RELATIONSHIP BETWEEN STUDENTS' SPATIAL ABILITY AND EFFECTIVENESS OF TWO DIFFERENT ECLIPSE TEACHING PEDAGOGIES

Shi Anne Kattner [1]
Andrea C. Burrows [2]
Timothy F. Slater [3]

Abstract: This article examines whether an active engagement kinesthetic classroom lesson or visual-immersive verbal-participatory planetarium lesson led to increased eclipse knowledge for students (aged 10-15 years) in the United States. Using a multiple-measures research design, a pre/post eclipse test and a three-part spatial ability test was administered to students who participated in either a kinesthetic classroom lesson (n=56) or visual-immersive planetarium lesson (n=82) about the nature of eclipses. Quantitative data was gathered immediately after the treatments, and again five months after the treatment. The authors compared each instructional treatment's effectiveness with students' spatial ability levels. A statistically significant increase in students' knowledge was observed in both treatments, but no statistically significant score difference between the two treatment groups. These results imply that students can increase their knowledge on eclipses independent of lesson style. Further results of this study strongly suggest that transformational spatial ability is related to learning about eclipses, independent of lesson pedagogy, as those students with higher spatial abilities exhibited higher achievements.

Keywords: Astronomy education; Eclipses; Pedagogy; Spatial thinking ability; STEM; Kinesthetic learning.

RELAÇÃO ENTRE A CAPACIDADE ESPACIAL E A EFICÁCIA DE DUAS DIFERENTES PEDAGOGIAS DE ENSINO DOS ECLIPSES

Resumo: Este artigo examina se uma aula de sala de aula cinestésica de engajamento ativo ou uma lição de planetário verbal-participativa e visual-imersiva levou ao aumento do conhecimento sobre o eclipse para os alunos (com idade entre 10 e 15 anos) nos Estados Unidos. Utilizando um desenho de pesquisa de múltiplas medidas, um teste pré/pós eclipse e um teste de capacidade espacial de três partes foi aplicado aos alunos que participaram ou da lição de sala de aula cinestésica (n = 56) ou lição planetária imersiva visual (n = 82) sobre a natureza dos eclipses. Os dados quantitativos foram coletados imediatamente após os tratamentos, e novamente cinco meses após o tratamento. Os autores compararam a eficácia de cada tratamento instrucional com os níveis de habilidade espacial dos alunos. Um aumento estatisticamente significativo no conhecimento dos alunos foi observado em ambos os tratamentos, mas não houve diferença estatisticamente significativa na pontuação entre os dois grupos de tratamento. Estes resultados implicam que os estudantes podem aumentar seus conhecimentos sobre eclipses independentemente do estilo de aula. Outros resultados deste estudo sugerem fortemente que a capacidade espacial transformacional está relacionada ao aprendizado sobre eclipses, independente da pedagogia da lição, já que aqueles com maior capacidade espacial apresentam maiores aproveitamentos.

Palavras-chave: Educação em astronomia; Pedagogia; Habilidade de pensamento espacial; Ciência, tecnologia, engenharia e matemática; Aprendizagem cinestésica.

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[1] University of Arizona, Tucson, USA. E-mail: <skattner@mmto.org>.
[2] University of Wyoming, Laramie, USA. E-mail: <andrea.burrows@uwyo.edu>.
[3] University of Wyoming, Laramie, USA. E-mail: <timslaterwyo@gmail.com>.

RELACIÓN ENTRE LA HABILIDAD ESPACIAL DE LOS ESTUDIANTES Y LA EFICACIA DE DOS DIFERENTES PEDAGOGÍAS DE ENSEÑANZA DE LOS ECLIPSES

Resumen: Este artículo examina si una clase cinestésica de compromiso activo o una visita a un planetario verbal-participativa y visual-inmersiva llevó al aumento del conocimiento sobre el eclipse para alumnos con edades entre 10 y 15 años en los Estados Unidos. Utilizando un esquema de investigación de múltiples medidas, una prueba pre/post eclipse y una prueba de capacidad espacial de tres partes se aplicaron a los alumnos que participaron o de la clase cinestésica (n = 56) o visita al planetario inmersiva visual (n = 82) sobre la naturaleza de los eclipses. Los datos cuantitativos se recogieron inmediatamente después de los tratamientos, y nuevamente cinco meses después del tratamiento. Los autores compararon la eficacia de cada tratamiento instruccional con los niveles de habilidad espacial de los alumnos. Un aumento estadísticamente significativo en el conocimiento de los alumnos fue observado en ambos tratamientos, pero no hubo diferencia estadísticamente significativa en la puntuación entre los dos grupos de tratamiento. Estos resultados implican que los estudiantes pueden aumentar sus conocimientos sobre los eclipses independientemente del estilo de clase. Otros resultados de este estudio sugieren fuertemente que la capacidad espacial transformacional está relacionada al aprendizaje sobre eclipses, independientemente de la pedagogía de la lección, ya que aquellos con mayor capacidad espacial presentan mejores aprovechamientos.

Palabras clave: Educación en astronomía; Pedagogía; Habilidad de pensamiento espacial; Ciencia, tecnología, ingeniería y matemáticas; Aprendizaje cinestésico.

1 Introduction

Natural phenomena represent a unique opportunity to engage people of all ages in learning science. Examples that gather widespread attention include tsunamis, dust storms, catastrophic hurricanes, and tornadoes. Much less hazardous to humans, but nonetheless captivating, include easily observable sky phenomena such as meteor showers, planetary conjunctions, and eclipses. One such notable sky event was a total solar eclipse of August 2017 that stretched across the entirety of North America, being viewed by more than 100,000,000 people.

These unique sky events offer the astronomy education community opportunities not only to educate students and the public about eclipses, but also to elicit new interest in astronomy. But such a situation begs the question of how do both formal and informal educators successfully teach the concept of eclipses, especially when they typically only have a limited time to teach this traditionally difficult topic? Are astronomical topics, such as eclipses, best taught by interacting with people via discussions and lectures, by engaging students in demonstrations and interactive kinesthetic lessons, or under the virtual reality of a 360-degree planetarium dome? The astronomy education community would benefit from research-based insight on how to effectively teach this difficult topic that interests both students and the public.

Education reform committees in the United States (US), such as *Taking Science to School* (National Research Council [NRC], 2007), the *Framework for K-12 Science Education* (Framework) (NRC, 2012), and *Next Generation Science Standards* (NGSS Lead States, 2013) state that astronomical topics are taught throughout K-12 education. Unfortunately, many students graduate after twelve years of formal schooling without a solid scientifically accurate understanding of daily celestial motion, how the seasons occur, the cause of the Moon's phases, or how eclipses occur (BAILEY; SLATER, 2004) and (PLUMMER; ZAHM; RICE, 2010).

Astronomy education research is rapidly growing, with hundreds of studies published in journals over the past decades (BRETONES; JAFELICE; HORVATH, 2016). Most of the literature on astronomy education focuses on students' ideas or how they learn the topics of daily celestial motion, lunar phases, seasons, and patterns of the sky (BAILEY; SLATER, 2004; LELLIOTT; ROLLNICK, 2010; PLUMMER, 2014; SLATER; TATGE, 2017). There is, as yet, insufficient literature on teaching solar and lunar eclipses, even though the national US standards sets a bar of expectation for this topic and the NGSS strongly encourage crosscutting concept system model use (NGSS, 2013). The limited research on eclipses shows that the majority of elementary and secondary students as well as pre-service teachers improve their eclipse process understanding after instruction, but many participants continue to carry naïve and misconstrued ideas about eclipses even after the instruction (BARNETT; MORRAN, 2002; YALCIN; YALCIN; ISLEYEN, 2012). Needless to say, teaching eclipse phenomena can be a difficult task for any educator (SLATER; GELDERMAN, 2017; SLATER; FIELD, 2017). Add the hurdle of overcoming misconceptions about the Sun, Moon, Earth system, which many people hold onto, and astronomy educators also need to take into account the fact that understanding the majority of astronomical phenomena requires strong spatial skills. One might naturally assume that developing conceptual astronomy understanding requires learners to understand complex three-dimensional moving systems from two-dimensional static images, phenomena that occur over long periods of time, movement between Earth-based and space-based perspectives, and size and distance scales of celestial objects. All of these concepts would seem to require strong spatial ability. Therefore, many educators suspect that to truly learn the process of eclipses, students often rely on their spatial ability. Thus, to effectively teach eclipse phenomena to students, educators might be best served understand how a student's spatial ability correlates with the type of instruction a student receives.

