighted for their enormous potential to enable people to construct new understanding (New Media Consortium, 2014). By layering digital displays (known as "digital augmentations") over real-world environments, the hybrid display of phenomena provides scaffolds for users to experience and perceive virtual elements as part of their present world (New Media Consortium, 2014; Kirkley & Kirkley, 2004). In so doing, the augmentations help users explore aspects of the world in more concrete ways than might otherwise be possible (Yoon & Wang, 2014).

This potential to augment users' interactions, engagement, and experiences has revealed numerous affordances of AR for science learning. These include supporting students' scientific spatial ability, by (a) allowing them to manipulate and learn content in three-dimensional perspectives (Kerawalla, Luckin, Seljeflot, & Woolard, 2006; Martín-Gutiérrez et al., 2010); (b) engaging them in scientific inquiry by encouraging them to make observations, ask questions, collaborate with others, and investigate and interpret data (e.g., Dunleavy et al., 2009; Rosenbaum, Klopfer, & Perry, 2007; Squire & Jan, 2007; Squire & Klopfer, 2007); and (c) enhancing their conceptual understanding by enabling them to visualize invisible or abstract concepts or events (e.g., Clark, Dunser, & Grasset, 2011; Dunleavy et al., 2009; Dunleavy, 2014). For further descriptions of the features and affordances of AR for educational purposes, see Cheng and Tsai (2013), Wu, Lee, Chang, and Liang (2013), and Dunleavy and Dede (2014). These studies demonstrate that, compared with traditional teaching methods, students who use AR applications tend to demonstrate higher academic achievement levels (Ibañez, Di Serio, Villarán, & Delgado Kloos, 2014; Kamarainen et al., 2013; Lin, Duh, Li, Wang, & Tsai, 2013).

AR technology is also starting to slowly extend into museum spaces. However, as most of these technologies are prototypes and still in the development stages, research on their use in museums is largely concerned with their design, evaluation, and usability (Bell, Lewenstein, Shouse, & Feder, 2009). Some studies have investigated the development of guidebooks to support visitors' navigation of AR displays and their interactions with the displays throughout the museum (e.g., Damala, Cubaud, Bationo, Houlier, & Marchal, 2008; Szymanski et al., 2008), while others have studied the technological design, architecture, and implementation of an AR system (e.g., Koleva et al., 2009; Wojciechowski, Walczak, White, & Cellary, 2004). Although these studies do not specifically examine the impacts on visitor learning, they do offer important insight into the general effects AR has on visitors' behavior. For instance, Asai, Sugimoto, and Billinghurst (2010) reported that an AR lunar surface navigation system implemented at a science museum exhibit encouraged more collaborative interactions between parents and their children. Szymanski and colleagues (2008) revealed that electronic guidebooks increased visitors' exploration of the objects being augmented, and Hall and Bannon (2006) demonstrated that children's engagement and interest increased when they interacted with several museum artifacts that were augmented.

There are only a few studies that look at museum visitors' knowledge and use of AR. Chang et al. (2014) investigated college students' appreciation of art by comparing the use of an AR enhanced guide, an audio guide, or no guide. Students who experienced the art museum through the AR enhanced guide showed greater art appreciation compared to the audio and non-guide experience. The behavior and amount of time with the paintings was not significantly different between the audio and AR guided students. The AR guide was credited with having more easily digestible information compared to the audio guide due to the use of visuals. Similarly, Sommerauer and Müller (2014) explored how AR contributed to visitors' mathematics knowledge in a museum mathematics exhibition. They found that visitors who interacted with the AR enhanced exhibit performed significantly better on knowledge acquisition and retention tests.

These studies demonstrate that AR has the potential to support learning. From conveying spatial information about scientific elements essential to understanding and visualizing phenomena to increasing collaboration and engagement among its users, AR technology offers promise for transforming science learning. However, particularly for informal environments such as science museums, more empirical research is needed to determine whether and how AR supports visitors' conceptual understanding of science ideas.

