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COMPARING TRADITIONAL AND EMBODIED DESIGN PLANETARIUM PROGRAMS AS SUPPORTS FOR LEARNING ASTRONOMY CONCEPTS

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ABSTRACT

Embodied design is a growing design type in education, as research has shown that through its use, participants typically show more learning or understanding of a concept. Though embodied design has been used in the planetarium previously, it has not been compared to traditional designed planetarium programs. In this study, we wrote two planetarium programs, one using embodied design principles and the other following a traditional approach to a planetarium program, where the three concepts covered were the Sun's daily motion, the nightly motion of the constellations, and the seasonal movement of the constellations. These programs were performed in multiple shows, and the participants in the shows (n=29 for the embodied program, n=19 for the traditional program) were interviewed before and after so that their learning of three astronomy concepts could be measured. The interviews were coded for the participants' answers in both the pre- and post-show interviews, and the responses were analyzed. The results from the analysis show that there were not any significant differences in learning between the traditional and embodied programs, both pre and post. However, after both programs participants did show improvement in almost all of the concepts.

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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, including visits to planetariums. In *Learning Science in Informal Environments*, one of the six strands of science learning, Strand 2, focuses on what participants are coming to experience when they interact with science in informal environments (National Research Council, 2009). Strand 2 is described as: "Com[ing] to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science" (National Research Council, 2009, p. 4). By having learners participate in an informal science environment that provides a form of enjoyment, the environment can also serve as a base to build additional conceptual understanding (National Research Council, 2009). Research previously performed in the planetarium includes the use of immersive programs in digital planetariums to teach seasons to undergraduates (Yu, Sahami, Sahami, & Sessions, 2015), the use of the planetarium to support early elementary students' understanding of celestial motion with kinesthetic supports (Plummer, 2009), and the use of the planetarium to support students' understanding of lunar phases (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 a planetarium using an embodied approach to one that uses a traditional style of teaching in the planetarium. Both programs focused on the same phenomena: the motion of the sun, the motion of the nightly constellations, and the seasonal constellations.

Embodied design draws on the theory of embodied cognition to develop instruction that supports learning with the body. Embodied cognition has been used to interpret how people learn math and sciences in the classroom (Abrahamson & Lindgren, 2014), through simulations of objects or events. These studies have shown that math or science subjects are not “abstract,” but are instead “deeply somatic, kinesthetic, and imagistic (Abrahamson & Lindgren, 2014, p. 11),” and that using these ideas from embodied cognition to inform the design of instruction is beneficial to learning (Abrahamson & Lindgren, 2014). Embodied cognition is the theory that one’s body is also involved in thinking and understanding, even for STEM topics (Lindgren & Johnson-Glenberg, 2013; Abrahamson & Lindgren, 2014; Jaegar et al., 2016). Current research also shows that these embodied cognition activities improve learning (Lindgren & Johnson-Glenberg, 2013; Abrahamson & Lindgren, 2014; Jaegar et al., 2016) and that using body movements allows for cognitive unloading to help understand and explain (Crowder, 1996; Abrahamson & Lindgren, 2014).

Previous research in the planetarium focused on a variety of concepts and differences in technological ability of the planetarium. Some of this research also includes the use of the participants’ body as part of the program design. Plummer (2009) studied a planetarium program for elementary students that included kinesthetic design elements. Students were taught the daily motion of celestial objects by combining their own arm motions and visual observations made during the program. The participants also responded to questions asked by the director, both verbally and using their arms and hands to point to different areas in the planetarium. Plummer, Kocareli, and Slagle (2014) used the same earth-based perspective planetarium program as one of the conditions in their study on daily celestial motion. In this program, the participants (elementary students) were 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 (Plummer et al., 2014). Plummer and Small (2018) used a field trip to the planetarium as a support to curriculum in the first grade classroom. The participants in the shows experienced an immersive planetarium program where they learned about three lunar phenomena. They watched a character make observations and create drawings about the moon. The participants were also asked questions by the show director, who also guided them in "mimicking patterning kinesthetically" (Plummer & Small, 2018, p. 7). All three of these studies found that students learned the astronomy concepts presented in the planetarium shows, suggesting that the use of embodied design in the planetarium helped participants learn. However, these studies did not compare students learning through embodied design (i.e. kinesthetically) 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 support cognitive load may be important in aiding the learning of the topics. Overall, the research question that we want to address is: how does learning in an embodied planetarium program compare to learning in a traditional program?

Literature Review

Theoretical framework for embodied cognition

For this study, we used the embodied cognition theory of how people learn. DeSutter and Steiff (2017) describe the theory of embodied cognition as a way to "explain the genesis of human conceptual knowledge representation and cognitive processing as rooted to varying degrees in the shape of the human body and its action with the environment," (p. 4). DeSutter and Steiff (2017) also describe evidence that knowledge and representation are related to movement, such as the way humans hold certain household items helps them identify the item. In 2014, Abrahamson and Lindgren argued that all school subjects, even abstract concepts were all related to embodied cognition, and "grounded in bodily experience" (p. 11). Developmental psychologists also agree that bodily action is important in the growth of conceptual understanding (Abrahamson & Lindgren, 2014). They believed that an embodied approach could help educators develop learning environments that strengthened the learners understanding of systems that may utilize new or unfamiliar symbolic notations, specifically in STEM fields (Abrahamson & Lindgren, 2014). They explained that there are two epistemic modes that a person undergoes while learning – the immediate intuitive mode and the mediated analytic mode (Abrahamson & Lindgren, 2014). These two modes are important to be able to differentiate because instructors should seek to build a connection between them so the learners can move between "immersive action to structured reflection," (Abrahamson & Lindgren, 2014, p. 2). Body involvement is connected to the intuitive mode, but this involvement can lead to better analytical thinking that is seen in a disciplinary field, such as the sciences (Abrahamson & Lindgren, 2014).

Abrahamson and Lindgren (2014) also argued that “conceptual reasoning originates in physical interaction and becomes internalized as simulated actions,” (p. 4). This idea is described further as the way that learners manipulate symbolic notation in a similar way that they would move physical objects, so even without physical objects in front of them, they are still thinking in a way that makes the problem physical. The authors also describe cognitive unloading as a way for learners to better think and explain a problem, which is a confirmation that thinking is an embodied process (Abrahamson & Lindgren, 2014).

Conceptual framework for embodied design

Embodied design is defined as the process of creating learning environments while applying the theory of embodied cognition (Abrahamson & Lindgren, 2014). When creating a learning environment, learners need to be able to approach the problems that they are thinking about in a way that allows them to use full and natural body movements. Abrahamson & Lindgren (2014) lay out three different challenges when creating an embodied learning environment: the challenges of creating activities, using materials, and offering facilitation.