This context motivates us to consider two aspects of astronomy teaching and eclipses. One is to determine if a kinesthetic classroom or a visual-immersive planetarium lesson is more effective for teaching about eclipses. The other is to systematically investigate whether a kinesthetic classroom or a visual-immersive planetarium eclipse lesson is more effective for students with a certain spatial ability level. If it can be shown that a certain style of lesson is more effective for learning about eclipses, and the lesson is correlated with a certain spatial ability level and characteristic, then astronomy and other science educators can use the information to enhance their teaching about eclipses.

2 Literature Review

Even though all the US science education standards and curriculum framework documents clearly expect teachers to teach about solar and lunar eclipses before the secondary level, there is not much literature on teaching the topic. Researchers discuss the importance and difficulties in teaching eclipses (SLATER, 2008; SLATER; GELDERMAN, 2017). These researchers highlight misconceptions about lunar phases; the size and scale of the Earth, Moon, and Sun system; and lunar orbital mechanics as the main barriers to teaching eclipses. The limited research on eclipses shows that that majority of students and adults carry naïve and misconstrued ideas about lunar astronomy pre-instruction (BARNETT; MORRAN, 2002; SLATER, 2008; SLATER; GELDERMAN, 2017; YALCIN; YALCIN; ISLEYEN, 2012). Kavanagh, Agan and Sneider (2005, p. 1) state "It is clear from the research literature that misconceptions about Moon phases and eclipses are widespread and resistant to change, even among adults". Even though many people have misconceptions about lunar phenomena, some studies explored whether students' lunar phases and eclipse knowledge changed after a taught lesson, and they found that using actively engaging lessons can lead to a more sophisticated understanding of eclipses (BARNETT; MORRAN, 2002; PALMER, 2007). However, these studies also found that even after instruction, students struggle to grasp a completely scientific understanding of the process of eclipses (BARNETT; MORRAN, 2002; PALMER, 2007). Therefore, it's imperative that researchers and teachers develop eclipse lessons that are effective for participants. Slater (2008) gives specific suggestions as to an effective lesson on eclipses; lessons should therefore encourage students to explain how a total solar eclipse occurs, why eclipses do not occur every month, and utilize diagrams of the Earth and Moon's orbit around the Sun to describe the necessary conditions for eclipses to occur. Researchers also suggest that using active models, kinesthetic learning techniques, collaborative learning, lecture-tutorials, and computer graded tasks can be useful in teaching the process of eclipses and engage students in both social and scientific aspects (FRENCH; BURROWS, 2017; SLATER, 2008).

Many astronomical phenomena are taught in a planetarium due to the visual nature of the subject and the long timeframe it takes to observe this phenomenon in real life (YU; SAHAMI; SAHAMI; SESSIONS, 2015). Unfortunately, during much of the last Century, planetarium research studies failed to demonstrate large, easy-to-achieve learning gains with using a traditional planetarium lesson (SMITH, 1966). Even when planetarium lessons included pre- and post-visit activities and rudimentary active participation where the planetarium instructor asked a few fundamental questions (FLETCHER, 1977; FLETCHER, 1980; REED, 1973; WRIGHT, 1968). Three of the earliest planetarium education research studies that do show small cognitive gains after a traditional planetarium lesson were those that included spatial visualization components and provided an explanation about the planetarium (RIDKEY, 1974) and (RIDKEY, 1975; TUTTLE 1965). In the early 1980s, planetarium education researchers began to move away from studies that compared traditional, lecture-style planetarium lessons to traditional, lecture-style classroom lessons and started concentrating on studies that compared traditional planetarium lessons to planetarium lessons that incorporated research confirmed best practices. These newly developed planetarium lessons included more active participation, used manipulatives, and implemented educational cognitive theories and were found to increase learning gains (BISHOP, 1980; EDOFF, 1982; GILES, 1981; MALLON; BRUCE, 1982). As argued in Slater and Tatge (2017, p. 7), "It is not presence or lack of presence of a planetarium that makes a difference in student learning. Instead, it is what is done in each learning environment that works, especially when planetariums are used for what they are best at – showing celestial motion to actively engaged students. The digital planetarium can uniquely provide desperately needed cognitive support for students on difficult topics involving spatial reasoning that consume considerable cognitive resources on the part of learners".

Further, astronomy education researchers found one type of actively engaging, highly effective instructional intervention that increases the conceptual knowledge of participants in psychomotor modeling, gesturing, and kinesthetic learning techniques (KLTs), where students use the movement of their bodies to model phenomena (FRENCH; BURROWS, 2017; MORROW, 2000; MORROW; ZAWASKI, 2000; MORROW; ZAWASKI, 2004; PLUMMER, 2006; PLUMMER, 2009; PLUMMER, 2014; PLUMMER; KOCARELI; SLAGLE, 2014; PLUMMER; KRAJCIK, 2010; REINFELD; HARTMAN, 2008; SLATER; MORROW; SLATER 2008; SMALL; PLUMMER, 2014). Modeling, gesturing, and KLTs further enable educators to assess learner's prior knowledge, and support students in developing embodied schemas which help to support the highly spatial aspect of astronomy (PLUMMER; KOCARELI; SLAGLE, 2014), and engages participants' multiple modalities of learning (PLUMMER, 2006; PLUMMER, 2009; PLUMMER; KOCARELI; SLAGLE, 2014; PLUMMER; KRAJCIK, 2010; PLUMMER; WASKO; SLAGLE, 2011). Studies that qualitatively evaluate the effect that gesturing and KLTs had on learning astronomy topics in the classroom show an increase in conceptual understanding on astronomical phenomena for children and adults (PLUMMER; MAYNARD, 2014; PLUMMER; WASKO; SLAGLE, 2011; TRUNDLE; ATWOOD; CHRISTOPHER, 2002; TRUNDLE; ATWOOD; CHRISTOPHER, 2007a; TRUNDLE; ATWOOD; CHRISTOPHER, 2007b; TRUNDLE; ATWOOD; CHRISTOPHER; SACKES, 2010). As with KLTs and gesturing used during a classroom lesson, lessons conducted in a planetarium environment that utilize KLTs and gesturing showed an increase in participants' descriptions and explanations on daily celestial motion and lunar phenomena, for students as young as 5 years old (PLUMMER, 2006; PLUMMER, 2009; PLUMMER, 2014; PLUMMER; KOCARELI; SLAGLE, 2014; PLUMMER; KRAJCIK, 2010; SMALL; PLUMMER, 2014). The results of studies that use gesturing and KLTs confirm the conclusion that lessons that engage students are extremely effective at increasing knowledge, not only in the field of astronomy, but in any educational field (FRENCH; BURROWS, 2017).

