An Allocentrist Approach to Teaching the Phases of the Moon in a Digital Full-dome Planetarium

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ABSTRACT
This research aims to identify what elements of an allocentric digital full-dome planetarium session are important for 5th and 6th graders (10-12 years old) to help them better understand Moon’s phases. Qualitative data will be obtained through semi-structured group discussions following the presentation of an allocentric session about the phases of the Moon at the Montreal Planetarium. Quantitative data will be gathered before and after the session using a multiple-choice questionnaire about different aspects of the phases of the Moon. Preliminary results show that an allocentric digital full-dome planetarium session about the lunar phases needs to present eclipses as well. It also needs to have sound effect to simulate the sound of rocket boost while navigating through space. The allocentric point of view and the feeling to be in a spacecraft in space was well received and showed interesting results on understanding the lunar phases.

INTRODUCTION
The teaching of the phases of the Moon in a traditional school setting has many shortcomings: the Moon is often invisible during normal school hours, bad weather can hinder observations, the change from one phase to the next is slow, etc. What’s more, research has shown that the experience of looking at the Moon from a geocentric point of view is often the source of the most common misconceptions, like the idea that phases are caused by clouds blocking our view, or the shadow of the Earth projected on the Moon (Bakas et Mikropoulos, 2003; Black, 2005; Cole *et al.*, 2015). Among many possible solutions to these problems, the visit to a planetarium has proved several times its usefulness for learning astronomical concepts (Brazell et Espinoza, 2009; Mikropoulos et Natsis, 2011). In recent years, new technologies have revolutionized the traditional planetariums. The introduction of video projectors and high-performance computers has transformed the planetarium theater into a spaceship that allows visitors to see and experience a different point of view than geocentrism on highly spatial and dynamic systems, like the Sun-Earth-Moon. While several studies in the past have concentrated on the pedagogical practices to be used in a traditional planetarium, none to our knowledge has been interested in the elements of an allocentric session under a planetarium dome that promotes a better understanding of a complex astronomical phenomenon like the lunar phases (Slater et Tatge, 2017). This research aims to explore the new capabilities offered by digital planetariums. We will attempt to develop guidelines and procedures for conducting educational sessions in such planetariums. To do this, we will perform a session about the phases of the Moon in a digital planetarium using design experiment. At the end of each implementation of the session, we will collect data that will allow us to improve it and to build our knowledge on this new learning tool that is the digital planetarium.

I. THE PLANETARIUM

1.1 Traditional
Since their appearance in the mid-1920s until the beginning of the 21st century, so-called traditional planetariums have not undergone any notable change (Chartrand III, 1973, Marché II, 1999, 2001). These are immersive environments that can simulate various movements of the celestial vault. They do it thanks to two fundamental elements: the star projector and the dome shape of the theater. The theater of a planetarium is a circular room surmounted by a dome-shaped ceiling that serves as a screen. In the center of this room, there is an optomechanical instrument known as a star projector. This projector reproduces the starry sky on the ceiling of the room. With the addition of other specialized projectors, it is also possible to project objects like the Moon, the planets and the Milky Way. This projection capability combined with the form of the theater allows the entire field of view of the visitor to be occupied and thus contributes to immersion and presence. In addition, the projection devices of a planetarium can move the stars in the sky faster than the regular passage of time. Thus, a visitor can observe a complete lunar cycle in just minutes rather than 28 days. He could also witness the movement of the Sun in the sky during the year (analemma), a phenomenon difficult to observe due to its temporal length.

1.2 Digital
With the new digital technologies of the first decade of the 21st century, planetariums are experiencing a real revolution. The new projectors and increasingly powerful computers allow the construction of digital planetariums. From an architectural point
of view, a digital planetarium is very similar to a traditional planetarium. Both are immersive virtual reality environments with a domed ceiling that acts as a screen. Some digital planetariums have an optomechanical star projector in the center while others do not. However, the big difference between the two types of planetarium, traditional and digital, lies in their ability to project images. Digital planetariums are equipped with high quality video projectors that have the ability to fill the screen, and thus the visual field of the viewer, with computer-generated imagery, videos and realistic representations. This digital projection capability is made possible by video projectors, of course, but also by computers. These computers include modern space mapping software, extremely powerful graphics cards, and numerous databases. These systems, coupled with video projectors, allow to present the starry sky, the solar system, the galaxy, etc. with great precision and based on the latest scientific data. The planetarium thus becomes, for the visitor, a true spaceship, allowing him to navigate through space and to explore different points of view. The visitor can discover the Universe with a look that is different from the traditional geocentric point of view. These new allocentric points of view make it possible to revisit common astronomical phenomena, like the lunar phases, in order to explain them adequately, without the biases and limitations of geocentrism and, possibly, to change the alternative conceptions of viewers (Chastenay, 2015 ). Like traditional planetariums, digital planetariums have shown their effectiveness in teaching astronomical concepts (Carsten-Conner et al., 2015; Chastenay, 2015; Yu et al., 2015; Zimmerman et al., 2014).