Activities are the most effective when educators want to have students 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 & Lindgren, 2014). The learners must use their “perceptual senses and kinesthetic coordination” (p. 6) so that they can review the characteristics of the stimuli and possibly perform new actions. DeSutter and Stieff (2017) make note that the movements the participant makes must be “purposeful and intentional” (p. 11). The space also needs to be able to accommodate the students’ movements so that they are able to create a connection within their environment. When students are able to imagine themselves in the environment where they learned a concept through an activity and bodily movements, they should be able to form connections that help them explain the concept (Abrahamson & Lindgren, 2014). This is done through materials, which can be the space itself or objects the learner manipulates. Finally, it is important that there is a way for learners to be facilitated into making the correct bodily movements and the correct connections to concepts (Abrahamson & Lindgren, 2014). This guidance from an instructor can come in the form of cueing of movements, as well as feedback as the student performs the activities. It may also be important for the instructor to scaffold the concepts and motions as they are presented to the students, so that the students have the opportunity to make connections as they move from a more basic to a more detailed understanding of a concept (DeSutter & Steiff, 2017).

These challenges have all been addressed in previous studies, typically taking place in a classroom setting (Jaegar et al., 2016), or in a setting that uses technology, such as a device that measures the heights of the users hands as they visualize ratios (Abrahamson & Lindgren, 2014), and mixed reality (Lindgren & Johnson-Glenberg, 2013; Abrahamson & Lindgren, 2014). For example, Jaegar et al. (2016) addressed these challenges in a study of fifth grade students learning about earthquakes in the classroom. In the classroom setting with the embedded simulation, students got to experience random earthquake events within the classroom, and used their bodies and string to act out the computation of earthquakes' epicenters. When comparing this embedded condition to a non-embedded condition that only used maps to calculate epicenters, students in the embedded condition showed more learning overall, performing better on the post-test than those in the non-embedded condition. An example of mixed reality simulations is described by Abrahamson & Lindgren (2014). *MEteor* is a "room-sized mixed reality simulation game" that prompts participants to move throughout the room and use their bodies to predict the movement of an asteroid as it encounters another object (Abrahamson &

Lindgren, 2014, p. 10). The main idea of the simulation is to help participants learn how to predict the movement of an asteroid due to gravitational influences, as well as “disrupt pre-existing misconceptions” and give participants a new view of the topic, which can be built on in a formal education setting (Abrahamson & Lindgren, 2014, p. 10)

Methods

Our study focuses on taking participants to the informal science education space of the planetarium, where the dome, starball projector, and props are utilized as a visual for the participants, and they are given the space to perform intentional movements. Our activities include watching and pointing to constellations on the dome, and standing to embody ourselves as the Earth around the sun, by performing specific motions. An instructor facilitates learning by the participants by also participating in the movements, giving an example of how the motions should look as the participants perform them. The instructor also scaffolds the movements, by first starting more general in how they ask the participants to move, and gradually begins adding more details and specifies further how the motions should look. These supports should help the participants to better understand the concepts of sun motion, nightly constellation motion, and the change in seasonal constellations. The traditional program was designed to teach the same concepts, but without these embodied design supports.

We used qualitative and quantitative methods to assess the changes in participants' understanding of three concepts. We conducted interviews before and after the planetarium show, using the same interview protocol for both the embodied design and traditional programs. These interviews were then qualitatively coded and statistically analyzed in order to examine a change in the participants' understanding and explanation of the topics.

Context for instruction

This study took place at a large research university in the North-eastern 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 in rooms in the same building as the planetarium, before and right after the planetarium shows.

Planetarium programs

Each planetarium program focused on three astronomy topics: the motion of the sun, the motion of nightly constellations, and the change in seasonal constellations. The premise of the program for the participants was that they would learn and understand 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, taking notes on the instructor, helping to ensure that all of the main points were covered and that the shows remained consistent over the duration of the data collection. The detailed, color-coded scripts used for both programs can be found in the appendix.

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 typically seen in planetarium shows, 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 from their body movements.

Embodied program design

In the embodied condition, participants were instructed to watch the constellation Taurus (pointed out by the instructor) move across the sky, and they were also asked to point and move their arm with the constellation as it moved across the sky. Using the cardinal direction markers around the planetarium, participants were able to say which horizon the constellation was moving away from, and which horizon to which it was moving toward. The instructor also told participants that in the time that Taurus moved from due east to due south in the planetarium show, a length of time equivalent to about three real-time hours would have passed, helping to push understanding that the motion of the constellations was a nightly occurrence. Participants were then asked, depending on condition, to watch or point at the constellation Gemini as it moved across the sky, again watching as the constellation moved from the eastern horizon to the western horizon. Finally, the sun rose on the eastern horizon of the dome, and participants watched or tracked its motion as it moved across the sky. They were then asked where the sun would have set if it had continued to move across the dome. To connect that the constellations and the sun move in the same way, the participants were asked which horizons the sun and constellations rose and set over. This should have helped the participants to begin to connect that the sun and constellations move in the same fashion across the sky from the Earth-based perspective, but not necessarily understand as to why that is the case at this point in the shows.

In the second portion of the show, the concept of the sun and stars moving in the same way was analyzed to determine what the earth is doing to cause those motions. For the embodied condition, the lights were turned up in the dome so that the center of the planetarium could be seen, where a yellow balloon was placed on the starball, representing the sun, and the horizon lights were turned up, simulating the light from the sun. Participants were asked to stand and use their bodies to simulate themselves as the Earth around the sun in the center, with a person on "Mount Nose," who sees everything that their (the participant's) eyes see, as described in the activity guide, *The Reasons for the Seasons* (Gould, Willard, & Pompea, 2000, p. 23). They were asked to use their bodies to show the instructor which way they needed to be facing for it to be day on Mount Nose, and which way for it to be night. They were then asked to use their bodies to simulate the rotation of the Earth, and the instructor explained that as they rotated counterclockwise, their left shoulder was the Eastern horizon and their right shoulder was the Western horizon. The instructor explained that the reason they had seen the sun and constellations move from east to west over the span of one day was due to the Earth's rotation.

For the final portion of the embodied condition, participants continued to think of the starball as the sun, but they also placed printouts of the different Zodiac constellations around the dome. The setup of the constellations follows the layout depicted in *Kinesthetic Astronomy Lesson One: Sky Time* (Morrow & Zawaski, 2004, p. 15). The participants continued to imagine that they had a person living on Mount Nose and that they were the Earth. The instructor asked the participants to turn to face the constellations as if it were night time, and then turn back to the sun for day time. A volunteer was selected to state their Zodiac constellation and to point it out on the dome. They were asked to move around the perimeter of the planetarium until they were opposite the constellation and the "sun" was in the way, and then they were asked if they could see their constellation from where they were standing, facing the sun. The expected response was that they could not. Then, the instructor asked the participants what other motion the Earth experienced, which is orbit. The instructor then had the participants "orbit" themselves around the sun, for a duration of six months, until the original volunteer was now in front of their Zodiac constellation. They were then asked to face the direction they needed to be to see their constellation, putting Mt Nose in night. Finally, the whole group was asked how long from their birthdays they would need to wait to see their Zodiac constellation at night, with the expected response being six months. Another volunteer was then selected to further help the participants' understanding of Earth's orbit and when the Zodiac constellations are visible. The show concluded after that.

