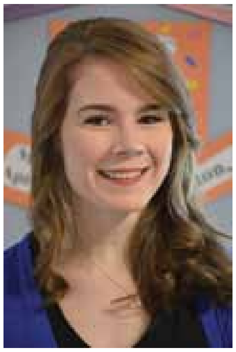
Design considerations for a seasonal constellations planetarium program: Comparison of embodied design and computer visualizations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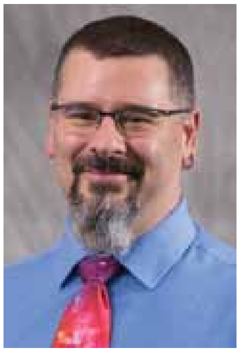
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Abstract

We compared two planetarium programs, one using embodied design principles—drawing on how humans naturally perceive and interact with the physical world—and one using a traditional approach, each addressing the sun's daily motion, the nightly motion of the constellations, and the seasonal movement of the constellations. Participants (n=29 for the embodied program, n=19 for the traditional program) were interviewed before and after the shows to measure change in explanations. After qualitatively coding the interviews, numerical values were assigned to the codes allowing us to statistically tests compare the outcomes. While no significant differences in learning were found between the traditional and embodied programs, participants showed significant improvement in almost all of the concepts after both program types.

Introduction

One of the goals of science education in informal environments is to support visitors' understanding of science concepts and phenomena. However, questions remain as to how best to support student learning in these environments, including during visits to planetariums. Prior research on learning in the planetarium includes the use of immersive programs in digital planetariums to teach seasons to undergraduates (Yu, Sahami, Sahami, and Sessions, 2015), comparing the use of the planetarium to a traditional classroom environment (Turk and Kalkan, 2015), and understanding the ways planetariums can support middle school students' comprehension of lunar phases by helping them visualize different viewpoints (Chastenay, 2016). There has been little research on embodied design (the use of the body to support learning) in the planetarium. Therefore, this study compares student learning following a planetarium program designed using an embodied approach to one that uses a traditional style of teaching in the planetarium using a computer visualization. Both programs focused on the same phenomena: the apparent motion of the sun, the apparent nightly motion of the constellations, and the seasonal change in constellations.

Embodied design draws on the theory of embodied cognition to develop instruction that supports learning with the body. Embodied cognition is the theory that one's body, and its sensory systems, is involved in thinking and understanding, including for STEM topics (Abrahamson and Lindgren, 2014; Jaegar et al., 2016; Lindgren and Johnson-Glenberg, 2013). One of the implications of embodied cognition is that off-line cognition is body-base, meaning that even when we are not physically engaged with the environment, our cognitive processing, mental imagery, and memories are shaped by our physical experiences with the world (Wilson, 2002). A further implication of embodied cognition is that using body movements and objects in the environment allows for cognitive unloading to reduce the amount of information one needs to keep in working memory, facilitating the process of generating explanations (Abrahamson and Lindgren, 2014; Crowder, 1996). Current research indicates that educational activities using embodied design improve student learning in STEM

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fields (Abrahamson and Lindgren, 2014; Jaegar et al., 2016; Lindgren and Johnson-Glenberg, 2013).

Previous research in the planetarium includes studies illustrating the potential of embodied design to support audience learning. Plummer (2009) studied a planetarium program for early elementary students that included embodied design elements. Students showed significant improvement in their understanding of the daily motion of celestial objects after using a combination of their own arm motions and visual observations made during the program, mimicking the motions of the celestial objects.

Plummer, Kocareli, and Slagle (2014) used the same Earth-based perspective planetarium program as one of the conditions in their study investigating how to support elementary students learning to explain daily celestial motion.

Plummer and colleagues (2014) found that participants (3rd grade students) improved their descriptions of the phenomena significantly when engaged kinesthetically, mimicking the motions of the sun, moon, and stars as they moved across the sky, by using their full arms to recreate the motions. They also found that when this planetarium program was combined with classroom lessons, which also used embodied design to support students' explanations for the phenomena, students made significantly greater improvement than conditions that did not attend the planetarium.

Plummer and Small (2018) investigated the combination of a field trip to the planetarium and classroom lessons to support student learning in first grade classrooms. Participants in the shows experienced an immersive planetarium program where they learned about lunar phenomena, including the apparent motion of the moon. Children were guided by the planetarium director to observe the moon's apparent motion and to mimic the pattern with their arms.