ARIEL studies in a science museum

Building on the research described in the previous section, over the last several years we have used the ARIEL project to investigate how augmented reality and various forms of learning scaffolds can improve visitors' scientific knowledge in an informal science museum setting. To date, three pre-existing exhibit devices have been modified to include digital augmentations. These devices were selected by museum staff because of their prevalence in science museums and centers worldwide. The first device, “Be The Path,” was augmented to show the flow of electricity when visitors completed an open circuit with their bodies. 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 1), was augmented to feature the interactions between two types of air to keep a plastic ball afloat. Jonassen and colleagues (1994) proposed that when investigating the role of media in student learning we should examine the process of learning first, then the role that context plays in understanding the kinds of cognitive tools and their affordances needed to support learning. The ARIEL project has conducted research examining both the learning afforded by AR in the context of an informal learning environment. Our previous research has shown that learning is largely influenced by collaboration among peers while using the AR device (Yoon, Elinich, Wang, Steinmeier, & Van Schooneveld, 2012b), all the while preserving core aspects of informal participation, such as self-directed experimentation (Yoon et al., 2013). In terms of the cognitive tools, results from experiments with our first two augmented devices demonstrate that AR can increase conceptual (content) understanding (Yoon et al., 2012a) and cognitive (theorizing) skills (Yoon et al., 2012b). For understanding the affordances of the media we have shown that learning is supported through the device’s dynamic visualization capabilities (Yoon & Wang, 2014).