Traditional program design

The first part of the traditional condition planetarium program follows the same script as the embodied condition, with one small change. When participants were asked to follow Taurus and Gemini across the dome, they were not prompted to use any body movements. The participants were asked the same questions as the embodied condition and the content remained the same.

The second portion of the program covered why the constellations and the sun appear to move in the same way. At this point, the show no longer uses the dome and begins using a projector and projection screen that were set up just outside the dome in the same room, connected to a computer running the planetarium software *Starry Night.* The participants were shown the sky again, for the same night that they had seen on the dome. Time was moved forward, and participants watched the same constellations from before (Taurus and Gemini) move across the sky on the screen. Participants were then asked why the constellations were moving across the sky or what was the Earth doing to cause this motion, with an expected response that the Earth is rotating. The instructor then sped up time more, showing the day and night cycle more quickly, and explained that Earth experiences day and night and sees the constellations move across the sky in the period of a night, all due to the Earth's rotation.

For the final portion of the program, Starry Night and the projection system continued to be used. Starry Night was set up so that the participants could see most of the zodiac constellations along the ecliptic around the Earth, with the sun “in” the constellations, all seen from above the Earth. They can see that on the side of the Earth that is facing the sun it is day time, and on the side facing away from the sun it is night. Figure 1 shows this view from Starry Night.

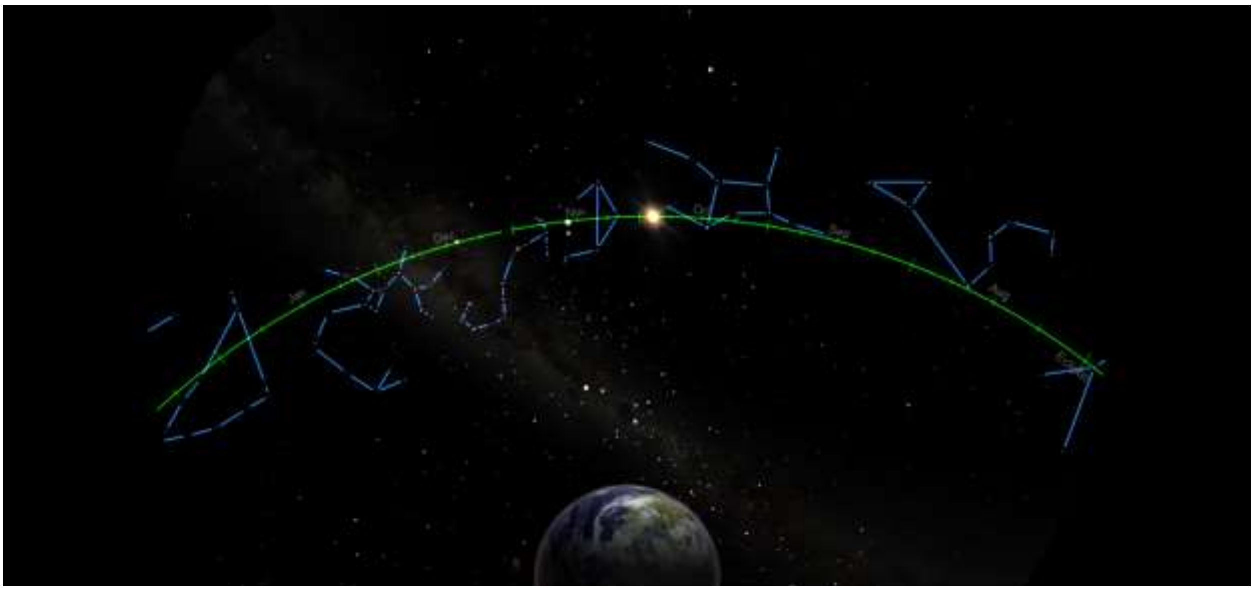

Figure 1: View from Starry Night

Participants were then asked questions about what could and could not be seen from the Earth, depending on which side of the Earth from which you would be viewing the constellations. After explaining that those on Earth would only be able to view certain constellations at night, the instructor asked the participants if they knew the other motions that Earth experiences, the answer being rotation. The instructor then went through the Zodiac constellations, moving the sun through them, but because it appears that the sun is moving and not the Earth orbiting, the instructor had to clarify that this is still from our Earth-based perspective. A volunteer was selected from the group to state their Zodiac constellation and the instructor then used that sign and volunteer to explain how the Zodiac constellation that corresponds with their birthday is actually up during the day time so it is not visible on their birthday at night. It was further explained and shown on Starry Night that the volunteer would actually have to wait six months before they would be able to see their Zodiac constellation high in the sky at night. Another volunteer was selected and engaged in a dialogue using the same set of questions to further drive the participants' understanding.

Participants and data collection

All of the participants in the shows were college students (freshmen through seniors) who were at the time enrolled in an introductory level astronomy course. Participants were offered credit for a required outside of class planetarium show, by their course professors, for participating and completing the planetarium show activity. All but two participants were non-science majors (one engineer, one pre-vet), and had not previously taken any astronomy courses while in college. All participants who attended the show agreed to participate in the research, but some were not interviewed due to time constraints. There was a total of 48 participants through all seven shows that were conducted. There were 29 participants over five planetarium shows with the embodied program, and 19 participants over the two planetarium shows with the traditional program.

Data was collected through pre- and post-show interviews. Each interview was one on one with an interviewer. Each show had between three and six interviewers conducting the interviews. An interview protocol with a series of questions pertaining to the three astronomy topics covered in the planetarium shows was followed by each interviewer. The protocol can be found in the appendix. The average length of pre-show interviews were between two and four minutes, while post-show interviews were between one and three minutes.

Analysis

The goal of our analysis was to compare student learning between the traditional and embodied planetarium programs. This was done by comparing their pre- and post-interviews (n=29 for embodied, n=19 for traditional) for the three astronomy phenomena to look for improvement.

A coding document was created to use in analyzing each interview, so that the participants' responses could be coded as *accurate, partially accurate, non-normative,* or *not sure*. The codes can be found in the appendix. The codes were 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 do the constellations change seasonally. 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 analysis (3 interviews for the traditional condition, and 3 interviews for the embodied condition). Any *not sure* codes were also removed from the data. Numerical values were used to replace the (3) *accurate,* (2) *partially accurate,* and (1) *non-normative codes.* This data was then placed into SPSS, so that nonparametric statistical tests, specifically the Wilcoxon Signed Ranks Test and Mann-Whitney Test, could be performed on the data. The Wilcoxon Signed Ranks Test is used to compare differences in related sample such as to look for improvement from one time point to the next. The Mann-Whitney Test

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. This analysis was performed by the first author. These pre and post interviews were coded further, looking for specific concepts that had been discussed in the planetarium programs. These concepts included: 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 videos were also coded for iconic gestures, which are gestures that are representative of a topic (Crowder, 1996). The gestures needed to be meaningful as the participant described their responses to the interview protocol. A total of 20 participants were coded, with nine participants coming from the embodied condition and 11 participants from the traditional condition.