Student cognitive abilities, like in all subjects, probably add to the complexity of teaching astronomy. As stated earlier, astronomy typically requires learners to understand complex three-dimensional moving systems from two-dimensional static images, phenomena that occur over long periods of time, movement between Earth-based and space-based perspectives, and size and distance scales of celestial objects, all which might require strong spatial ability. Therefore, astronomy educators and researchers suspect that many celestial phenomena, including eclipses, likely require strong spatial ability skills to fully understand and explain the astronomical processes (BLACK, 2005; HEYER; SLATER; SLATER, 2012; PLUMMER, 2014). Throughout the literature cited here, there is no clear consensus about what to call and how to define spatial thinking and many different terms are used interchangeably with spatial thinking: spatial ability, spatial reasoning, spatial cognition, visual-spatial ability, spatial intelligence to name a few. For this study, the term spatial ability is defined as the "skill in representing, transforming, generating, and recalling symbolic, nonlinguistic information" (LINN; PETERSEN, 1985, p. 1482). The term spatial ability selected since it "is the link among space, representation, and reasoning that gives the process of spatial thinking its power, versatility, and applicability" (NRC, 2006, p. 26). Table 1 summarizes the definitions for mental rotation, spatial transformation, and spatial visualization.

Spatial Ability Term	Definition
Mental Rotation	The ability to rapidly and accurately mentally manipulate objects by rotating the object around in order to perceive the object from different objects (HEYER, 2012) and (LINN; PETERSEN, 1985).
Spatial Transformation	The ability to mentally manipulate an object by changing the object's shape, as well as to be able to see an object from different points of view (HEYER, 2012).
Spatial Visualization	The ability to interpret three-dimensional information from two-dimensional representations, imagine objects from different perspectives, and to visualize how rotation can change the appearance of objects (PLUMMER, 2014).

Table 1 - Definitions of three spatial ability characteristics used in this study.

In the past, astronomy education researchers have found that the act of learning astronomy can be easier with more fully developed spatial skills. One way to help ease the spatially challenging aspect of learning astronomy is through the use of three-dimensional visuals in a planetarium setting. A spatial aspect that has been found to be crucial for learning astronomy phenomena is being able to mentally move between an Earth-based perspective and a space-based perspective (HEYER; SLATER; SLATER, 2012). Most astronomical concepts require shifting between these two reference frames and many studies show that understanding of astronomical topics is significantly improved when students are engaged in both reference frames (MATHEWSON, 1999; PLUMMER, 2014; PLUMMER; KOCARELI; SLAGLE, 2014; PLUMMER; MAYNARD, 2014). Just like being able to switch between reference frames is helpful for understanding spatially challenging topics, many astronomy education and spatial ability researchers have found psychomotor modeling, kinesthetic modeling, and gesturing during difficult spatial visualization tasks can improve performance; they have suggested the use of these during instruction in order to help support the spatial thinking challenges of astronomy and to support students' ability to switch between frames of references (CHU; KITA, 2011; PADALKAR; RAMADAS, 2011; PLUMMER, 2014; PLUMMER; KOCARELI; SLAGLE, 2014; PLUMMER; MAYNARD, 2014; WILHELM, 2009; WILHELM; JACKSON; SULLIVAN; WILHELM, 2013). The results of these studies show that just including KLTs and gesturing during instruction enables students to increase their descriptions and basic understanding of astronomical topics such as lunar phenomena, daily celestial motion, and the seasons. However, in order for students to construct a fully scientific explanation of these phenomena, instructional interventions need to incorporate both KLTs/gestures and the Earth- and space-based perspectives. Including both those aspects enables students to more easily handle the spatially demanding aspect of astronomy, especially for students who have low spatial ability.

A gap in the literature exists at the intersection of existing research showing that active-learning based kinesthetic lessons are more effective at enhancing student achievement than passive-student listening lessons (FRENCH; BURROWS, 2017), and the existing research showing the planetarium-based learning environments are effective at supporting students' spatial reasoning skills needed to flexibly understand the nature of eclipses (KATTNER, 2017). This study aims to fill two important cross-over issues not covered in the literature cited above: 1) whether a kinesthetic classroom or visual-immersive planetarium lesson has a larger effect on students' learning the topic of eclipses and 2) if there is a relationship between students' spatial ability level and the students' level of learning the process of eclipses dependent on the type of instruction received.

This study fills a gap in the literature by comparing a kinesthetic classroom lesson to a visual, verbally-interactive planetarium lesson in order to decide if one teaching style has a larger effect of students' learning. The literature showcases the benefits of using a kinesthetic activity *during* a planetarium or classroom lesson; however, there seems to be little to no research on comparing a kinesthetic lesson to a visual, verbal engagement planetarium lesson. Additionally, although the literature is filled with studies that compare traditional, lecture-style planetarium lessons to lecture-style classroom lessons that find no statistical differences between the two lesson styles, this study differs from those studies. This study is unique in that it compares a kinesthetic classroom lesson to a visual, verbally-interactive planetarium lesson. This study's planetarium lesson is not a didactic, non-engagement lesson; instead there is a discourse between the planetarium educator and the participants throughout the entire lesson, as well as verbal interaction between participants through think-pair-share dialogue. This comparison study also uses a comparison between two groups (not yet found in the literature), between a kinesthetic classroom lesson and a visual, verbal-engagement planetarium lesson. Not only has no other study found compared these two lesson styles, but previous researchers have suggested a need for comparison along these lines. Lelliott an Rollnick (2010, p. 1791) suggest future research should investigate if both virtual and physical modeling activities enable students to "more clearly understand the three-dimensional nature of astronomical concepts". Plummer (2009, p. 206) states that important future research is needed that "compares planetarium programs with and without kinesthetic learning techniques [in order to] more clearly state how kinesthetic learning techniques impact learning".

This study fills a second gap by investigating if a correlation between spatial ability level and students' learning gains is dependent on the type of instruction (kinesthetic classroom or visual-immersive planetarium) a student receives, something that is also lacking in the literature. The majority of authors that have reported a relationship between spatial ability and science knowledge suggest future research continue to determine if this relationship holds true for different scientific fields, types of instruction, and spatial ability levels (BLACK, 2005; HEGARTY, 2011; HEYER, SLATER, & SLATER, 2012; PLUMMER, 2014). To date, there seems to be little to no literature on the relationship between spatial ability and student learning related to eclipse pedagogy. Heyer, Slater and Slater (2012, p. 68) state that the astronomy education research community should "systematically determine which of the many available astronomy concepts are directly tied to spatial reasoning". Plummer (2014, p.38) states that a step for future research is to "be able to consider which types of instruction provide the most support for students with low spatial ability". Though there are studies that look at the relationship between spatial ability and science knowledge, this is one of the only studies that looks at the relationship between spatiality ability level and gains in learning depending on lesson style.

3 Methods and Analysis

A quasi-experimental quantitative approach was adopted to analyze the possibility of relationships among variables framing this study. The study used a pretest-posttest two group design. The students in one group participated in an active kinesthetic eclipse classroom lesson where they used the movement of their body and Styrofoam balls to model eclipses. The students in the other group engaged in a visual planetarium lesson where they viewed the process of eclipses using a 360-degree immersive theater. The participants were not randomly assigned; each previously defined class was allocated to either the kinesthetic classroom or visual-immersive planetarium group.

3.1 Participants

The previously mentioned US national science education reform documents describe that students between 10-15 years-old, should learn the process of eclipses (BARNETT; MORRAN, 2002; NGSS LEAD STATES, 2013; SCHLEIGH; SLATER; SLATER; STORK, 2015; SLATER; SLATER, 2015). In response, this study targeted middle school students in the US 6th, 7th, and 8th grade, ages 10-15 years-old.