All three of these studies found connections between ways students learned the astronomy concepts presented in the planetarium shows and the use of embodied design in the planetarium. However, these studies did not compare students' learning through embodied design to a traditional program, so it is not known whether one program design supports learning more than the other.

For this study, we have applied the concepts of embodied cognition in planetarium program design, in order to see if we can create an interactive planetarium program that improves participants' understanding of phenomena that have been discussed in the show. Our chosen phenomena are spatially rich, so strategies to reduce cognitive load may be important to support learning the topics. The research question that we addressed was: How does learning in an embodied planetarium program compare to learning in a traditional program?

Conceptual framework for embodied design

Embodied design is defined as the process of creating learning environments while applying the theory of embodied cognition (Abrahamson and Lindgren, 2014). Activities are the most effective when educators build opportunities for students to use their ability to orient themselves in a space, as well as offer students a way to use the space in order to find a purpose in the environment (Abrahamson and Lindgren, 2014). Learners must use their "perceptual senses and kinesthetic coordination" (Abrahamson and Lindgren, 2014, p. 6) so that they can review the characteristics of the stimuli as a guide to performing new actions.

DeSutter and Stieff (2017) suggest that the movements the learner makes must be "purposeful and intentional" in ways that align to the targeted learning objective (p. 11). The space also needs to be able to accommodate the learners' movements so that they are able to create a connection within their environment. When learners are able to imagine themselves in the environment where they learned a concept through an activity and bodily movements, they are better able to form connections that help them explain the concept (Abrahamson and Lindgren, 2014). This is aided by materials, which can be the space itself or objects the learner manipulates. Materials are purposefully selected and designed to align with learning objectives in ways that support how learners develop new embodied cognitive pathways.

Finally, it is important that learners are facilitated in making the correct bodily movements and the correct connections to concepts (Abrahamson and Lindgren, 2014). This guidance from an instructor can come in the form of cueing movements or feedback as the student performs the activities. It is also important for the instructor to scaffold the concepts and motions as they are presented to the learners, so that the learners have the opportunity to make connections as they move from a more basic to a more detailed understanding of a concept (DeSutter and Steiff, 2017).

Researchers have begun to investigate ways to address these challenges in classroom settings (Jaegar et al., 2016), clinical interviews (Abrahamson and Lindgren, 2014), and interactive museum exhibits (Abrahamson and Lindgren, 2014; Lindgren and Johnson-Glenberg, 2013). In this study, we extend embodied design research into the planetarium environment.

Methods

Our study compared two planetarium programs through statistical analysis of pre and post-interviews with audiences of college-age students.

Context for instruction

This study took place at a large research university in the northeastern United States, where a planetarium is present on campus. All of the shows in both program types were instructed by the first author. All interviews were conducted before and immediately after the planetarium shows.

Planetarium programs

Each planetarium program focused on three astronomy topics: the apparent motion of the sun, the apparent motion of nightly constellations, and the change in seasonal constellations. The premise of the program for the participants was that they would learn why they do not see their zodiac constellation at night on their birthday. Each show lasted approximately 20 minutes. A note taker sat in on each show to ensure that all of the main points were covered and that the shows remained consistent over the duration of the data collection. (Full scripts used for both programs will be provided upon request.)

A side-by-side comparison of the two planetarium program scripts is included in Table 1.

The embodied planetarium program engaged audiences in the planetarium in ways that included observing and pointing to constellations on the dome and standing to embody the Earth's motion around the sun (see Figure 1). The planetarium operator facilitated participants' experiences by modeling the movements, giving an example of how the motions should look as the participants perform them. The embodied activities were modified from the Kinesthetic Astronomy Sky Time activities (Morrow and Zawaski, 2004) and earlier planetarium programs using embodied design (Plummer, 2009; Plummer et al., 2014). The traditional program was designed to teach the same concepts, without these embodied design supports, using computer visualizations in place of visitors' own embodied motions (see Figure 2).

Overall, both program designs covered the same concepts, but used different methods of teaching to support learning. The traditional planetarium condition used a more passive approach that engaged audience members primarily through questions, while the embodied planetarium program was a more participation-based show that still featured questioning from the instructor, but also allowed the participants to make connections to topics using their body movements.