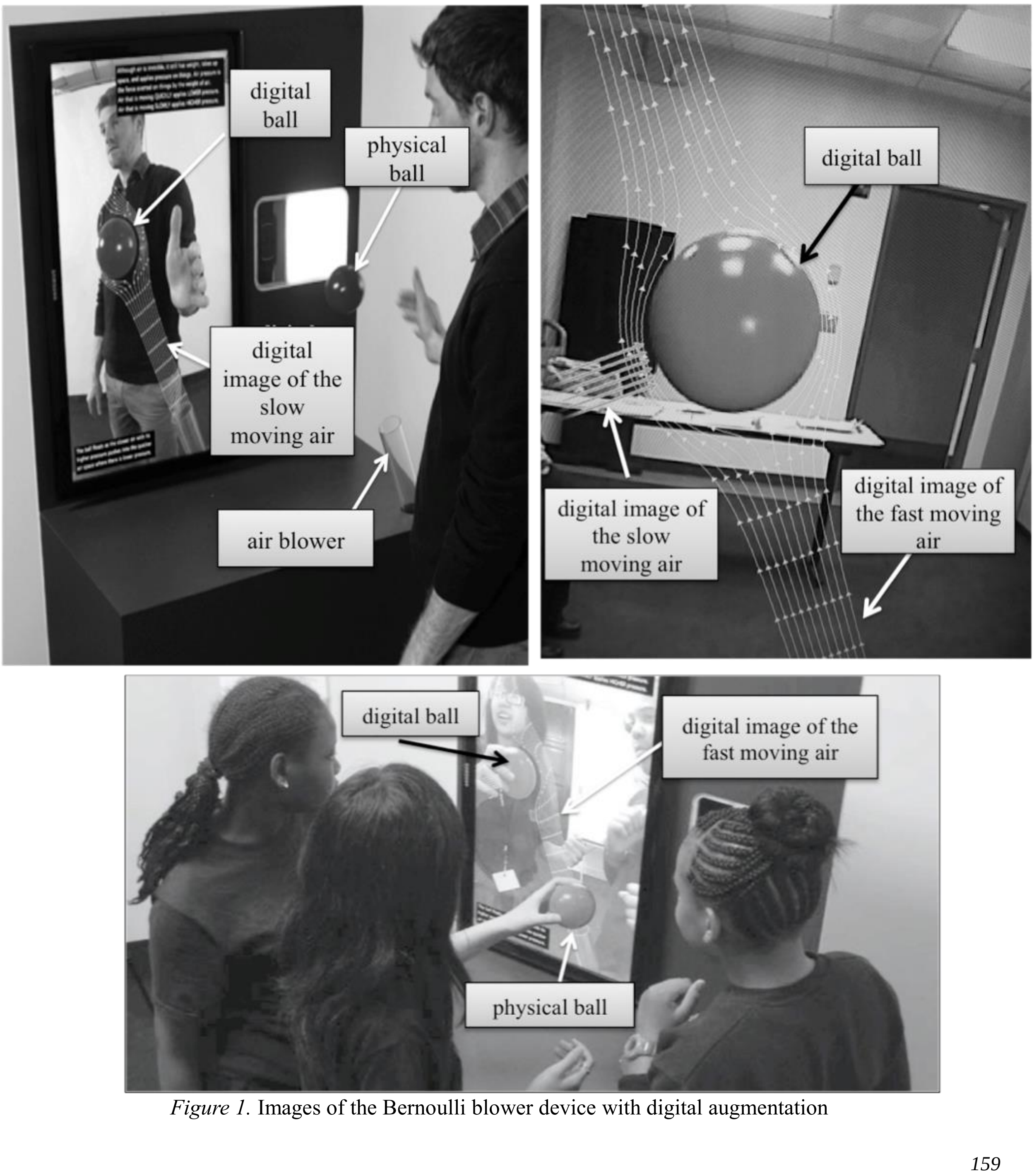

Figure 1. Images of the Bernoulli blower device with digital augmentation

It is important to note that the ARIEL studies take place in a science museum where learning is characterized by free choice, individual motivation, and open-ended playful exploration (Bell, Lewenstein, Shouse, & Feder, 2009). In this informal learning environment there is no set curriculum, there is no instructor and the only change to the learning environment is the addition of AR to the Bernoulli Blower. Here the instructional method is intertwined with the media of AR. It is this change in instruction enabled by the dynamic visualization of hidden information in real time that this particular study aims to explore.

In this study, we examine how the digital augmentations in "Bernoulli Blower" can serve as a scaffold for learning about Bernoulli's principle. Briefly, the exhibit features a physical plastic ball that is able to float in midair because it is caught between the fast moving air coming from a blower attached to the exhibit and the slow moving air in the room. The digital augmentation is produced on a screen that depicts the fast moving air through arrows that point diagonally up and curve around a real time image of the physical plastic ball. At the same time the screen displays the slow-moving air from the room by depicting shorter arrows that point in and at the real-time image of the plastic ball. Although the normal room air moves at a lower speed than the faster moving blown air, the room air exerts greater pressure on the ball and is therefore able to keep the ball floating in the stream of fast-moving air instead of being blown away. Thus the speed and pressure of flowing air are inversely proportional.

Methods

Participants and context

This study was conducted at a large, well-established science museum in a northeastern U.S. city. The students who participated in this study were selected by their teachers, who themselves responded to a mass email invitation sent to middle school (6th to 8th grade; 11 years old to 14 years old) science teachers in the surrounding area. In total, 58 students (41% male, 59% female) from five schools (three charter, two community public) participated (see Table 1 for other demographic data). We specifically targeted students in this grade band because the concept of air pressure is first introduced in 5th grade in our state's standards; therefore, all students would have some prior knowledge of the science concepts illustrated by the device. This study was embedded within an all-day school field trip to the museum, and participating students were given free general admission to the exhibits. The total amount of time it took to participate in the research was approximately 1 hour.

Table 1. Student demographic data

School	Economically disadvantaged	Percent non-white
Public A	75%	31%
Public B	83%	84%
Charter A	84%	99%
Charter B	82%	100%
Charter C	80%	100%

On the day before the students' field trip, researchers went to the schools to collect consent forms and to administer pre-intervention surveys of students' knowledge of Bernoulli's principle. On the day of the field trip, each chaperoned group (assigned by the teacher, with roughly nine students in each group) was given a specific time to report to the research area, a space commonly used for museum workshops and classes. (Outside of this time slot, students were free to explore the museum per their teacher's instructions.) When students arrived at the research area, they were randomly assigned to one of two conditions: the non-AR condition (device with no digital augmentation) or the AR condition 2 (device with digital augmentation). In groups of three, students were invited to the research area and shown the device. Depending on the condition that the students were assigned to, the computer screen, which displayed the augmentations, would either be turned on (AR condition) or off (non-AR condition) and the red ball would be lying on the table. The students were told "see if you can make the red ball float" and asked to play with it as if they had found it on the museum floor. After students signaled that they were finished, they were individually asked a set of interview questions about their experience with the device. Their responses were audio recorded and later transcribed. The day after the field trip, researchers went back to the schools to administer post-intervention surveys of student knowledge. In total, the non-AR condition had 29 students (55% female, 45% male, 55% 7th graders, 45% 8th graders) who spent on average 11 minutes and 43 seconds interacting with the device. The AR condition had 29 students (62% female, 38% male, 66% 7th graders, 34% 8th graders) who spent on average 9 minutes and 41 seconds interacting with the device.

Data sources and analyses

Two qualitative data sets were collected, coded, and analyzed to determine how AR impacted students' conceptual knowledge of Bernoulli's principle.