As an IRB approved study, three science teachers, parents of the students, and the students themselves gave permission for the students to participate. The sample of students were largely Caucasian participants from a rural US state and ranged from 10-15 years-old. Two 7th grade classes were put into the kinesthetic classroom group (n=12) and two were put into the visual-immersive planetarium group (n=37), while four 8th grade classes were assigned into the kinesthetic classroom group (n=28) and four put into the visual-immersive planetarium group (n=31). One mixed class of 6th and 7th graders participated in the kinesthetic classroom group (n=16) and another 6th and 7th grade mixed class in the visual-immersive planetarium group (n=14). Students who were missing a pre-eclipse assessment, a post-eclipse assessment, spatial ability test, or signed consent form were excluded from the analysis, providing a sample size of 56 students in the kinesthetic classroom group and 82 students in the visual-immersive planetarium group (N=138).

The students were divided between high and low spatial ability levels based on the average combined spatial ability score of this study's entire sample. Students who scored higher than the average score of all participants for the combined spatial ability score (10.24) were put into the high spatial ability level and students who scored lower than the average were put into the low spatial ability level, as shown in Table 2.The students were further divided by lesson style spatial ability level, with 30 students in the kinesthetic classroom low spatial ability level group, 40 students in the visual-immersive planetarium low spatial ability level group, 26 students in the kinesthetic classroom high spatial ability level group, and 42 students in the visual-immersive planetarium high spatial ability level group.

3.2 Procedure

Both the kinesthetic classroom lesson and visual-immersive planetarium lesson were approximately one-hour in duration. Plummer, Wasko and Slagle (2011) and

Plummer (2014) found that students develop a more sophisticated understanding of astronomical concepts if they are able to move between an Earth-based perspective and a space-based perspective; therefore, both lessons incorporated an Earth-based and space-based perspective.

3.3 Kinesthetic Classroom Lesson

During the hour-long kinesthetic classroom lesson the instructor went into the students' classroom and instructed the students to use the movement of their body, Styrofoam balls, and light bulbs to model the Earth, Moon, and Sun to demonstrate a solar and lunar eclipse. The first two parts of the lesson had students "view" solar and lunar eclipses from an Earth-based perspective. A light bulb was set up in the middle of the classroom, representing the Sun. The students held a small Styrofoam ball on a stick to represent the Moon, while their head represented the Earth. The students modeled a solar eclipse, and with guidance from the instructor another student explained and demonstrated how a solar eclipse is created. The same process was repeated for modeling a lunar eclipse.

The next part of the kinesthetic lesson was similar to the first part, except that the Moon Styrofoam ball was attached to a hula hoop, which represented the Moon's orbit. The students modeled the incline (tilt) of the Moon's orbit to demonstrate why a solar eclipse does not occur every month, even though the positions of the Earth, Moon, and Sun is correct for a solar eclipse. This same process was repeated for modeling a lunar eclipse.

The last part of the kinesthetic lesson had the students view the Sun, Earth, Moon system from a space-based point of view. The students were seated at a table with a light bulb (representing the Sun), a large Styrofoam ball on a stand (representing the Earth), and a small Styrofoam ball on a ring that sat around the "Earth" (representing the Moon and orbit). Again, the students were asked to manipulate the Moon and orbit to create a solar eclipse and to demonstrate how the Earth, Moon, and Sun can have the correct positioning for a solar eclipse to occur but no solar eclipse is observed. The same process was used for a lunar eclipse.

3.4 Visual-Immersive Planetarium Lesson

During the visually-based participatory planetarium lesson the students came to the planetarium and participated in an hour-long immersive experience using planetarium software to help them visually model a solar and lunar eclipse. The lesson also had the students engage in learning about the process of eclipses through educator-student verbal interactions where the educator asked questions to the students and the students answered them out-loud and through student-student verbal interactions via think-pair-share discussion.

For the first part of the lesson the Media Globe II planetarium software was used to model a solar and lunar eclipse from an Earth-based perspective. Students were shown a total solar eclipse and asked some questions about what they observed. They were then shown the entire process of a solar eclipse from start to end. The same process was used for a total lunar eclipse.

The second part of the lesson used the Uniview planetarium software to model a lunar and solar eclipse from a space-based perspective. Uniview allowed the students to view the Sun, Earth, and Moon system as if they were out in space, looking out at the three celestial objects. The students were first shown the Moon orbiting Earth and were asked how long it takes for the Moon to make one complete orbit. The alignment of the Earth, Moon, and Sun was shown to the students, creating a total solar eclipse, and one student explained the process for a solar eclipse. The same process was used for a lunar eclipse.

The students were then asked how the Moon could be between the Earth and Sun but was not blocking out the Sun. They were shown a date when this occurred but the Moon's orbit was inclined (tilted) above the alignment of the Sun and Earth putting the Moon above the Sun; therefore, the Moon did not block out the Sun and no solar eclipse occurred. The same process was used for a lunar eclipse. Four assessment instruments were used to measure conceptual understanding and spatial abilities of the students: a pre-eclipse assessment, a post-eclipse assessment, a post-post-eclipse assessment, and a three-part spatial ability assessment. A spatial ability assessment is basically defined as a 3D object manipulation challenge without the use of the object itself, thus it is a visual test of object rotation.

3.5 Eclipse Assessments

3.5.1 Administration of Eclipse Assessment

To measure the students' conceptual understanding of eclipses a pre-, post-, and post-post-eclipse test was administered using the same questions. All students in both the kinesthetic classroom and visual-immersive planetarium groups took the same eclipse-assessment via paper and pencil and had 30 minutes to complete the assessment. The researcher administered the pre-eclipse assessment for the mixed 6th/7th grade classes, while the pre-assessments for the 7th and 8th grade classes were given by their teacher as were all the post-eclipse assessments for all the classes. Participants took the pre-assessment anywhere between one hour to 26 days prior to their eclipse lesson and the post-assessment between four to 14 days after the eclipse lesson.

A delayed post-post-eclipse assessment was given to a subsample of 26 students of the mixed 6th/7th grade classes by their teacher five months after the initial lesson. The post-post-eclipse assessment was the same as the pre- and post-eclipse assessment and the subsample of students took the assessment via paper and pencil and had 30 minutes to complete it. Of the kinesthetic classroom group, 14 students had taken all three eclipse assessments, the spatial ability assessment and had consent forms, while 12 students in the visual-immersive planetarium group had all assessments and consent forms, making for a total sample of 26 students.

3.5.2 Eclipse Assessment Content

The eclipse test contained six multiple choice and three short answer questions. The three short answer questions were divided into two or three multiple sub-questions: three sub-questions asked students to draw and label a diagram, one asked students to fill in the blanks to complete the sentence, and three had students choose the correct response(s). The questions assessed students' understanding of the position and alignment of the Sun, Earth, Moon system from an Earth-based and space-based perspective, the orbital period of the Moon, and the Moon's tilt and how the inclination of the Moon's orbit affects the frequency of eclipses. View the article's appendix for the eclipse assessment.

3.5.3 Creation and Concept Validity of Eclipse Assessment

The test questions utilized were created specifically for this study by the first author due to the limited amount of validated test questions relating to solar and lunar eclipses found in the literature. A pilot study completed the previous year used a similar eclipse assessment with 162 5th-9th grade students, ages 10-15 years-old. The assessment items were updated for this study using the comments and responses from the pilot study. The new assessment items were written to directly measure the four main fundamental concepts that the students should have understood from the lesson. Due to the lack of answers on many open-ended questions on the pilot study, all open-ended response questions were re-written to provide choices for student selection. Post-test and distract or items were taken from frequent incorrect responses on the pilot study post-test. Improvements to the questions were also taken from reviews of the assessment from six experts in the field of astronomy and/or education.