Participants and data collection

All of the participants in the shows were

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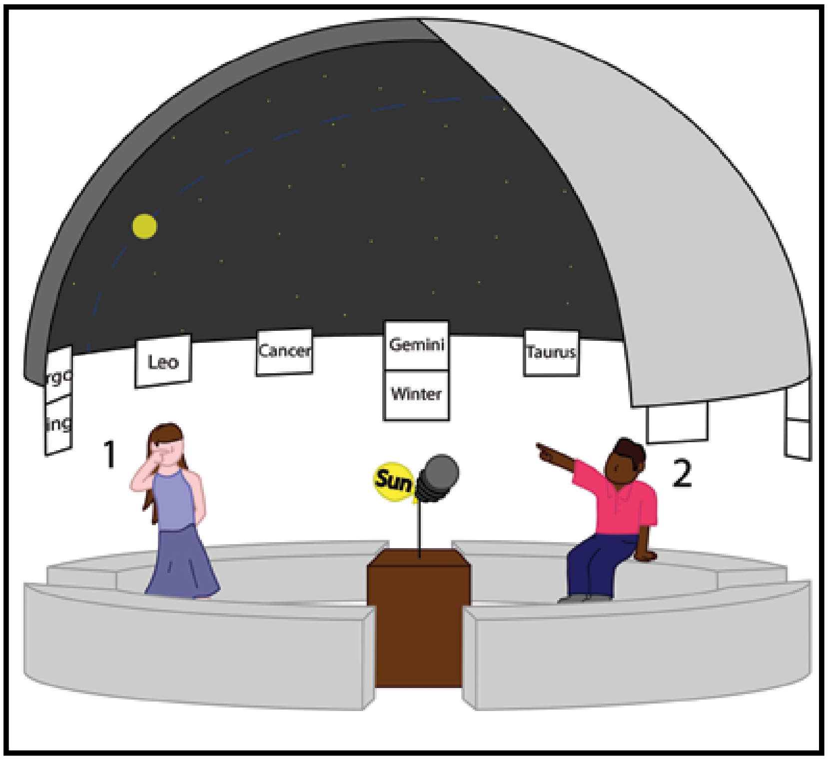

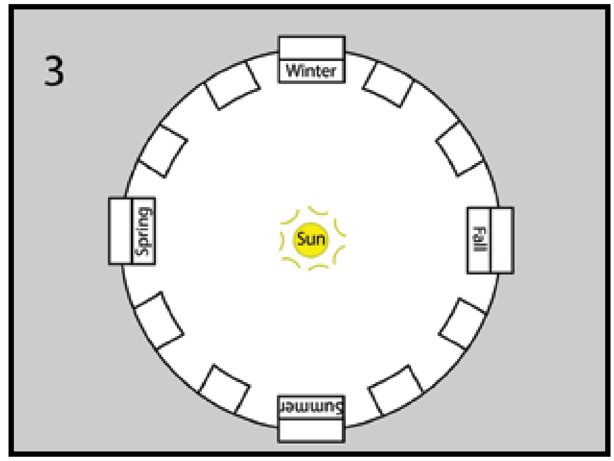

Figure 1. Set-up for embodied planetarium program. At 1, student pointing to her nose to indicate the perspective from "Mt. Nose" as a viewer perceives the change from day to night as she rotates. At 2, student pointing to a constellation as it appears to move across the dome. At 3, top-down view of zodiac constellation printouts and seasons printouts as positioned on interior of dome. Images by Margaret Teuber.

Table 1. Mapping the progression of planetarium program topics between program designs