Pre- and post-intervention surveys of student knowledge

The pre- and post-intervention surveys consisted of four multiple-choice (MC) questions and one open-ended (OE) response question. These questions were constructed by a team of researchers and are modeled on similar questions found in middle school science textbooks. Three of the MC questions could be considered near-transfer questions, as the correct answers could be directly accessed from the exhibit device itself. The fourth MC question could be considered a far-transfer question, as it asked students to select a real-world situation that illustrated Bernoulli's principle. The OE response question depicted a similarly constructed device using common household materials and asked, *Why do you think the plastic ball floats in the stream of fast-moving air?* The complete intervention survey can be found in the Appendix. Students' responses were coded using a previously validated categorization manual on a six-point Likert scale ranging from limited understanding (1) to complete understanding (6) (Wang, 2014). Refer to Table 2 for a description of the levels of understanding. Two analyses of covariance (ANCOVAs) were separately conducted for the MC responses and the OE responses. For the MC responses, the independent variable in the ANCOVA was the condition students participated in and the dependent variable was the students' post-intervention MC scores. The covariate was the students' pre-intervention MC scores. Similarly for the ANCOVA on the OE responses, the independent variable was the students' condition and the dependent variable was the students' post-intervention OE responses. The covariate was the students' pre-intervention OE scores.

Table 2. Levels of content understanding

Level	Description	Sample response
1 – Little Understanding	Identifies the air from the blower as the only factor making the ball float. May discuss various aspects of the air that contribute to the phenomenon, but the focus is on the air itself.	The air pressure, if you have too much air pressure, it'll just push it away. But if you have just the right amount right in the line of symmetry, it will stay right in place.
2 – Emergent Understanding	Considers *features of the ball* that may impact its ability to float. Discussion of the air from the blower may or may not be expressly stated.	It was able to float because it was light and it's plastic so it has air already in it. Since it's light enough, the air pushing on it won't make it move around because it's not just solid. It has enough air in it to make it move.
3 – Partial Understanding	Acknowledges *other sources of forces*—forces not associated with the air from the blower—that are involved, such as gravity and the normal air in the room. May describe how the forces interact (e.g., pushing up/down) with each other to keep the ball floating.	The air, the actual air, is pushing down I think. And the one from the tube is going up so then it's making it float cause it was pushing on the sides.
4 – Basic Understanding	Begins to consider that the ball floats because of *differences in the pressure/force* of the various airs involved. These differences may be described in the amount of pressure/force exerted on the ball or simply identified as high(er) or low(er) pressure. Although they may incorrectly describe these differences, they acknowledges that the interaction of the varying amounts of pressures is integral to the phenomenon. (Note: Simply acknowledging that pressures are involved is not enough).	The air was pushing it up so it would stay away from the tube and the air was also going around it so it could stay stabilized. And also like, slow moving air could stabilize it too…but it wouldn't push it that far. It would just like…it wouldn't make a big impact.
5 – Adequate Understanding	Considers both the *speed AND pressure* of the airs involved understanding there is a *relationship* between the speeds and pressures, though the relationship may be incomplete or inaccurate. May only address the speed and pressure of just one kind of air.	So the air from the tube is pushing it up and the air around it's pushing it in to make sure that it doesn't fall off the air flow that's keeping it up...The slow air has the lower pressure and the fast air has the higher pressure.

6 – Complete Understanding	Understands that the ball floats because the high pressure from the slow-moving room air keeps the ball in the low-pressure, fast-moving air stream. Both kinds of airs must be explicitly addressed. These responses cannot contain any misconceptions.	The faster air was pushing it up and the slower air had more…pressure so it was pushing it up and down and keeping it in the same spot so it couldn't really go out of the air circle. (*About the slow air)* It's just like…like not moving air has higher pressure than really fast air.

Interviews

Post-intervention interviews were administered to understand how students interpreted the concept illustrated by the device. Interview questions included the following:

What did you learn from playing with this device?
How did you learn this?

For the AR condition students we asked a follow up question that probed whether they felt the AR supported their learning: *Do you think you would have learned this without the digital augmentations?*

Responses were qualitatively mined both for content understanding (using the same categorization manual that we used for the OE post-intervention survey questions) and for the affordances of AR as a visualization tool (Yoon & Wang, 2014).

For both the OE survey and interview data sets, two graduate students were trained on the categorization manual and scored 20% of the OE survey data (12 out of 59), yielding 83% agreement (on 10 out of 12 responses). The discrepancies on codes were negotiated until one code was assigned. After this step, one researcher coded the rest of the OE survey and interview data.