Think out-loud interviews with three students were also performed to help validate the questions of the eclipse assessment. For the multiple-choice questions all three students stated remembering diagrams and activities from the lessons that helped them answer the questions, or they already knew the answers from previous knowledge. Two students did mention that they were stressed or nervous while taking the assessment, but that was not unusual for them while taking tests. One student mentioned, that looking back on the assessment the questions made sense and that the assessment was easy, while another student realized he had answered a question incorrectly after reading the question again during the interview. When asked why they may have answered the question the way they did, they said they were stressed because of the assessment time limit. All three students stated that they were confused by questions eight and nine on the assessment, though these were written to be the more challenging, higher order cognitive thinking questions. When asked why they may have been confused with these questions, two students talked about being stressed or nervous and the third student discussed the wordiness of question eight. Overall, the students interviewed seemed to think the content and length of the eclipse assessment was reasonable compared to the science tests they usually take in school. Some questions were slightly confusing to them, though this could be because of their apprehension to taking tests in general. Taken together, the authors of this paper judge the interview results to lend weight to the concept validity of the assessment.

3.6 Spatial Ability Assessment

To quantitatively measure spatial ability, the same single three-part, timed spatial reasoning assessment, adapted from three well-known validated spatial ability assessments, was administered to all participants via pencil and paper (SPATIAL ABILITY ASSESSMENTS, 2013). The first component tested the students' mental rotation ability using eight questions of the re-drawn Vandenberg Mental Rotation Test

(PETERS, et al., 1995). This test showed students five cube snake-like figures. The left-most figure was the original figure and the students had to determine which of the other two figures were the same as the original, just rotated around, and which two were completely different figures. The second component assessed the students' spatial transformation ability using 10 questions from the adapted Paper Folding test (obtained from *spatiallearning.org*). Students had to follow an illustration of a piece of paper being folded multiple times with a hole punched in it during the final fold. The students had to mentally unfold the paper and determine where the holes would be placed on the unfolded paper. The third component tested the students' spatial visualization ability using 10 questions from the adapted Guay's Visualization of Viewpoints test (obtained from *spatiallearning.org* as per the method described in Heyer, Slater and Slater (2014). This test showed the students a shape surrounded by a hollow cube and then showed them the same shape, but viewed from a different perspective. The students had to determine where along the hollow cube they would need to be placed to see the shape from the different perspective.

3.7 Eclipse Assessment Data Analysis

To determine how much each student improved from pre- to post-lesson and post- to post-post-lesson the normalized gain was calculated between the pre- and post-eclipse assessment and post- to post-post-eclipse assessment using the equation below.

$$< g > = \frac{(posttest\ score - pretest\ score)}{(TOTAL - pretest\ score)}$$

In order to compare the pre- to post-test scores and the post- to post-post-test scores for each student a two-tailed paired *t-test* was calculated using *scipy.stats* package in Python. A two-tailed independent *t-test* was used to compare the scores of the kinesthetic classroom group to the scores of the visual-immersive planetarium group using the same Python statistics package. The Python statistical package was used over SPSS due to the researcher's familiarity with Python.

3.8 Correlation Data Analysis

To determine if one type of instruction was more effective for teaching eclipses given a student's spatial ability level, a Pearson's *r* correlation factor was calculated between eclipse knowledge and combined spatial ability score for low and high spatial ability levels for both the kinesthetic and planetarium groups. A Pearson's *r* correlation test was also used to determine if there is a correlation between gain in eclipse understanding and rotation, visualization, or transformation spatial ability. The Pearson's *r* correlation equation is as follows:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{(N-1)s_x s_y}$$

A *r* correlation value ranges between -1.0 and +1.0, with a -1.0 value meaning a perfect negative (decreasing) linear relationship, a +1.0 value meaning a perfect positive (increasing) linear relationship, and a value of 0 meaning no relationship between the two variables. A Pearson's *r* correlation was used since a linear relationship between variables was being investigated.

4 Results

4.1 Eclipse Assessment Scores

To determine the participants' initial and post-instruction levels of conceptual knowledge of eclipses the authors of this study first administered the eclipse assessment pre- and post-instruction to all participants regardless of the instructional experience they received. The averages of the eclipse test scores increased from 10.80 (SD=3.92) to 15.34 (SD=4.84) pre- to post-test for the kinesthetic classroom group and from 10.49 (SD=4.13) to 14.07 (SD=4.71) for the visual-immersive planetarium group. The entire sample significantly increased from a pre-test score of 10.62 (SD=4.05) to a post-test score of 14.58 (SD=4.81) as well, implying students' knowledge improved after instruction, independent of lesson type. The normalized gain between pre-test and post-test for both the kinesthetic classroom and visual-immersive planetarium groups and the entire sample was found to be 0.32 (SD=0.36), 0.25 (SD=0.30), and 0.28 (SD=0.33) respectively, with the increases being statistically significant at the 0.01 level. These results show students in both styles of lesson increased their knowledge on eclipses. See Table 2 for summary of average scores and the gains.

Looking at the average normalized gains, the students who participated in the kinesthetic classroom lesson had a similar normalized gain (<g> = 0.32) compared to those who participated in the visual-immersive planetarium lesson (<g> = 0.25). Independent t-test results show no statistically significant results between the kinesthetic classroom and visual-immersive planetarium groups for either post-eclipse score or normalized gain. Table 3 provides the independent *t-test* scores and *p-values*. Therefore, the results do not clearly show whether one type of lesson used in this study has a larger effect on learning the topic of eclipse than the other. This result and the statistically significant normalized gain between pre-test and post-test result implies that middle school students increase their knowledge on eclipses independent of lesson style, but one style of lesson does not appear to be more effective than the other insofar as the survey instrument could measure.

Groups	**N**	**Average Pre-Test (SD)**	**Average Post-Test (SD)**	**<g> (SD)**	**Dependent *t-test* score**
Kinesthetic	56	10.80 (3.92)	15.34 (4.84)	0.32 (0.36)	-7.13**
Planetarium	82	10.49 (4.13)	14.07 (4.71)	0.25 (0.30)	-7.81**
Everyone	138	10.62 (4.05)	14.58 (4.81)	0.28 (0.33)	-10.55**

Table 2 - Average scores and normalized gains for the pre- and post-eclipse assessment, along with dependent t-test results between pre- and post-eclipse survey scores for each of the kinesthetic group, the planetarium group, and the entire sample.

** indicates statistical significance at 0.01 level.

Planetarium versus Kinesthetic Groups	**Independent *t*-test score**	**Independent *t*-test p-value**
Post test	1.53	0.13
Normalized Gain	0.96	0.34

Table 3 - Independent t-test results between the kinesthetic and planetarium groups for post-eclipse assessment scores and normalized gains.

4.2 Spatial Ability Assessment

Three separate spatial ability assessments were given to the students to measure their rotation, transformation, and visualization spatial ability characteristics. The average individual spatial ability scores were added to determine the students' combined spatial ability score. Table 4 illustrates the average spatial ability scores for the kinesthetic classroom group, visual-immersive planetarium group, and the entire sample combined.

Group	**N**	**Average Mental Rotation (SD) (8 points)**	**Average Spatial Transformation (SD) (10 points)**	**Average Spatial Visualization (SD) (10 points)**	**Combined Average (SD) (28 points)**
Kinesthetic	56	3.37 (2.40)	3.44 (2.25)	3.40 (3.00)	10.21 (5.26)
Planetarium	82	2.99 (2.45)	3.81 (2.39)	3.46 (3.02)	10.26 (5.75)
Everyone	138	3.14 (2.44)	3.66 (2.34)	3.44 (3.01)	10.24 (5.56)

Table 4 - Average scores for the three spatial ability tests, individually and combined for the kinesthetic group, planetarium group, and entire sample.

4.3 Lesson Pedagogy and Spatial Ability Level Correlation

To determine if there is a relationship between the type of lesson the students received and students' spatial ability level, a Pearson's *r* correlation factor was calculated between the normalized gain and the combined spatial ability score for the kinesthetic classroom high/low spatial ability level groups and the visual-immersive planetarium high/low spatial ability level groups.