II. PREVIOUS RESEARCH

In order to realize a session allowing the learning of an astronomical concept in a planetarium, many studies have been interested in the different elements which contribute to it. Mallon (1974) demonstrated the importance of the physical presence of a communicator in a planetarium. In his study, he presented two planetarium programs identical to 2nd grader students, one with a live communicator and the other with a pre-recorded narrative tape. Students who attended the session with a facilitator performed better on the post-test than the second group.

In his studies, Ridky (1974) focused on public reception in a planetarium. Using two identical programs with 8th grader students, he showed that students who received an orientation session (presentation of the architecture of the room and its equipment) before the presentation of the program had a better retention of the information and performed better at the post-test. Ridky titled “demystification of the planetarium” this orientation session where we present the projectors, the dome-shaped screen, the operation of the star projector, etc. In the same way, Bisard (1979) demonstrated the importance of a welcome note summarizing the upcoming session, whether done by a live presenter, pre-recorded, or simply projected on the screen.

With regard to the sound and musical plot of a session in a planetarium, Wooten (1979) compared two groups of viewers who attended a live performance, one with a musical score and the other without. His study showed that the musical framework can sometimes interfere with understanding when it is not well synchronized with the visual elements. Note however that when the score is well synchronized with the show, the results are different. Brunello (1992) discovered a positive effect on learning. The music and soundtrack come at best to enhance the experience, but can also be the source of distractions that undermine learning.

It is also noted that the success of the planetarium lies in its visual impact and it should focus on this aspect (Gutsch, 1978). Based on the visual success of the planetarium, Hunt (1991) has shown that it is important for viewers to have time to appreciate visual information. Moreover, in certain situations where there is a lot of information to be processed, it is relevant to orient the visitor, using a pointer, arrows, etc., towards certain important elements (Hunt, 1991).

Several researchers (Bakas et Mikropoulos, 2003; Fletcher, 1977; Friedman et al., 1976; Merger, 1975; Schafer, 1977) were interested in the form of the scenario that should be adopted by a learning session in a planetarium. They compared participatory approaches (ask & do) and more traditional approaches (show & tell). In the majority of research (Fletcher, 1977; Friedman et al., 1976; Merger, 1975; Schafer, 1977), an approach based on public participation was more appreciated by the audience and gave better results in terms of learning. However, there are some precautions to take. In their research, Bakas et Mikropoulos (2003) studied the learning of various astronomical concepts (the movement of the Earth and the Sun, the day-night cycle and the seasons) with 102 high school students in a virtual environment. Their conclusion is that it is better to accompany students in their navigation than to let them go freely.

In short, the learning sessions within a traditional planetarium should be presented live by a communicator in the room. It should begin by presenting the theater and its accessories as well as the program of the session. The session will have to give a measured place to the musical frame and focus on visual information, while drawing the spectators' eyes towards the most important elements. In addition, the moderator and session designers should coordinate to provide spectators with an immersive and interactive experience.

The researches mentioned above were conducted using traditional planetariums, but what about digital planetariums? With the new perspectives offered by these planetariums, what do we know about the elements that an allocentric session in a digital planetarium should adopt to promote the learning of an astronomical concept? We have no reason to believe that the elements noted in the traditional planetariums could not be used during such a session, but perhaps other elements, related exclusively to the allocentric point of view, are important. To our knowledge, no research has yet addressed this issue (Slater et Tatge, 2017).

III. THEORETICAL FRAMEWORK

In science education, it is generally accepted that students learn by interpreting the nature of things around them based on their experiences. Thus, the learner will build personal theories based on his observations, past experiences, values, etc. (Chastenay,
At the age of 10-12, learners have few experiences and knowledge to guide them and therefore the primary theories they develop are often at odds with accepted scientific theories (Kücüközer et al., 2009; Vosniadou, 1991). These primary theories are called misconceptions and despite the fact that they do not fit scientific theories, they make a lot of sense for children (Kücüközer et al., 2009). Misconceptions therefore hinder learning and this is especially true in the case of the lunar phases (Kücüközer et al., 2009; Palmer, 2007; Vosniadou, 1994). Instead of just passing on information, teachers should consider the students’ conceptions in order to provoke a real conceptual change.