Results

Table 3 shows that students in the AR condition scored significantly higher on the MC portion of the knowledge survey than the non-AR students, $F(1, 55) = 8.600$, $p = .005$, effect size (Cohen's d) = .802. However, the difference in means between conditions was not found to be significant for the OE responses on the knowledge survey, $F(1, 55) = 2.679$, $p = .107$.

Table 3. Mean scores on student knowledge of Bernoulli's principle

Student knowledge	Mean Pre (*SD*)	Mean Post (*SD*)	*N*
MC Condition 1	1.517 (.726)	2.000 (.598)	29
MC Condition 2	1.793 (.789)	2.517 (.688)	29
OE Condition 1	1.862 (.785)	1.931 (1.193)	29
OE Condition 2	1.759 (.773)	2.276 (1.750)	29
Interview Condition 1	n/a	2.660 (.550)	29
Interview Condition 2	n/a	3.100 (.770)	29

Regarding students' interview responses, an independent samples t-test showed that there was a significant difference between the knowledge scores of students in the non-AR condition and students in the AR condition, $t(56) = -2.543$, $p = .014$, effect size (Cohen's d) = .658 where more AR condition students scored in the higher levels of understanding. In the non-AR condition, 38% of the students had a Level 2 understanding (defined as describing 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). In contrast, in the AR condition (device with digital augmentation), although there was a similar frequency of students with a Level 3 understanding, only 17% had a Level 2 understanding, and 21% reached a Level 4 (defined as identifying the involvement of both air speed and pressure) or 5 (defined as recognizing a relationship between varying air speeds and pressures) understanding.

Collectively, these results suggest that the digital augmentation had a positive effect on students' content knowledge. A perusal of student responses illustrates how the AR influenced their understanding. For example, one student (ID6) in the AR condition who scored a Level 5, said,

> *It helped you see the air currents that* [were] *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" in which 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.

Other student responses illustrated how the AR acted as a scaffold for more accurate understanding the phenomenon. Students commented on the affordance of visualizing scientific details:

> *…what kind of air like how many, how much pressure do you need to put on it or what kind of pressure do you need to put on it slower, quicker, faster.* (ID186)

Students also commented on the affordance of visualizing hidden information:

> *That the ball was being caught in the air pressure between the outside and what's coming from the tube… In school, we don't really have the, I would say the visual learning of it. We just picture it in our minds.* (ID17)

These responses demonstrate the affordances of the AR as well as students' ability to acquire an accurate understanding of how Bernoulli's principle works in the brief time they were exposed to the exhibit during their museum visit.

Discussion

In this study, we hypothesized that augmented reality, because it enables the visualization of typically invisible causal mechanisms that underlie complex phenomena, could be used as an effective scaffold to help visitors learn about challenging scientific content in a museum. Through the multiple-choice portion of the knowledge survey and interviews, our results indicate that students in the AR condition significantly improved in their understanding of Bernoulli's principle and showed greater gains compared with students in the non-AR condition. That the results from the open-ended response portion of the knowledge survey did not show a significant difference between conditions may be attributed to the fact that those kinds of surveys draw on limited information while interviews provide the opportunity for students to be probed for deeper understanding. Student interviews also showed that the AR served as a valuable learning scaffold by enabling students to visualize scientific details, recognize and make sense of hidden information, and gain a more accurate understanding of the science. Elsewhere we have documented similar dynamic visualization affordances of another, conceptually less-challenging AR device in our ARIEL series of experiments (Yoon & Wang, 2014), which points to the continuing validity and reliability of these results.

These results also support the viability of AR in challenging misconceptions of pressure-related concepts concerning the undetectable nature of air movement (Kariotoglou & Psillos, 1993) and students' inabilities to recognize complex relationships between scientific variables (Basca & Grotzer, 2001). From the interviews, we can see clear evidence of students' reasoning accurately about the inverse relationship between fluid speed and pressure in Bernoulli's principle (Hewitt, 2004)—they recognized that slower moving air has higher pressure and faster moving air has lower pressure. Students were also able to articulate how the two kinds of air worked together to make the ball float, which attests to growth in understanding of the complex relationship of variables (Basca & Grotzer, 2001). Furthermore, some students were able to identify the non-obvious influence of the surrounding air pressure, which they would not have understood without the AR.