A weak positive, but nonsignificant relationship was found between the normalized gain and the combined spatial ability score for both the kinesthetic low-level group and the visual-immersive planetarium high-level group (r=0.022, p=0.906 and r=0.002, p=0.990, respectively). A weak negative correlation that was nonsignificant was found between normalized gain and combined spatial ability score for both the visual-immersive planetarium low-level group and the kinesthetic high-level group (r= -0.111, p=0.495 and r= -0.086, p=0.086, respectively). These results show that there does not appear to be a statistically significant correlation between normalized gain and spatial ability for any lesson type or spatial ability level, suggesting that a specific lesson style is not more effective given a student's spatial ability level. See Table 5 for the summary.

Group	N	Pearson *r*	Two-Tailed p-value
Kinesthetic Group Low Level	30	0.022	0.906
Planetarium Group Low Level	40	-0.111	0.495
Kinesthetic Group High Level	26	-0.086	0.677
Planetarium Group High Level	42	0.002	0.990

Table 5 - Pearson r correlation factor and two-tailed p-value between normalized gain and combined spatial ability score for the low and high spatial ability levels of the kinesthetic and planetarium group.

4.4 Lesson Pedagogy and Spatial Ability Characteristic Correlation

A Pearson's *r* correlation factor was calculated between normalized gain and spatial ability scores, both individually and combined for the kinesthetic classroom and visual-immersive planetarium participants. Table 6 summarizes these findings.

Only a statistically significant correlation between normalized gains and transformational spatial ability for the kinesthetic classroom group was found, thus suggesting that transformational spatial ability characteristics are moderately related to learning about eclipses.

4.5 Eclipse Knowledge and Spatial Ability Characteristic Correlation

A Pearson's *r* correlation coefficient was calculated between the normalized gain and the separate spatial ability scores for all students, regardless of lesson type to determine if learning eclipses is correlated with spatial ability. Table 7 summarizes these results. Again, a statistically significant correlation between normalized gains and transformation spatial ability were found, but no other statistically significant correlations were found. These findings suggest that transformational spatial ability is correlated with learning eclipses. Uncovering the precise causal relationship between the two would require a different study design than the two-group experimental approach used in this study.

	N	Post-eclipse score and Rotation	Post-eclipse score and Transformation	Post-eclipse score and Visualization	Post-eclipse score and Combined
Kinesthetic Pearson *r* and *p-value*	56	0.071 (0.604)	0.370 (0.004) **	-0.018 (0.896)	0.180 (0.184)
Planetarium Pearson *r* and *p-value*	82	0.074 (0.510)	0.167 (0.134)	0.123 (0.913)	0.107 (0.337)

Table 6 - Pearson *r* correlation factor and two-tailed p-values between normalized gain and spatial ability scores, individually and combined, for the kinesthetic and planetarium groups.

** indicates statistical significance at the 0.01 level.

	N	Normalized Gain <*g*> & Rotation Test	Normalized Gain <*g*>& Transformation Test	Normalized Gain <*g*>& Visualization Test	Normalized Gain <*g*>& Combined Test Score
Pearson *r* and *p-value*	138	0.078 (0.364)	0.246 (0.004)*	-0.002 (0.797)	0.137 (0.110)

Table 7 - Pearson *r* correlation factor and two-tailed p-values between normalized gain<*g*> and three spatial ability tests for the entire sample.

*Indicates statistical significance at the 0.05 level

4.6 Longitudinal Results

Both the kinesthetic classroom and visual-immersive planetarium groups decreased in score from post-test to post-post-test, as well as the entire sample. The normalized gains between the post-test and post-post-test scores were -0.176 (SD=1.859) for the kinesthetic classroom group, -0.264 (SD=1.379) for the visual-immersive planetarium group, and -0.216 (SD=1.655) for the entire sample. The kinesthetic classroom group did not have a statistically significant decrease from post-test to post-post-test. The visual-immersive planetarium group's decrease from post to post-post-test was found to be statistically significant, as was the average decrease for the entire sample. Table 8 summarizes these results. These findings show, overall, that students' eclipse knowledge scores decrease five months after learning about the topic.

Table 9 shows the independent *t-test* results between the kinesthetic classroom and visual-immersive planetarium groups for the post-post-eclipse assessment scores and the normalized gain between post- and post-post-eclipse scores. There is no statistical difference between post-post scores of kinesthetic classroom and visual-immersive planetarium groups or the normalized gain of kinesthetic classroom and visual-immersive planetarium groups, again suggesting there is little measurable difference between an eclipse lesson taught using the kinesthetic classroom lesson or the visual-immersive planetarium lesson used in this study.

	N	**Average Pre-Test (SD)**	**Average Post-Test (SD)**	**Average Post-post Test (SD)**	**Normalized Gains between post and post-post assessment (SD)**	**Dependent *t-test* Score**
Kinesthetic	14	11.071 (4.480)	16.071 (5.270)	14.500 (5.053)	-0.176 (1.859)	1.321
Planetarium	12	9.583 (4.86)	16.167 (4.579)	13.833 (3.912)	-0.264 (1.379)	3.189**
Everyone	26	10.385 (4.715)	16.115 (4.964)	14.192 (4.574)	-0.216 (1.655)	2.691*

Table 8 - Average scores for the pre-eclipse, post-eclipse, and post-post-eclipse assessment, along with normalized gains between post- and post-post assessment, and dependent t-test results between post- and post-post eclipse assessment scores for each the kinesthetic group, the planetarium group, and the entire sample.

*Indicates statistical significance at the 0.05 level.
** indicates statistical significance at the 0.01 level.

Planetarium versus Kinesthetic	**Independent *t-test* score**	**Independent *t-test p-value***
Post-post test	0.357	0.724
Normalized Gain	0.132	0.896

Table 9 - Independent t-test results between the kinesthetic and planetarium groups for post-post eclipse assessment scores and normalized gains between post- and post-post eclipse assessment scores.

5 Conclusions, Discussion, and Implications

The value of utilizing a planetarium, psychomotor modeling, and attention to spatial reasoning in relation to three-dimensional versus two-dimensional perspectives has long been argued as being important and intertwined, but systematic astronomy education research data specifically backing up these tacit assumptions has been weak to date (*viz*., SLATER; TATGE, 2017). In response, this study investigated two types of lessons with a quasi-experimental quantitative structure to gain insight into the educational value the targeted treatments might deliver. The findings of this two-group comparison study suggest middle school students can improve their knowledge about eclipses with varied approaches of targeted instruction. On average, all participating students' scores significantly increased from pre- to post-eclipse test, implying that students increased their knowledge about eclipses after instruction. The normalized gains for the kinesthetic classroom group visual-immersive planetarium group and the entire sample illustrate that, in this study, the increases from pre- to post-eclipse tests and were statistically significant.

The kinesthetic classroom group had statistically similar post-test scores and normalized gain scores as the visual-immersive planetarium group. The results cannot state for certain if either a visual-immersive planetarium or kinesthetic classroom lesson had a larger effect on learning the topic of eclipses over the other. One reason for a non-statistically significant independent *t-test* could be that there really is no difference between the two instructional styles.

The authors of this article were curious if the type of instruction—kinesthetic classroom or visual-immersive planetarium—was more effective for students with low or high spatial ability levels in this specific sample. A Pearson's *r* correlation factor was calculated between normalized gain and combined spatial ability score for both the low and high kinesthetic classroom and visual-immersive planetarium groups. No statistically significant results were found suggesting educators can use either a kinesthetic classroom or visual-immersive planetarium lesson for their entire class, regardless of students' spatial ability level; the educator does not need to create two different lessons based on the spatial ability levels of the class to effectively teach eclipses.