In the case of teaching the phases of the Moon, constructivism is particularly interesting since it has been proven to be well equipped to address misconceptions (Kavanagh et al., 2005; Lelliott et Rollnick, 2010; Mills et al., 2016). Lunar phases are an abstract astronomical concept. In order to fully understand it, one must be able to mentally construct a three-dimensional interacting system with the Earth, Sun and Moon (Chastenay, 2015; Cole et al., 2015; Kavanagh et al., 2005; Vosniadou, 1994). However, our strictly geocentric point of view and the difficulty we have in representing the sizes and distances of astronomical objects contributes to limit this mental construction (Black, 2005; Chastenay, 2015). This difficulty contributes to a profusion of misconceptions about lunar phases from students, the most common ones being that the phases of the moon are created by Earth’s shadow or by clouds passing in front of the Moon (Bell et Trundle, 2008; Chastenay, 2013; Kavanagh et al., 2005; Kücüközer et al., 2009; Liu, 2005; Vosniadou, 1994). A traditional teaching approach, based on textbooks for example, does not bring about any real conceptual change in the student (Kücüközer et al., 2009). On the contrary, it could even have contributed to creating and reinforcing some of the most common misconceptions (Chastenay, 2013; Kücüközer et al., 2009). Learning can be seen as “the result of the interaction between what the student is taught and his current ideas or concept.” (Posner et al., 1982). So, when the student is faced with observations that challenge his personal theory, we can encourage him to use a new model. To make this conceptual change, the new model must be intelligible, plausible and fruitful (Posner et al., 1982). This mechanism of conceptual change will be the basis of our teaching strategy.

The most popular misconceptions about the lunar phases are the result of a multitude of misconceptions about the Earth, Moon, and Sun. Among these are the Earth-Moon distance which is often underestimated, the Earth and the Moon imagined as two-dimensional circles instead of spheres, and the light of the Moon which is sometimes believed to be emanating from the Moon itself instead of being the reflected light from the Sun (Chastenay, 2013; Comins, 1999; Kücüközer et al., 2009; Vosniadou et Brewer, 1992; Vosniadou et Brewer, 1994). To fully understand the phenomenon of the phases of the Moon, one must be able to understand the place of the Earth in relation to the Moon and the Sun as well as the movements of these celestial objects (Barnett et Morran, 2002; Chastenay, 2015; Cole et al., 2015; Vosniadou, 1991). He needs to understand that the Moon, like the Earth and the Sun, is a solid and spherical object, know that the light of the Sun is actually that of the Sun reflected on the lunar surface and that our natural satellite is 400,000 km away from our planet. A digital planetarium session about the phases of the Moon should take into account these misconceptions in order to properly initiate a conceptual shift from its viewers. A final aspect should be emphasized with regard to the teaching of the phases of the Moon: spatial skills. Spatial skills are a type of mental skill used by an individual to mentally treat objects in two and three dimensions (Palmer, 2007). These skills are necessary to master astronomical concepts such as the phases of the Moon (Black, 2005; Heyer et al., 2012; Kikas, 2006; Palmer, 2007; Plummer, 2014). It has been shown many times in the past that a session in a traditional planetarium encouraged the development of such skills (Black, 2005; Heyer et al., 2012; Kikas, 2006; Palmer, 2007; Plummer, 2014). Although several spatial skills exist, Black (2005) retains three that are more relevant in astronomy learning: spatial perception, spatial visualization, and mental rotation.

### IV. METHODOLOGY

Since the research aims to identify the elements and components of a learning session that are most important to the audience, it will be necessary to develop a session in a digital planetarium that can bring out elements specific to the digital environment. This development should be based on existing theories, but also allow some flexibility and evolution. This evolution will result in different implementation of the session. Following the comments of the spectators at the end of each implementation, the session will have to be modified and improved in order to be able to collect new data with new viewers. This type of methodology is very similar to design experiment (Cobb et al., 2003; Shavelson et al., 2003; Thouin, 2014; Van der Maren, 1996) also known as design-based research (Design-Based Research Collective, 2003). Design experiment is a type of applied research using various theories and aimed at solving problems arising from everyday practice (Van der Maren, 1996). Design experiment does not just produce a “grocery list”, but rather interactive systems (Cobb et al., 2003). This allows the production of design theories that can be adapted to new circumstances. Shavelson et al. (2003) describe design experiment as cyclic and based on seven characteristics: iterative, process focused, interventionist, collaborative, multileveled, utility oriented, and theory driven. In short, design research makes it possible to apply and study theories of teaching and learning in their environment while developing educational interventions and improving existing theories (Chastenay, 2013).