<table>
<tr><th>Learning objective</th><th>Embodied design</th><th>Traditional design</th></tr>
<tr><td rowspan="2">Nightly motion of the stars</td><td colspan="2">tar projector is used and the stars for that night are projected onto the dome
Students are asked questions related to how the stars move and why</td></tr>
<tr><td>Students are prompted to follow the motion of the stars by pointing to constellation of interest with their full arm (see Figure 1.2)</td><td>Students are prompted to follow the motion of the stars with their eyes and not using any full body motion</td></tr>
<tr><td rowspan="2">Motion of the sun</td><td colspan="2">Star projector is used to project the sun onto the dome
Students are asked to connect how the daily motion of the sun is related to the nightly motion of the stars and why</td></tr>
<tr><td>Students are prompted to follow the motion of the sun across the dome by pointing with their full arm</td><td>Students are prompted to follow the motion of the sun with their eyes</td></tr>
<tr><td>Rotation of the Earth</td><td>A balloon is placed in the center of the dome, representing the sun
Students are prompted to stand and face the "sun"
Students are then guided to show with their bodies (representing Earth), how the Earth moves to create day and night cycles (see Figure 1.1)</td><td>A computer projector and projection screen are set up outside of the dome
Using Starry Night software, day and night cycles are shown again
Students are asked what motion is causing this cycle, which is rotation</td></tr>
<tr><td>Seasonal constellations</td><td>Students place images of the zodiac constellations around the dome (see Figure 1.3)
The instructor prompts the students to face toward the constellations (night) and then back to the sun (day).
Students were asked to identify the seasonal marker closest to their zodiac sign
A volunteer is asked to find their sign and whether they could see the constellation on their birthday
They are then asked to move around the "sun" to the location where they would be able to see their sign at night (about six months later)
The students are guided to describe the type of motion the Earth is doing to change the constellations over the year as orbiting
Additional volunteers identify their zodiacal constellation and when they would be able to observe it in the sky</td><td>Earth perspective (i.e., a space-based perspective; see Figure 2)
Students can see the day and night side of the Earth and are asked which side would be able to see constellations
Season markers are placed over the constellations
The instructor moves the time forward monthly so that the students can see the sun move through the constellations, symbolizing the Earth orbiting around the sun. The sun does not move.
A volunteer is asked to state their zodiac constellation, which the instructor moves the sun into, and is then asked if they would be able to see the constellation during their birthday (no)
The instructor guides volunteer to identify that the Earth would need to orbit the sun for about six months for them to see their constellation at night.</td></tr>
</table>

college students enrolled in an introductory level astronomy course. All but two participants were non-science majors (one engineer, one pre-vet), and had not previously taken any astronomy courses while in college. There were 29 participants over the five planetarium shows with the embodied design program, and 19 participants over the two planetarium shows with the traditional program. The content covered in the programs had been recently covered in the lectures prior to the conduction of the study.

Data was collected through pre- and post-show interviews using a semi-structured interview protocol covering the three astronomy topics from the programs. Each interview was conducted one on one with an interviewer. All interviews were video recorded to capture student gestures and body-movements that might aid our understanding of their explanations though these gestures/body-movements were not explicitly prompted during interviews. Most pre-show interviews were between two and four minutes, while most post-show interviews were between two and three minutes.

Analysis

A coding document was created with codes organized into three categories, describing participants' explanations for why the sun moves across the sky, why the constellations move across the sky at night, and why the constellations change seasonally. Each category was broken down into codes (accurate, partially accurate, non-normative, or not sure) using knowledge of the discipline and an initial review of students' interview responses. Two members of the research team separately coded 10 interviews. Inter-rater reliability of at least 80% was achieved for all three categories. All disagreements in the coding were discussed and resolved.

After each of the interviews were coded, any participant with a pre-interview that was accurate for all three phenomena was removed from further analysis (3 interviews for the traditional condition, and 3 interviews for the embodied condition were removed). Numerical values were used to replace the (3) accurate, (2) partially accurate, and (1) non-normative codes. Nonparametric statistical tests were then performed using SPSS. The Wilcoxon Signed Ranks Test was used to compare differences in related sample allowing us to look for improvement from before and after each planetarium program. The Mann-Whitney Test was used to compare different conditions, allowing us to compare differences in student responses between the two planetarium conditions.

Further analysis was also performed on pairs of interviews in which the student gave an accurate response to the seasonal constellation portion of the post-show interview to examine potential differences in how students learned to explain seasonal constellations. A total of 20 participants were coded, with nine participants coming from the embodied condition and 11 participants from the traditional condition. These pre and post interviews were coded for specific concepts that had been discussed in the planetarium programs, including looking at opposite constellations after six months, constellations blocked by the sun/up during the day, the length of time before the same constellations are seen at night again being 12 months, and the earth facing another direction. These interviews were also coded for iconic gestures, which are gestures that directly illustrate or represent a concept (e.g., tracing a circle in the air to indicate an orbit; Crowder, 1996). The gestures needed to be meaningful as the participant described their responses to the interview protocol.