In questioning whether one characteristic of spatial ability has a larger effect on student eclipse learning the authors found a statistically significant correlation between normalized gain and spatial transformation for the entire sample and the kinesthetic classroom group. Therefore, the results of this study strongly suggest that transformational spatial ability is related to learning about eclipses, independent of lesson pedagogy. This relationship indicates students who have larger overall spatial ability skills tend to do better on the eclipse assessment, and students who have strong transformational spatial ability skills tend to have an easier time learning about eclipses, regardless of instructional intervention. This apparent connection is worth more targeted study in the future.

Finally, the authors of this article wondered whether a subsample of students retained their knowledge on eclipses months after the initial lesson, and, if one type of instruction led to a higher retention. The longitudinal results show negative normalized gains between average post-eclipse test scores and post-post-eclipse test scores for the kinesthetic classroom and visual-immersive planetarium subsample groups as well as for the subsample as a whole. The dependent *t-tests* show the decrease in eclipse content knowledge scores are only statistically significant for the visual-immersive planetarium subsample group and the entire subsample. For both groups and the sample as a whole, the average post-post eclipse test score was still larger than the average pre-eclipse test score. Again, there appears to be no statistically significant difference in the post-post scores or normalized gains between the kinesthetic classroom and visual-immersive planetarium subsample groups. The sample size for the longitudinal data are under 30 participants, making for low statistical power. The longitudinal aspect of this study is worth more targeted study in the future, using a larger sample size.

The results showed no difference between the kinesthetic classroom and visual-immersive planetarium lessons and the correlation results between eclipse knowledge and spatial ability level for this study also seem to have no or minimal relationships. It is possible there is no difference between the two lesson styles when learning about eclipses and maybe the topic of eclipses is not as related to spatial ability as other astronomy topics, but this does not seem likely. Learning the reason for eclipses seems just as likely to be spatially challenging to learn as any other astronomical topic. One seemingly needs to understand the relationship between the Earth, Moon, and Sun and how their orbital parameters create eclipses. It seems that one needs to visually move from an Earth-based perspective to a space-based perspective to understand the connection between what is seen on Earth during an eclipse to what is happening in space to create the eclipse.

Considering limitations of the study undertaken here, our observations point to an obvious limitation of this study being the eclipse assessment instrument itself. The eclipse test, which was created specifically for this study, might not have been sensitive enough to uncover a large difference between students' pre-lesson knowledge and post-lesson knowledge. The assessment was created by using the results of a pilot study that was done the prior year using 162 students as well as undergoing an evaluation by six experts in the field of education and/or astronomy. Along these same lines the eclipse test items themselves could have also been confusing for the students, causing them to not do as well as they could have. However, the validating think-aloud interviews with students confirmed that the eclipse assessment results were what was expected from the students for a typical science test; it was neither too difficult nor too easy. The two higher-order cognitive questions did seem to confuse the three students interviewed, though this was most likely because of their apprehension to taking tests in general and have nothing to do with the test questions themselves. During the assessments the students may have also become fatigued or disinterested. The authors of this article attempted to mitigate for fatigue by using a test with only nine questions (six multiple choice and three short answer) that was four pages long and contained no open-ended questions that asked students to describe the process of how eclipses occur in their own words. This type of question could have been useful to really distinguish whether students knew how eclipses occurred; however, the researcher felt this type of question would have been too much of a struggle for the students given what she found from the pilot study. Creating a more validated and reliable assessment would be worth doing for any future studies covering the topic of eclipses.

Implications for this work include attention to students' transformational spatial ability as a baseline for extra support or expansion topics for an advanced learner. Regardless, the results of this study motivate the community to continue this line of questioning in the future. One direction for future work would be to redo this study with an improved eclipse assessment in order to tell if there really is no difference between the two types of lessons in teaching the process of eclipses. Some ideas for a revised eclipse assessment would be to field test it with more students; allow for open-ended questions so students could explain, in their own words, how eclipses occur; and perform a think out loud interview with more students. If the eclipse assessment could be heavily validated like other astronomy assessment found in the literature, such as TOAST Test Of Astronomy Standards (*viz*., SLATER, 2014), maybe a similar study would find a statistically significant difference between the visual-immersive planetarium and kinesthetic classroom lessons and find a statistically significant correlation between eclipse knowledge and spatial ability level. In the same way, a more focused qualitative/inquiry approach with more detailed phenomenological interviews might lead to more compelling results.

Another approach that could prove to be interesting would be to determine if a combined kinesthetic-planetarium lesson would have a larger effect on learning eclipses than a purely kinesthetic classroom or purely visual planetarium lesson, encouraging a three-group study: kinesthetic classroom group, visual-immersive planetarium group, and kinesthetic and planetarium group. This type of study could possibly state how kinesthetic learning techniques and visuals in a planetarium, both separately and combined, impact learning the topic of eclipses. Along the same lines, another comparative study that used a control group that participated in a traditional lecture-based lesson could be interesting in order to determine if any lesson style helps increase eclipse knowledge for participants or if it takes a lesson that visually and/or kinesthetically engages the participants, both immediately and months after the lesson.

One might naturally assume that could have higher spatial ability than middle school students, seeing as they have had more experience with spatial tasks, but that might not be the case. Spatial ability seems to be a learned skill, but most adults have not had structured learning opportunities on how to improve their spatial ability (HEGARTY, 2011). Therefore, it might be interesting to perform this same study using pre-service teachers, and even college students, to decide if similar results are observed.

Moreover, a study of how gender may play a role in the most effective way to learn about eclipses and how eclipse knowledge is related to spatial ability. Does this hold true for learning about eclipse? Is the most effective lesson pedagogy dependent of the gender of the student?

All of this seems to beg the question of the extent to which spatial ability can affect the learning of science, and if science knowledge can have an effect on spatial ability. This study considered whether spatial ability was related to eclipse knowledge, but an interesting study would be whether learning about eclipses can increase participants' spatial ability. Another worthy study would be to establish whether a specific type of lesson, kinesthetic classroom or visual planetarium, could help improve students' spatial ability. This could easily be done by administering the spatial ability assessments pre- and post-lesson.

In summary, the results of this study provide preliminary data for improving our understanding of how to effectively teach the topic of eclipses and model systems to students of all spatial ability levels. Formal and informal educators can use these results when developing their lessons on eclipses and astronomy in general, and when they are developing a lesson involving any model systems. It appears fruitful for educators, especially those who teach middle school, to consider the use of interventions developed for this study to teach the topic of eclipses. With it becoming more and more costly for teachers to take students on field trips to such places as planetaria, it useful to recognize that an in-classroom kinesthetic lesson on eclipses can help students of any spatial ability level learn about the topic, and do so just as effectively as if they went on a field-trip to an immersive planetarium.

This study lends further weight to the notion that spatial ability is related to learning about eclipses. Therefore, including spatial ability tasks throughout the school year to enhance students' spatial skills could likely be important for all educators to implement. This has the potential to benefit all students, especially those with lower spatial ability levels, in all educational fields, not just astronomy. Including tasks that enhance one's spatial ability appears to be beneficial for students' future success.

The results of this study further suggest that middle school students can increase their understanding of eclipses by participating in a kinesthetic classroom or visual-immersive planetarium lesson that is engaging. Not only can these lessons be used with students of any spatial ability level to increase their knowledge on eclipse phenomena, but also to possibly increase their overall spatial ability as well. There are numerous studies that could be done within this area of astronomy and with the next North American total solar eclipse happening in only a few years (April 8, 2024), discipline-based astronomy education researchers and astronomy educators have more opportunities to continue to better understand the effective ways for students and adults to learn about eclipses, their conceptual knowledge on this topic, and how spatial ability is related to eclipse learning.