Results

After placing the numerically coded data into SPSS and performing the test, we found that the Mann-Whitney Test shows no significant differences between the embodied and traditional conditions for each category, both before and after instruction. Table 1 shows the comparison between to pre- and post-show results for both conditions. These results suggest there is no evidence that one program has a greater effect on learning that the other.

Table 1: Results of Mann-Whitney Test comparing both 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

We then looked at the results from the Wilcoxon Signed Ranks test. Table 2 shows each condition and the concepts, the number of participants who either improved, regressed, or showed no change, and the results of the Wilcoxon test. This table shows that students in both conditions improved significantly for each concept, except that in the traditional program, where there was no evidence of significant improvement for sun’s motion.

Table 2: Results of the Wilcoxon Signed Ranks Test

Embodied Condition					
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					
Concept	*Improved*	*Regressed*	*No Change*	*Total*[a]	*Wilcoxon Z*
Sun's Motion	5 (31.25%)	1 (6.25%)	10 (62.50%)	16 (100%)	-1.633

**p* < 0.05, ***p* < 0.01, ****p* < 0.001
[a] This table reflects the removal of interviews that yielded “unsure” coding during analysis. This is shown later on in Table 3.

We continued to look further at the data to see if any trends could be identified in the interviews between the two conditions. All the data for both show conditions were compared to see exactly how much participants improved in their understanding of the concepts. Each of the interviews were examined to see if the participants improved from, for example, non-normative to partially accurate, and so forth. We also noted the interviews that remained the same in the pre- and post-interviews, and at which level they remained. Table 3 shows this information.

Table 3: Changes in pre- and post-show interview responses

Embodied Program	**participants**		**Traditional Program**	**participants**
Sun's Motion			*Sun's Motion*	
NN to ACC	10		NN to ACC	5
No change - ACC	8		No change - ACC	8
No change - NN	5		No change - NN	2
Regressed	1		Regressed	1
Unsure	2		Unsure	0
Total interviews	26		Total interviews	16
Nightly Constellations			*Nightly Constellations*	
NN to ACC	10		NN to ACC	6
NN to PA	0		NN to PA	1
PA to ACC	2		PA to ACC	2
No change - ACC	4		No change - ACC	4
No change - PA	1		No change - PA	0
No change - NN	6		No change - NN	0
Regressed	0		Regressed	1
Unsure	3		Unsure	2
Total interviews	26		Total interviews	16
Seasonal Constellations			*Seasonal Constellations*	
NN to ACC	4		NN to ACC	5
NN to PA	3		NN to PA	1
PA to ACC	4		PA to ACC	6
No change - ACC	6		No change - ACC	1
No change - PA	4		No change - PA	1
No change - NN	3		No change - NN	1
Regressed	2		Regressed	1
Total interviews	26		Total interviews	16

Response abbreviations:

- NN – Non-normative
- PA – Partially accurate
- ACC - Accurate

This table allows us to see if there are any trends that the statistical tests did not show, since we did not see any differences in improvement between the two program types. One example of this is that in the traditional program, we see that 8 participants, half of those interviewed (n=16), started out with the correct knowledge of the Sun's motion. Other than this pattern, we noted few differences between the two conditions.

Finally, we also have the results from the further analysis on accurate post-show interview responses for the seasonal constellations in the pre- and post-interviews for both conditions. This analysis focused on looking responses that included further concepts, as well as the use of gestures by the participants. We found that there was no differences in the further concepts in the interviews. However, we did find differences in gesturing. Table 4 shows the coding of gestures in pre- and post-show interviews in each show condition.

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%)

The evidence in this table suggests that the embodied condition influenced participants to use more gesturing in their responses in the post-interview. This leads us to suggest that the embodied condition may provide supports through the use of body motion, to help participants explain their answers to the questions on seasonal constellations.

Discussion

In both program conditions, we saw improvement in each of the three concepts, as we had expected. This suggests that our programs both offer some support for learning of these three astronomy concepts. However, we did not see significant differences in the improvement in the embodied condition compared to the traditional condition. This may be due to the small numbers we had in the program conditions that were used in the analysis (N = 26 for embodied; N = 16 for traditional). If we had had more participants in both program conditions, we may have found different results.

Based on previous research, we expected the traditional program should not have supported learning as much as the embodied program, due to the traditional program being a passive design approach, compared to an active design. We suggest that the improved understanding we observed in the traditional condition may be due to the use of the combination of projector and planetarium software, which provided a better visual of what each concept meant. This may have been equally as effective as the embodied program presented alone, where the participants were not given a visual of the Earth and Sun, other than the simulation in which they participated. Powerful and detailed visuals in the traditional program may be the reason that the program produced similar results as the embodied program.

As previously stated, our number of participants also limits how much we can say is significant about the findings. If we could perform this study again, we would want to try and have more shows to have more participants, as we had a limited number of participants. We also know that some students started with knowledge of the concepts before, because they were currently taking an astronomy course. This limited how much improvement they could make during the program. We would like to perform the study again with students who had not studied the concepts recently.

One other change in the shows would be getting permission and consent for recording the shows as they are performed. Because there were volunteers used for the seasonal constellation portions of both programs, we have wondered if it was possible that the participant who was asked to be a volunteer for the show may have better understood the concepts and performed better in the post-interviews. By also collecting data during the shows, we may have been able to see if a participant's direct interaction with the instructor while talking about their own Zodiac constellation supported their understanding further. If that happened to be true, adding length to the program and having more volunteers would help strengthen the understanding of the concepts.

In future research, we hypothesize that by combining both embodied design and a powerful visualization of the astronomical concepts, a program that supports greater improvement understanding for the three concepts could be created. It is also possible that by using a larger planetarium and engaging more participants, enough evidence may be collected to better support our hypothesis that the embodied program would better support the understanding of the concepts. These changes could hopefully lead to creating better planetariums programs for the public, that are more engaging and active compared to the more traditional programs we experience today.

Appendix A

Scripts

Embodied Planetarium Show

How does learning from a planetarium program that uses embodied approach compare to a planetarium program using a combination of verbal and observational strategies?

Color coding:

Gesture

Embodiment

Questions that would need to be repeated in both planetarium shows, with some changes – embodied and traditional

Blue text is script.

*Starred notes may need to be omitted after discussion

Pre-show setup:

- have zodiac images needed for part 3 of the show placed on the front row around the planetarium, except for the one that would go directly behind me. Tape should be placed on the back already. The zodiac constellations that also coincide with a time of year marker should be attached together.
- have students stow their backpacks out of the way as they enter, due to the movement involved in the show.
- have students sit in the back row of the planetarium around the full circle so that there is plenty of room for gestures and embodiment

Learning Goals	**Investigation**
	Daily Motion of Constellations
Seasonal constellations: • Describe the apparent motion of the zodiac constellations through the year • Explain the motion of the constellations due to the Earth's orbit and rotation	Hook for the show? – "Have you ever wondered about your zodiac constellation and where they are? By the end of this show, we're going to learn about our Zodiac constellations, and where and why they move through the sky throughout the year. For those not familiar with them, those are the constellations that are associated with the month when you were born One important thing about today's show is that we are talking about astronomy, not astrology. I won't be telling you your horoscope today, as I am not an astrologer. However, astrologers had to be good astronomers to notice shapes in the sky, and observe how they move throughout the year."