Our findings in this most recent study in our ARIEL series investigating the use of AR devices in museums (e.g., Yoon et al., 2012a) convince us that AR can be used to support learning in informal environments through specific scaffolds. We have shown in this study that AR not only supports learning of science content but can also support learning of very challenging science content during brief periods of exploration. We acknowledge that our results, though positive, revealed only modest conceptual gains, with participants' improving on average less than a level on the knowledge survey and reaching just above partial understanding in the interviews. 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 and multiple scaffolds (Reiser & Tabak, 2014), some of which are already common practices within museums, such as grouping exhibits into clusters based upon conceptually related content. In our future work, we will investigate various aspects of exhibit design, in addition to what we have learned about AR devices in museums, to understand how content learning is best facilitated.

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Appendix

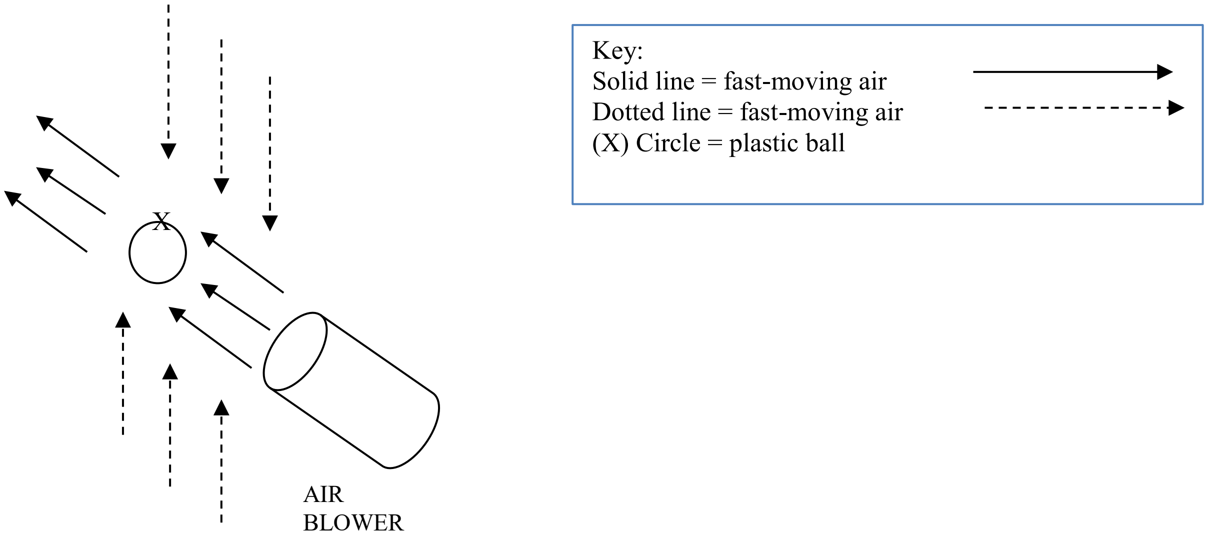
Knowledge Test

1

What is the relationship between the speed and pressure of moving air?

a. The faster the speed is, the higher the pressure.
b. The slower the speed is, the lower the pressure.
c. The faster the speed is, the lower the pressure.
d. Speed and pressure are not related.

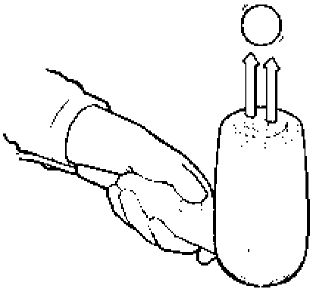
2



A) When the air blower begins to blow, what will happen to the ball?
a. It will blow away and fall to the ground.
b. It will stay floating in the stream of fast-moving air.
c. It will float for a few seconds and then blow away.

B) Which air puts MORE pressure on the ball?
a. The fast-moving air from the blower (solid line).
b. The slow-moving air around the ball (dotted line).
c. Both put the same amount of pressure (solid & dotted lines).

3



Look at the picture.

The electric hair dryer is blowing a stream of fast-moving air upwards.

A small, lightweight, plastic ball is floating in the stream of fast-moving air. It will continue to float there until the hair dryer stops blowing.

Why do you think the plastic ball floats in the stream of fast-moving air?

4

Which of the following real-world scenarios illustrates the concept you just learned? (Circle all that apply).

a. running a race

c. climbing a mountain

b. paper lifting off the desk due to a gust of wind

d. ejecting out of a plane