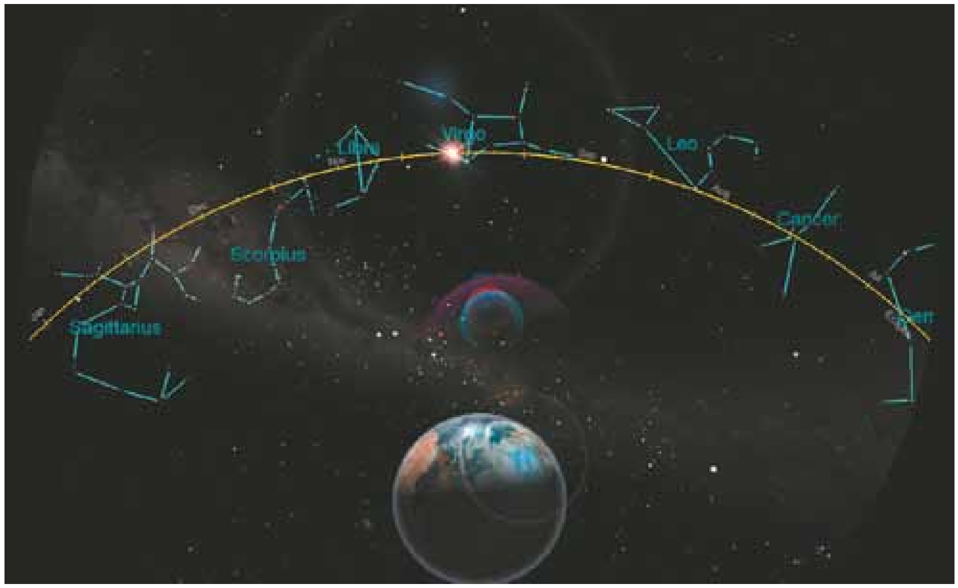

Figure 2. Visualization of the seasonal constellations portion of the traditional program, as seen in *Starry Night*.

Table 2. Results of Mann-Whitney test comparing embodied (N=26) and traditional (N=16) conditions

Concept	Pre-show Z	Pre-show p	Post-show Z	Post-show p
Sun's Motion	-1.116	0.264	-0.391	0.696
Nightly Constellations	-1.398	0.162	-1.437	0.151
Seasonal Constellations	-0.772	0.44	-1.141	0.254

Results

No significant differences were found between the embodied and traditional conditions for each category when comparing responses before and after instruction using the Mann Whitney test (Table 2). The lack of difference between pre-instruction responses suggests that both the group of students attending the embodied and traditional design programs began with comparable levels of understanding. Thus, the non-significant post-instruction results suggest there is no evidence that one program has a greater effect on learning that the other.

Comparison using a Wilcoxon Signed Ranks Test on pre and post-instruction responses within each condition shows that students' explanations improved significantly for each concept, except in the traditional program where there was no evidence of significant improvement for students' explanations for the sun's motion (Table 3). However, eight participants (50%) in the traditional condition provided an accurate explanation during their pre-instruction interview, suggesting the lack of improvement observed may have been due to a ceiling effect.

Finally, we analyzed the sub-set of interview responses which provided accurate explanations in their post-interviews for seasonal constellations. This analysis considered whether students in one condition explained seasonal constellations differently, after

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Table 3. Results of the Wilcoxon Signed Ranks test comparing pre- to post-instruction explanations within conditions

Embodied Condition (N=26)					
Concept	**Improved**	**Regressed**	**No Change**	**Total[a]**	**Wilcoxon Z**
Sun's Motion	10 (41.67%)	1 (4.17%)	13 (54.17%)	24 (100%)	-2.714**
Nightly Constellations	12 (52.17%)	0 (0%)	11 (47.83%)	23 (100%)	-3.276 ***
Seasonal Constellations	11 (42.31%)	2 (7.69%)	13 (50.00%)	26 (100%)	-2.586**
Traditional Condition (N=16)					
Concept	Improved	Regressed	No Change	Totala	Wilcoxon Z
Sun's Motion	5 (31.25%)	1 (6.25%)	10 (62.50%)	16 (100%)	-1.633
Nightly Constellations	9 (64.29%)	1 (7.14%)	4 (28.57%)	14 (100%)	-2.176*
Seasonal Constellations	12 (75.00%	1 (6.25%)	3 (18.75%)	16 (100%)	-2.961**

*p < 0.05, **p < 0.01, ***p < 0.001
a Responses coded as "unsure" were removed during analysis resulting in fewer than the total number of participants in some categories.

instruction, than the other condition. The analysis also looked at whether participants used gestures differently in their explanations in each condition. We found no differences in the concepts used when explaining seasonal constellations when comparing the embodied to the traditional group.