• Move from the earth based to the space based perspective and identify the time of year that certain constellations would be visible	**Planetarium Introduction**
	• Set up the planetarium for the current time of year.
	• Describe how the planetarium shows us the constellations for the time of year it is set (Planetarium overview)
	
	• "Constellations are patterns formed from groups of stars that make up shapes of animals, mythological people or creatures, and objects, that were identified and named by humans. Many of these patterns were identified across many cultures around the world. There are 88 modern constellations that have been chosen by the International Astronomical Union, and the 12 that we will be focusing on are the Zodiac Constellations.
	• Ask if they can name any zodiac constellations, or the astrological signs, and then see if you can point any out in the planetarium.
	
	Identification
	• Identify for them the current zodiac constellations that are visible in the sky for the time of year (TAURUS)
	• Have students point to the constellation and prompt them to follow the constellation's path across the sky when I begin moving the sky forward
	• "As the sky is moving, time is progressing through the night. The time has moved forward as this constellation has moved toward the western horizon. The amount of time it would have taken for this constellation to have moved from due east (laser point to due south) to due south (trace laser to the western horizon) would have been about 6 hours."
	
	• Stop the movement and ask:
	  • "Can you predict the movement of the constellations before I begin moving the sky again? Point and show the approximate motion of where the constellations will move."
	    • Make sure students are using full arm motion to show movement
	• Continue the movement/time progression and have students continue to follow the motion of the constellation. The constellation will now be on the floor, no longer on the sky, so the motion is approximate.

	• "After the constellation drops below the western horizon, what happens to it? Does it continue to move?"
	  • Expected response: yes, it continues to move
	• "If we wanted to see those stars, what would we have to do to see them? Where would we have to look?"
	  • Expected response: We would have to look through the Earth
	
	• Compare motion of constellations to apparent motion of the sun
	  • Continue the motion at the planetarium, and have the sun rise on the Eastern horizon, so that they can see that the sun follows the same path as the constellations
	
	• Next, select another constellation that is now in the sky, and repeat the previous questions after watching the constellation move (reinforce the idea) - GEMINI or LEO
	  • However, note that this movement would not be seen in a single night due to the sun rising (begin turning up the eastern horizon light), but the constellations would still be there as the sun is in the sky during the day.
	• "If the sun was to continue to move across the sky, what path would it take? Can you show me with your arm how the sun would move?"
	  • Students should point their arm at the sun, and move there arm from the east to the west
	• "When we look at the direction markers around the planetarium, we see that we have East, South, West, and North (point to each one with the laser pointer). Which direction did the constellation set?"
	  • Expected response: West
	• "Which direction did the sun rise?"
	  • Expected response: East
	• "Where will the sun be setting?"
	  • Expected response: West

	<u>Understanding why the sun and constellations move like they do</u>
	• The star ball in the center of the planetarium would be representative of the sun. – horizons lights would be the light from the sun, ball is sun
	• Turn on the horizon lights to represent light from the sun, Have them imagine that they are Earth, (stand up)
	    • "Here at the center of the planetarium is the star ball, which is going to be representing the sun for this activity. These lights on either side of the star ball, the horizon lights, are going to be the light from the sun. I would like you all to imagine that your head is Earth, and that there is a person living on Mt Nose. Move to where the person would be in day, where would you be to have them in night?"
	        • Facing the star ball to be in day, back to the star ball to be in night
	    • "The person who is living on Mt Nose would see the same thing that your eyes see, so remember that as we continue with the show."
	    • "Thinking about what you see as you move from what would be day on Mt Nose to what is night, what would the Earth be doing? Show me how Earth would move so that day and night happen."
	        • Students should begin to spin their bodies to simulate Earth's rotation
	    • "Turn towards your left shoulder, so that you turn counterclockwise like the Earth does. If you are waiting for the sun to rise, which shoulder would you see if rise over as you turn?"
	        • Response: the left shoulder
	
	    • "Now think back to when the sun rose earlier. Which horizon did it rise up from?"
	        • Response: East
	    • "So which horizon would your left shoulder be?"
	        • Response: The Eastern Horizon
	    • "Which shoulder does the sun set over as you continue to slowly rotate as the Earth?"
	        • Response: The right shoulder
	    • "So which horizon would your right shoulder be?"
	        • Response: The Western Horizon
	    • "Where did the constellations we followed earlier set?"
	        • Response: West/Western horizon

Materials:
• Planetarium
• Images of the 12 zodiac constellations
• Equinox and solstice markers
• Ball/Balloon for the sun
	• "What can we infer about the movement of the sun and the constellations?"
	    • Response: They move in the same way/same directions
	• "The earth is rotating, which is why we see the sun/constellations move the way that we do"
	• "Now why do we not see constellations during the day time? If you turn Mt Nose to the sun, could you see any other stars or constellations? Think about what you see during the day."
	    • Response: No, you do not see any stars, because it is too bright during the daytime.
	    • "Turn your body away from the sun, would you be able to see constellations now?"
	    • Response: Yes, because it is dark out
	
	<u>Seasonal motions of Constellations</u>
	
	Zodiac Constellations
	• Have the students take the images of the constellations on the bench in front of them, and place them on the wall behind them. Some will also place the solstice and equinox up, as well, as reference for which time of year the constellations are visible at night. Have them remain standing. Remind them that the ball in the center of the room is the sun and that you are still a person standing on Mt Nose
	    • "These constellations that you are placing on the wall are the Zodiac constellations that are related to your astrological sign. We are going to find out when you can see your astrological sign and why."
	    • When would be a good time to see your zodiac constellation?
	        • If no answer, follow up with -- Is your birthday a good day to see your zodiac sign? Let's find out.
	• Students should be placed around the room in front of the constellations
	    • "Think about where you can see constellations and where you can't."
	• "What constellations would you be able to see right now, from where you are standing, based on where you are in relation to the sun? Turn in that direction."

	- Should turn to have back to the sun (star ball)
	- "Turn back to face the sun. Which constellations would you not be able to see? Point in the direction of those constellations."
	  - Should gesture to the other side of the planetarium, in front of themselves, on the other side of the star ball.
	
	- Establish that Earth spinning is not the only motion. The Earth also orbits around the sun.
	- The students represent different points in the Earth's orbit
	  - Reference the equinox and solstice markers, and explain that as the Earth moves in its orbit, the time of the year is changing.
	  - "There are four different markers around the room, showing different days in the year: the Summer Solstice, Winter Solstice, Vernal Equinox, and Autumnal Equinox. These days represent a specific place in Earth's orbit. (Point to summer solstice person) If you are Earth on the Summer Solstice this year, you will also be at that place one year from now."
	  - "Now we are going to walk around the sun in the direction of Earth's orbit for six months. Make sure to remember the constellations you can see and those you can't. As you walk, pay attention to what happens to the constellations your passing."
	    - Have the learners walk around the planetarium in the direction of the Earth's orbit for 6 months, to enforce the idea of movement, and have them look to see that as they move around as Earth, the constellations that are nearest to them are changing.
	- Repeat the earlier questions, with the new constellations that they are standing near.
	- "What constellations would you be able to see right now, from where you are standing, based on where you are in relation to the sun? Gesture in that direction."
	  - Should gesture behind themselves
	- "Which constellations would you not be able to see? Point in the direction of those constellations."
	  - Should gesture to the other side of the planetarium, in front of themselves.
	- "Why can't you see the constellations in front of you?"