The strength of this type of research lies in its types of data and in the bridge it creates with the theory. The use of qualitative and quantitative data allows a triangulation that legitimizes the discoveries. The bridge it creates with the theory makes it possible to check the existing theories by applying them directly in the appropriate context. However, it is necessary to remain vigilant since this type of research places the researcher at the heart of the interventions and modifications of the implementations. Thus, an outside observer might question the legitimacy of pushing the approach in one direction or another (Design-Based Research Collective, 2003). Also, this type of research does not allow the researcher to control all variables (Design-Based Research Collective, 2003) and often, he will only focus on a few parameters. Despite these limitations, we believe that the benefits of using design experiment to create and improve an allocentric session in a digital planetarium far outweigh the disadvantages of this methodological approach.
To date, only the first implementation has been tested. It was presented on February 15, 2017 with about twenty 6th graders (11-12 years old) at the Montreal Planetarium. Several authors agree that the subject of the phases of the Moon is appropriate for this age group (Barnett et Morran, 2002; Kavanagh et al., 2005). Since we are at the first implementation and therefore still at an exploratory stage, we did not pass pre and post-test. The students were all from the same class and it was chosen according to the availability of the teacher, the author and the planetarium. The session was presented and commented live by the author of this paper. An audio recording was made of the session and the group interview that followed. This group interview was semi-directed and aimed at highlighting the elements that pleased or disturbed the participants. It was also a great opportunity to check their understanding of the lunar phases. Since the Montreal Planetarium lent its facilities for free, no fees had to be paid by the class.

V. PRELIMINARY RESULTS AND DISCUSSION

The verbatim analysis of the meeting was done in two different ways: pure inductive and inductive deliberative. As part of this work, pure inductive analysis aims to bring out the elements of the interview without relying on a theoretical framework while deliberative inductive analysis is based on the theoretical framework. In both cases, the Huberman et al. (1991) procedure was used for the analysis. This approach proposes to make two rounds of coding in order to bring out the essential of the verbatim. We used the QDA Miner Lite software to code the interview.

Six elements emerged from our analysis, three positive and three to improve. The three positive elements are: the space trip, the immersion and the allocentric point of view of the session. A positive element shared by the majority, if not the whole group, is the pleasure they had to feel in a spaceship and navigate through space. During the session, all the movements were done in a sequence shot. In our opinion, the fact that there is never a break contributes to the sense of presence and immersion. Without being mentioned directly, the allocentric point of view was another positive point. Among the many comments, we retain this one: “I liked that we could see other moons than ours, including those of Jupiter. And I liked that we could see from another point of view our Moon in space. I knew that the Earth had its phases but I did not know that it was the opposite of those of the Moon”. We can tell the student pleasure he had exploring different points of view, but also that these points of view have helped to teach him key elements to understanding the phases of the Moon.

The elements to be improved for the second implementation are the eclipses, the speed of displacement in rotation and the sounds. During the interview, even before the author asked the first question, one of the students raised her hand and asked, “But how is a solar eclipse formed?”. This first implementation does not deal with eclipses and obviously, it is an important missing element. Eclipses and lunar phases are intrinsically related concepts and should be presented together. Some students confided that they had been stunned and even nauseous during some rotational movement. It is therefore important to pay attention to the rotational movements so that they are more harmonious. Finally, this implementation included no sound or music. No evidence suggests that the absence of music was a negative factor, but the lack of sound was noted: “The noise would have helped us because we were sure we were taking off but sometimes it felt like things were moving around. You did not really feel in a spaceship and at other times you really felt like you were on a spaceship”. In short, incorporating engine noises as one travels through space would add to the feeling of presence and immersion. It would also contribute to a better understanding of the scenario and movements in a three-dimensional environment.

Thus, the next implementation of our lunar phases scenario will have to include a section dealing with eclipses, both lunar and solar, and reactor sounds as the “spaceship” moves. The section on eclipses should take full advantage of the allocentric point of view that the digital planetarium allows.
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