Acknowledgements

The authors would like to thank the science teachers, parents, planetarium staff, and especially the students for investing time and efforts in this research study. This work was funded in part by the Wyoming Excellence in Higher Education Endowment for Science Education.

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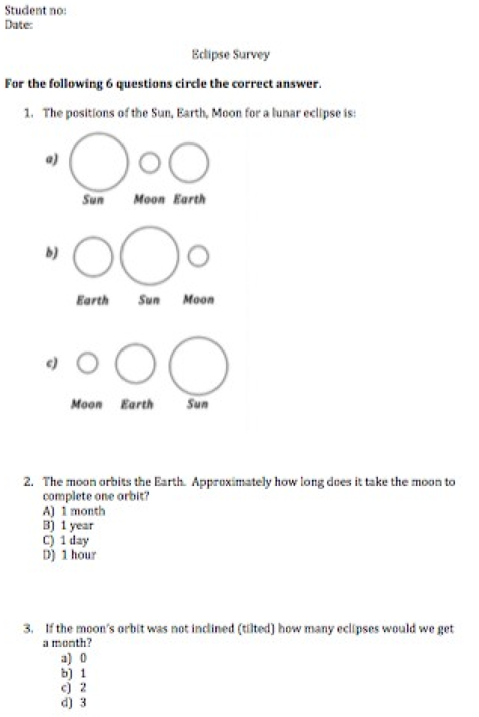
Artigo recebido em 07/02/2017.
Aceito em 05/11/2018.

Appendix A - Eclipse Survey Assessment



Student no:
Date:

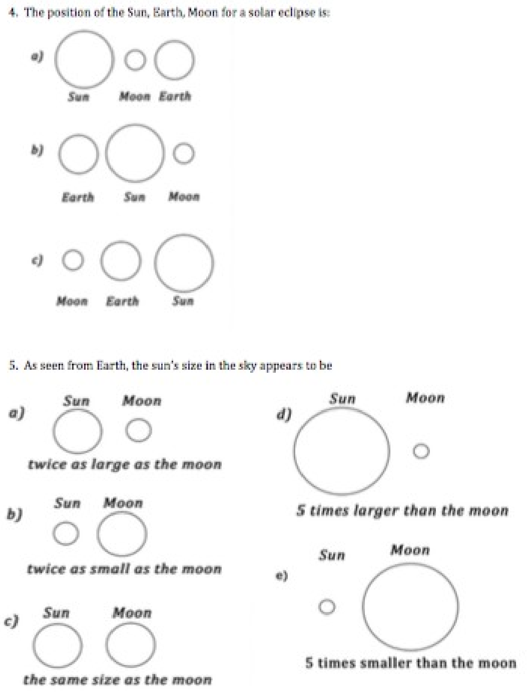
Eclipse Survey

For the following 6 questions circle the correct answer.

1. The positions of the Sun, Earth, Moon for a lunar eclipse is:

2. The moon orbits the Earth. Approximately how long does it take the moon to complete one orbit?
   A) 1 month
   B) 1 year
   C) 1 day
   D) 1 hour

3. If the moon's orbit was not inclined (tilted) how many eclipses would we get a month?
   a) 0
   b) 1
   c) 2
   d) 3



4. The position of the Sun, Earth, Moon for a solar eclipse is:

5. As seen from Earth, the sun's size in the sky appears to be

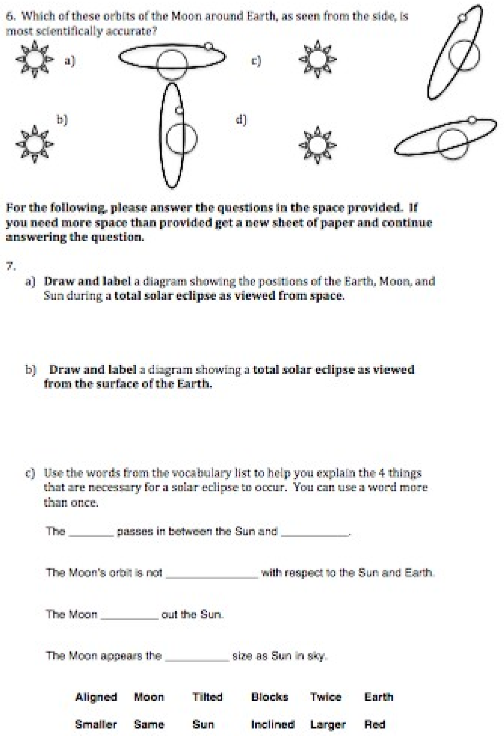
a) *twice as large as the moon*

b) *twice as small as the moon*

c) *the same size as the moon*

d) *5 times larger than the moon*

e) 5 times smaller than the moon



6. Which of these orbits of the Moon around Earth, as seen from the side, is most scientifically accurate?

For the following, please answer the questions in the space provided. If you need more space than provided get a new sheet of paper and continue answering the question.

7.
   a) **Draw and label** a diagram showing the positions of the Earth, Moon, and Sun during a **total solar eclipse as viewed from space.**

   b) **Draw and label** a diagram showing a **total solar eclipse as viewed from the surface of the Earth.**

   c) Use the words from the vocabulary list to help you explain the 4 things that are necessary for a solar eclipse to occur. You can use a word more than once.

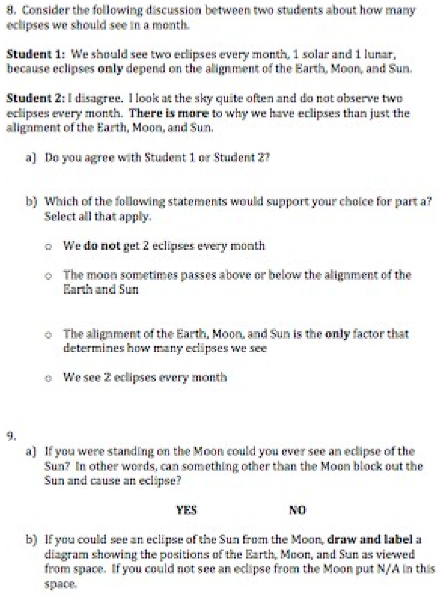
The _______ passes in between the Sun and ___________.

The Moon's orbit is not ______________ with respect to the Sun and Earth.

The Moon _________ out the Sun.

The Moon appears the __________ size as Sun in sky.

Aligned	**Moon**	**Tilted**	**Blocks**	**Twice**	**Earth**
Smaller	**Same**	**Sun**	**Inclined**	**Larger**	**Red**



8. Consider the following discussion between two students about how many eclipses we should see in a month.

Student 1: We should see two eclipses every month, 1 solar and 1 lunar, because eclipses **only** depend on the alignment of the Earth, Moon, and Sun.

Student 2: I disagree. I look at the sky quite often and do not observe two eclipses every month. **There is more** to why we have eclipses than just the alignment of the Earth, Moon, and Sun.

   a) Do you agree with Student 1 or Student 2?

   b) Which of the following statements would support your choice for part a? Select all that apply.

      ○ We **do not** get 2 eclipses every month

      ○ The moon sometimes passes above or below the alignment of the Earth and Sun

      ○ The alignment of the Earth, Moon, and Sun is the **only** factor that determines how many eclipses we see

      ○ We see 2 eclipses every month

9.
   a) If you were standing on the Moon could you ever see an eclipse of the Sun? In other words, can something other than the Moon block out the Sun and cause an eclipse?

YES **NO**

   b) If you could see an eclipse of the Sun from the Moon, **draw and label** a diagram showing the positions of the Earth, Moon, and Sun as viewed from space. If you could not see an eclipse from the Moon put N/A in this space.