	- Response: The sun is in the way/they are on the other side of the sun • "Now that we have created a model of the Earth, Sun, and Zodiac constellations throughout the year, we are going to be able to do science! Because we've created a model with our bodies, we can answer questions that we have about when we can see certain Zodiac constellations during the year." - Have students locate their Zodiac sign and also look at the equinox or solstice markers that are near it. Have them move closer to their sign, if possible, but have them continue to be spread out. - "What do you notice about your constellation and the markers near it? Do they line up with the time of year for your birth month?" - "So if you are a Pisces, when would you see the constellation at night?" - The answer should be in the fall, near the fall equinox - "So what does that mean for a person who is a Pisces, since you see the constellation at night in the fall? Where would the constellation be during their birthday month? What time of day would it be in the sky?" - During the month of February and March for Pisces, the constellation is not visible because the sun would be in front of it, and it would be up during day time. (Reference the star ball and students' positions during this) - Discuss how the Zodiac constellation that corresponds with a person's zodiac sign is not seen at night during that month, but is instead what constellation the sun would be in during that time. - The constellation for your Zodiac would be seen at night half a year after the month that the Zodiac corresponds to • Reinforce the idea by taking volunteers' zodiac signs, locating them, and then asking them to say when it would be visible. • Ask for a volunteer to say what zodiac they were and have everyone point to where the zodiac is - Have them state when that zodiac would be visible

	• "Would this zodiac constellation be visible during the month of [volunteer's] birthday?"
	  • The answer should be No
	• "When would this constellation be visible at night?"
	  • Half a year later
	
	<u>Closing</u>
	
	"Using this model that we've created, you can see that the time of year correlates to the zodiac constellations that we can see in the evenings. Dates are also locations for astronomers. We created the orbit of the earth around the sun and simulated the constellations changing as we viewed them from different perspectives around the sun. As we moved to the Summer Solstice, we could see the constellations that are associated with that time of year, meaning that the earth is in a particular location in its orbit, which would happen every year at the same time.

Traditional Planetarium Show

How does learning from a traditional planetarium program compare to a planetarium program that uses gestures and embodiment to learn the motion of the constellations?

Blue text is director's script; black is set up and expected responses.

Safety should not be a concern for this show.

Students should sit where they can see the projection screen easily. Be sure to ask that everyone can see when you begin the projector part, just in case.

<table>
<tr><th>Learning Goals</th><th>Investigation</th></tr>
<tr><td>Seasonal constellations:
Describe the apparent motion of the zodiac constellations through the year
Explain the motion of the constellations due to the Earth's orbit and rotation
Move from the earth based to the space based perspective and identify the time of year that certain constellations would be visible</td><td>Planetarium Introduction
Set up the planetarium for the current time of year.
Describe how the planetarium shows us the constellations for the time of year it is set (Planetarium overview)
"Constellations are patterns formed from groups of stars that make up shapes of animals, mythological people or creatures, and objects, that were identified and named by humans. Many of these patterns were identified across many cultures around the world. There are 88 modern constellations that have been chosen by the International Astronomical Union, and the 12 that we will be focusing on are the Zodiac Constellations.

Identification - Using Dome
Identify for them the current zodiac constellations that are visible in the sky for the time of year (TAURUS)
Have students watch the constellation move and prompt them to follow the constellation's path across the sky
"As the sky is moving, time is progressing through the night. The time has moved forward as this constellation has moved toward the western horizon. The amount of time it would have taken for this constellation to have moved from due east (laser point to due south) to due south (trace laser to the western horizon) would have been about 6 hours."
Stop the movement and ask:
"Can you predict the movement of the constellations before I begin moving the sky again?
Continue the movement/time progression and have students watch the motion of the constellation. The</td></tr>
</table>

	constellation will now be on the floor, no longer on the sky, so the motion is approximate.
	• "After the constellation drops below the western horizon, what happens to it? Does it continue to move?"
	    • Expected response: yes, it continues to move
	• "If we wanted to see those stars, what would we have to do to see them? Where would we have to look?"
	    • Expected response: We would have to look through the Earth
	
	• Compare motion of constellations to apparent motion of the sun
	    • Continue the motion at the planetarium, and have the sun rise on the Eastern horizon, so that they can see that the sun follows the same path as the constellations
	
	• Next, select another constellation that is now in the sky, and repeat the previous questions after watching the constellation move (reinforce the idea) - GEMINI or LEO
	    • However, note that this movement would not be seen in a single night due to the sun rising (begin turning up the eastern horizon light), but the constellations would still be there as the sun is in the sky during the day.
	• Identify the cardinal direction markers, so that learners can identify which directions the objects would be moving towards.
	• "When we look at the direction markers around the planetarium, we see that we have East, South, West, and North (point to each one with the laser pointer). Which direction would the sun set?"
	    • Expected response: West
	  Which direction would the constellations have set?
	    • Expected response: West
	• "Which direction did the sun and constellations rise?
	    • Expected response: East

	<u>Earth Based Perspective in Starry Night</u> • Show the night sky for that evening, at sundown

	• Move forward in time to watch the constellations move from Eastern Horizon and along the ecliptic, stopping at midnight • "Here we have the night sky that we would see if we went out at 9:00PM tonight. As we move time forward, you see that the constellations are moving like we saw them move on the dome." • "Notice that we can see a few different constellations in the sky at midnight, the same ones that we saw on the dome. • "What is causing the constellations to move across the sky? What is the earth doing?" • Expected response: The earth is rotating • Have Starry night cycle through day and night. • "We see the change from day to night and back to day because of the Earth's rotation, which is also why we see the constellations move across the sky over the period of a night." • Switch to "Spaced Based perspective"

	<u>Spaced Based Perspective in Starry Night</u>
	• "Now we are viewing the Earth from above its orbit. We can see the Zodiac constellations surrounding Earth, and the Sun is in the middle of the screen opposite the Earth, in between the constellations. (Go to the screen and point to each side of the earth you are referencing)
	• Based on what you can see here, would the side of the Earth that is in day time be able to see those constellations around the sun?
	    • Expected response: No
	"The sun is in front of those constellations, so we aren't able to see them, since the sun is too bright."
	"What about the other side of the Earth that is currently in night? Would they be able to see those constellations?"
	    • Expected response: No
	"What constellations would they be able to see?"
	    • Expected response: The constellations behind them; the ones that the dark side of earth is facing
	"As I move the Earth around to where we can no longer see the sun, we see a different set of constellations again, exactly the same as we saw when we were still on Earth."
	"We know that the Earth rotates giving us night and day, but what else does the Earth do?
	    • Orbits around the sun
	"As I turn back to face the sun, I'm going to also move time forward month by month. As I do this, the sun moves through the

	different Zodiac constellations and months of the year. This movement of the sun is because as the Earth orbits around the sun, the sun appears to move relative to the constellations."
	• "As I pass through different constellations, I am also passing through different time of year markers, called the Equinoxes and Solstices: The Spring Equinox, The Autumnal Equinox, Summer Solstice, and Winter Solstice. The Earth is in front of these constellations for the different markers every year." (reference these as you move the sun around)
	
	• "If we look at the Autumnal Equinox, in the constellation Virgo, the sun is in that constellation, so the constellation is up in the day time. Would you be able to see Virgo at the equinox, though?"
	    • Expected response: No, it's day time.
	