However, we did find differences in how the groups used gestures in their explanations (Table 4). While there are a similarly small number of students who used gestures before and after the traditional program, more students used gestures after the embodied program than before the program. The small number of students in this sample do not allow us to make a statistical comparison. However, these results may indicate some difference in how students learned in the embodied program. The use of body to support learning may have influenced the ways these students explained seasonal constellations after instruction.

Discussion

In both embodied and traditional program conditions, we found that students' explanations improved, suggesting that both of our programs provide support in learning these concepts. However, we did not find significant differences in improvement between the embodied condition and the traditional condition. While additional research with larger sample sizes or alternative methods of implementing an embodied design program may find differences between embodied and non-embodied programs, other factors may explain these results and may suggest next steps on how to design planetarium programs that engage visitors in embodied learning experiences.

The findings suggest students' experience in the embodied condition helped many of them to develop a spatial understanding of phenomena observed from the Earth. Spatial thinking can be addressed in a variety of ways through education but is notably addressed through an active implementation of embodied design, which matches students' physical, bodily movements to the learning goals of instruction (DeSutter and Steiff, 2017). Students embodied actions during the planetarium program may have helped develop new representations of the spatial concepts, through gestures and physical rotations as they faced towards and away from the constellations and the sun, that were then available to draw upon when explaining the celestial phenomena later during the interviews (DeSutter and Stieff, 2017).

We anticipated the traditional program, a passive design approach, would not support learning as much as the embodied program; this was not supported by evidence from this study. We suggest that the improvement we observed in the traditional condition may be because, as in the embodied planetarium condition, we provided students with both an Earth-based perspective with the planetarium projector and a space-based perspective with the Starry Night software. This allowed students to directly compare the two perspectives to facilitate their understanding of how the perspectives change and create an explanation for the phenomena.

Further, we supported learning of this dual perspective by organizing information in a coherent visual format. The types of visual-spatial displays used during both conditions were complex displays (Hegarty, 2011), which showed a change in perspective over time. However, the embodied planetarium show used simple images to support students' physical movements as they modeled the explanations for the phenomena. The traditional program used a complex visualization (using Starry Night) to represent the complex details of how motions in the solar system explains what students had observed on the dome of the planetarium.

Visual displays have the potential to support cognition by "freeing up working memory resources for other aspects of thinking" as well as organizing information in ways that aid understanding of spatial relationships (Hegarty, 2011, p. 450). Just as students may have been able to offload some of their cognition needed to make sense of the phenomena through physical modeling in the embodied condition, students in the traditional condition may have offloaded cognition onto perceptual processes—using their visual system to help them think through the relationship between the earth-based and space-based perspectives (Hegarty, 2011).

Future research and implications for planetarium show design

Future research should investigate conditions in which the participants have limited background knowledge on these topics, as the participants in the study were part of an astronomy course and had recently reviewed the material covered by the planetarium show. A wider variety of participant knowledge may provide additional insight into how much each condition improves understanding of the concepts.

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Table 4: Results of gesture coding in pre- and accurate post-show interviews for seasonal constellations

	Embodied Condition (n=9)	Traditional Condition (n=11)
Pre-Interview	3 (33.33%)	3 (27.27%)
Post-Interview	8 (88.89%)	2 (18.18%)

We further suggest that future research consider how students' gestures may provide insight into how and what they learned in an embodied planetarium program; gestures provide insight into students' thinking as they reveal how students have learned concepts, as mental processes and the learning pathways they form are mediated by body movement, perceptions, and how neural systems engage in action planning (Alibali and Nathan, 2012). We would therefore hypothesize that students in the embodied condition would use more accurate gestures as they would be able to build on embodied ways of learning in the gestures they construct. Further, educators may find observing these gestures to provide insight into students' thinking as a form of on-the-spot assessment.

A critical next step in research on this topic is to compare programs that combine embodied design with high quality computer simulations against programs that use embodiment and passive visualizations alone (as was used in this study). As we found that each condition in this study supported student learning, we hypothesize that the combination of these methods could provide greater support for student learning than either design feature alone. Future research that combines these design features could lead to the creation of improved planetarium programs for the public that are more active and engaging compared to passive designed programs still used in many planetariums today.

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Mankind is drawn to the heavens for the same reason we were once drawn into unknown lands and across the open sea. We choose to explore space because doing so improves our lives, and lifts our national spirit. So let us continue the journey.

George W. Bush, speech at NASA Headquarters, January 14, 2004