	If I turn the Earth around here so that we are now looking from the night side, we see a different constellation. Pisces would be up in the sky at night on the same day."
	• "What does Earth need to do to be able Virgo at night?" (wait for possible response, then just say let's find out)
	
	• "We know that Earth rotates and orbits. Let's look back at the constellations that the sun is currently in, and the constellations for tonight. Now I'm going to move Earth six months into the future."
	• "When I advance six months forward, which constellations can we see from Earth at night?"
	    • Response: The constellations that the sun had been in at first
	"So what this is showing us is that in order to see a Zodiac constellation that corresponds to a certain month, we have to wait until six months later in order to see it. The Zodiac Constellation that is related to a certain month is the constellation that the sun would be in during the day time for that month."
	• Repeat this exercise with different constellations.
	
	• "Now we know that the Earth is rotating and causing the constellations to move across the sky over a night, as well as orbiting, causing the constellations up at night to change throughout the year. To really see this, let's go back to the Earth surface and see these changes happen from the ground."
	• Start Starry Night for tonight at 9PM again.

	• "Here we see the same constellations we saw on the dome earlier, and I'm just going to have them move for six hours so we can see the same motion we saw before." • "Try and remember what the constellations look like right now, and now I'm going to show you the constellations as they are in the sky during the day time for a 24 hour period." • This way, we have viewed the night constellations and the day constellations for the month of October • "Now we're going to move 6 months into the future, so now it's April. What set of constellations should we see at night? Remember we've moved six months, so would we see the same constellations at night as October, or would we see that day constellations?" ◦ Expected response: The day time constellation. • "Virgo and Libra are in the sky in April, but we know that those Zodiac signs are associated with September and October. • "Let's move forward 12 hours into the future in April, so that it will be around noon now. After turning off daylight effects here, we can see some familiar constellations again. Taurus and Aries are in the sky again, but now it's around noon time in April, instead of around midnight in October." • "After using the dome and Starry Night, we've talked about Earth's two motions, rotation and orbit. Rotation causes the constellations to move throughout a night, while orbits causes the constellations to change throughout the year. Remember in our space based perspective we watched the sun move through the constellations, although it's actually the Earth's orbit causing that to happen. By looking at the Earth at a certain time of year, such as the Autumnal equinox, we know that that time of year corresponds to a place in Earth's orbit, since we would see that constellation at that time every year."

Appendix B

Interview Protocol

PRE-SHOW SET-UP

- Tape the constellation map to the wall where it will be easy for you and the subject to point to and access.
- Position the video camera so that it can capture the subject while standing next to the constellation map.
- Prepare the consent forms and a pen for students to sign. Ask students to sign consent form once you have them in the interview room.

Planetarium Interview Protocol

"Thank you for agreeing to participate in this interview and this research study. Part of our research design includes conducting these interviews standing up. Is that okay? If you need to sit for any reason, please let me know."

If asked why:

"In order to not influence your answers, we can discuss that at the end of you post-interview."

Demographic questions:

What year are you?

What is your major?

Have you previously taken an astronomy course?

The movement of the Sun:

1. Imagine we are outside during the day, and are observing the sun throughout the day. Describe to me what the sun does throughout the day.
    a. *If they describe the sun as moving/changing positions throughout the day:*
        i. Why does the sun appear to move throughout the day?
    b. *If they do not describe the sun as moving throughout the day:*
        i. What does the sun do? Why do you think it does this?

The movement of constellations:

1. *Referring to the image of the constellations for that evening:* These are the constellations we would see tonight at 9:00. If we go inside for a while and then come back out to look at them at midnight, would we still see the constellations in the same place?
    a. *If they say no:*
        i. How did the stars appear to change or move between those two times?

ii. Can you indicate for me on the picture how they would have moved?
iii. Why did they move that way?

b. If they say yes:

i. Do the constellations ever appear to move? Will they ever be in a different place?

1. Why is that?

The changing of constellations throughout the year:

1. *Referring to the image of the constellations for that evening:* Tonight we go outside and observe these constellations in the southern sky. If we went back outside and looked again six months later, would we see these same constellations again?

a. If yes:

i. Why would we see the same constellations six months later?
ii. Is there ever a time that we would see a different constellation?

b. If no:

i. What would we see? Would we see something different six months later?
ii. Why would we see something different? What causes us to see different constellations tonight than what we would see six months later?

If they say something about the Earth:

a. What is the Earth doing to cause us to see different constellations six months later?

iii. Why can't we see the constellations we see tonight six months from now?

If they say they would be behind the sun/up during the day (prompts, if needed):

a. So would we ever be able to see those constellations?
   i. *No, the sun is blocking them*
b. How long would we have to wait for them to move back to where they are tonight?
   i. *Six more months*

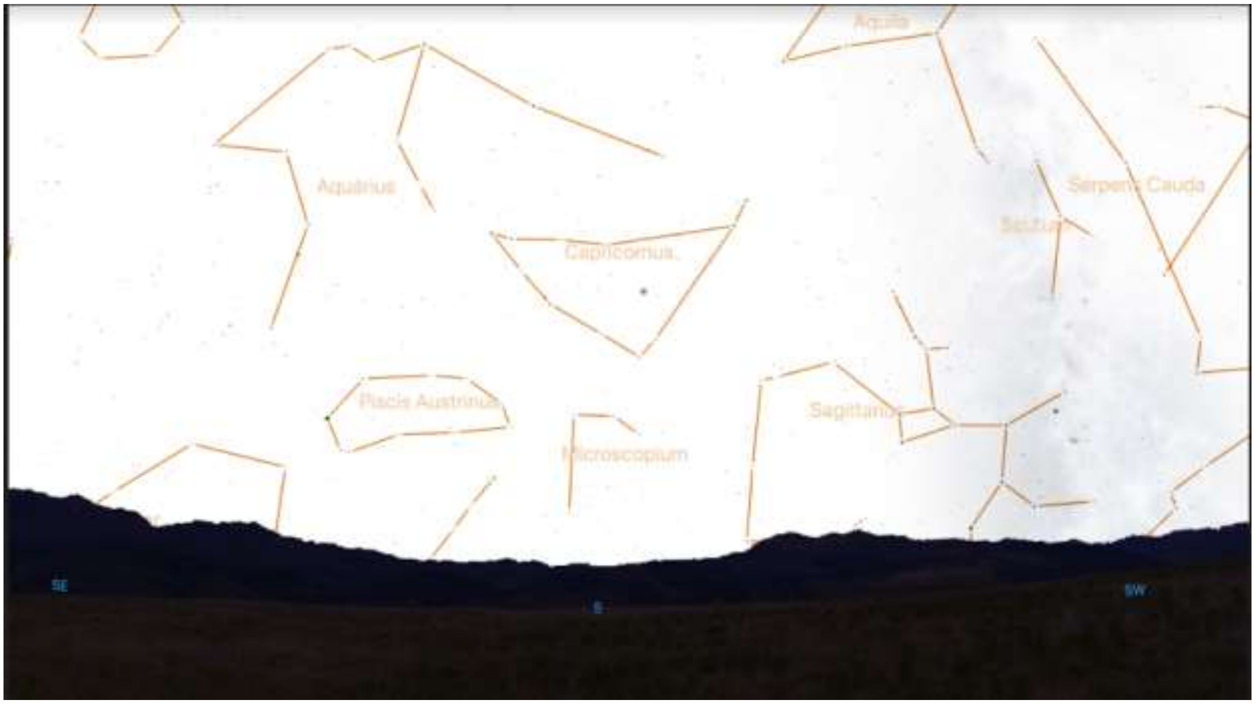

Image used for the interviews. From Starry Night.

Appendix C

Interview Coding Document

Coding document for pre- and post-interviews to determine accurate, non-normative, or unsure answers

Sun's Motion		
Protocol Question	*Describe to me what the sun does throughout the day. Why does it move that way?*	
	Codes	
	Accurate	Student explains the earth rotating (in one direction) when asked why the sun appears to move. Does not include other motions to explain the sun's motion.
	Non-normative/Inaccurate	Student describes other kinds of motion, such as orbit, (and may also include rotation) to explain why the sun appears to move. For example: Student explains that the sun rises and sets/moves across the sky due to Earth's rotation and the orbit around the sun.
	Unsure	Can't determine whether the answer is accurate or non-normative.
Nightly Constellations		
Protocol Question	*If we go inside for a while and then come back out to look at them at midnight, would we still see the constellations in the same place?*	
	Codes	
	Accurate	Student explains the earth rotating (in one direction) when asked why the stars appear to move. Does not include other motions to explain the stars' motion. Can use this to explain non-normative descriptions of apparent motion, including saying that the stars do not appear to move.
	Partially Accurate	Student uses other kinds of motion AND earth's rotation to explain why the stars appear to move. For example, the earth's rotation and orbit around the sun or the earth's rotation and the stars actual motion. OR, Student gives non-normative description of stars nightly motion (such as they don't appear to move or move too slowly to see) but still explain this with Earth's rotation.
	Non-normative/Inaccurate	Student uses other kinds of motion to explain why the stars appear to move (other than earth's rotation). Student uses proper motion (stars actually moving). Or says that

		the stars do not appear to move and does not explain further.
	Unsure	Can't determine whether the answer is accurate or non-normative.
Seasonal Constellations		
Protocol Question	*If we went back outside and looked again six months later, would we see these same constellations again? Why/why not?*	
	Codes	
	Accurate	Earth's revolution around Sun and Sun blocking other constellations AND/OR Earth's revolution around Sun and facing away from constellations that we do not see, AND/OR Earth's revolution around Sun and facing towards new constellations.
	Partially Accurate	Earth's revolution around Sun changes our location in relations to the constellations without other explanation of why this changes observation OR Talks about how the Sun blocks the constellations but does not explain how our orbit changes which constellations are blocked over time.
	Non-normative/Inaccurate	Other explanations, such as non-specific use of rotation.
	Unsure	Can't determine whether the answer is accurate or non-normative.

References

Abrahamson, D., & Lindgren, R. (2014). Embodiment and embodied design. *The Cambridge Handbook of the Learning Sciences, 2*, 358-376.

Chastenay, P. (2015). From Geocentrism to Allocentrism: Teaching the Phases of the Moon in a Digital Full-Dome Planetarium. *Research in Science Education, 46*(1), 43-77.

Crowder, E. (1996). Gestures at work in sense-making science talk. *Journal of the Learning Sciences*, *5*(3), 173-208.

Desutter, D., & Stieff, M. (2017). Teaching students to think spatially through embodied actions: Design principles for learning environments in science, technology, engineering, and mathematics. *Cognitive Research: Principles and Implications, 2*(1)

Gould, A., Willard, C., & Pompea, S. M. (2000). The real reasons for seasons -- sun-earth connections: Unraveling misconceptions about the earth and sun. Berkeley, CA: Lawrence Hall of Science, University of California at Berkeley.

Jaeger, A., Wiley, J., & Moher, T. (2016). Leveling the playing field: grounding learning with embedded simulations in geoscience. *Cognitive Research: Principles and Implications,* 1-14.

Lindgren, R., & Johnson-Glenberg, M. (2013). Emboldened by embodiment: six precepts for research on embodied learning and mixed reality. *Educational Researcher*, *42*(8), 445-452.

Plummer, J. D. (2009). Early elementary students' development of astronomy concepts in the planetarium. *Journal of Research in Science Teaching*, *46*(2), 192-209.

Plummer, J. D., Kocareli, A., & Slagle, C. (2014). Learning to Explain Astronomy Across Moving Frames of Reference: Exploring the role of classroom and planetarium-based instructional contexts. *International Journal of Science Education, 36*(7), 1083-1106.

Plummer, J. D., & Small, K. J. (2018). Using a planetarium fieldtrip to engage young children in three-dimensional learning through representations, patterns, and lunar phenomena. *International Journal of Science Education, Part B, 8*(3), 193-212.

Morrow, C., & Zawaski, M. (2004). Kinesthetic Astronomy Lesson One: Sky Time. Boulder, CO: Space Science Institute.

National Research Council. (2009). *Learning Science in Informal Environments: People, Places, and Pursuits.* Committee on Learning Science in Informal Environments. Philip Bell, Bruce Lewenstein, Andrew W. Shouse, and Michael A. Feder, Ed. Board on Science Education, Center for Education. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Starry Night Enthusiast 7 [Computer software]. (2013). Retrieved from http://starrynight.com.

Yu, K. C., Sahami, K., Sahami, V., & Sessions, L. C. (2015). Using a Digital Planetarium for Teaching Seasons to Undergraduates. *Journal of Astronomy & Earth Sciences Education (JAESE),2*(1), 33-43.

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Publications and Presentations
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Bradley, H., Schrader, V., (March 2017). "We Can Never Go Back to Before:" A Rhetorical Analysis of Mother and Father's Relationship in *Ragtime*. Presented as part of a panel at the Eastern Communication Association 108th Annual Convention: James C. McCroskey and Virginia P. Richmond Undergraduate Scholars Conference

Bradley, H., Luszcz-Cook, S., de Kleer, K., Ádámkovics, M., de Pater, I., Hammel, H. (January 2019). Extracting cloud properties from Keck OSIRIS observations of Neptune. Presented as a poster at the 233rd Meeting of the American Astronomical Society, Seattle, WA

Honors
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