Spatial Perception of the Moon Phases: A Web-Based Module Employing Design Principles for Socio-Constructivist Learning and Scientific Visualization

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Abstract

The present research describes a web-based module we developed in order to assist middle school students to acquire the spatial abilities required for understanding the formation of the lunar phases. The pedagogical design of the module is based on a synthesis of the current knowledge in astronomy education and on design principles for computer-based learning environments. This research explores the effect of students' interaction with the module on the learning processes with a focus on their spatial perception of the moon phases phenomenon. Outcomes from enactment with 35 students indicated that students significantly improved their spatial perception of the moon-phases phenomenon. The simultaneous use of both physical computerized models, together with scaffolds, peer learning, and the teacher as a guide, were critical factors in supporting student learning.

This research enhances our understanding of the specific spatial abilities required for understanding the moon-phases phenomenon, and contributes design knowledge to the public Design-Principles-Database (http://www.edu-design-principles.org). On the practical side, the module, developed using WISE, can be used freely by students and teachers around the world.

Keywords: Astronomy Education; Scientific Visualization; Web-Based Simulations; Spatial Perception; Pedagogical Design-Principles.

Rationale and Goals

Understanding of topics in earth science curricula, such as seasonal cycles, eclipses and moon-phases, requires advanced cognitive skills and spatial perception. Research from the past decades indicate, that students from various cultures and ages have difficulties in understanding these basic astronomical phenomena and hold alternative conceptions, which they use for explaining their observations of astronomical phenomena (e.g.: Atwood & Atwood, 1996; Nussbaum & Novak, 1976; Stahly, Krockover & Shepardson,1999; Trumper, 2003). To understand astronomical phenomena one is required to build a mental model of the Sun-Earth-Moon system, and make complex mental manipulations on this model (Callison & Wright, 1993; Mualem & Nussbaum, 2002; Yair, Schur & Mintz, 2003).

To assist students in dealing with the cognitive challenges inherent in such topics, several physical and computerized models were developed in the past decades. Although several studies show specific affordances of such tools for supporting learning and instruction of basic astronomical phenomena (e.g.: Bakas & Mikropoulos, 2003; Barab et al., 2000; Barnett & Morran, 2002; Baxter & Preece, 2000; Gazit, Yair & Chen, 2005; Hansen, Barnett, MaKinster & Keating, 2004; Lightman & Sadler 1993; Mualem, 2001; Trundle, Atwood & Christopher, 2002), much remains to be revealed. Some questions that require more research include: What characterizes the specific spatial abilities involved in the understanding of astronomical phenomena in general, and the moon-phases in particular? What kind of pedagogical scaffolds are required to assist students in developing these abilities? Are there benefits of using physical and computerized models simultaneously for learning and instruction? What is the role of collaborative learning in the process of making sense of such models?

To provide answers to such questions, we developed a web-based module for middle school students. The module intends to assist students in acquiring the spatial abilities required for understanding the moon-phases. The pedagogical design of the unit is based on design principles for socio-constructivist learning and scientific visualization for computer-based learning environments found in the Design Principles Database (http://www.edu-design-principles.org) (Kali, 2006; Kali & Linn, in press). The research goals were:

1) To explore middle-school students' spatial perceptions of the moon-phases phenomenon.
2) To examine the effect of students' interaction with the module on these perceptions, with a focus on the effect of: a) Interweaving the use of physical and computerized models, b) supporting peer (collaborative) learning, c) scaffolding the development of the spatial perception.

Pedagogical Design of the Module

The moon-phases module was developed using the Web-based Inquiry Science Environment (WISE). WISE, developed at Berkeley (Linn, Clark & Slotta, 2003), includes a simple authoring environment, open for public use, which enables developing and running online inquiry modules.

The moon-phases module consists of five activities (2-3 periods each), in which students, working in pairs, progress at their own pace, while the teacher serves as a guide. The tasks in these activities include personally relevant problems that require students to make connections between the way the moon is seen from earth and the spatial configuration of the sun earth and moon (e.g.: figure 1). To assist students in solving these tasks they are provided with two scientific visualization tools: physical and computerized models. The physical model (Figure 3) includes a ball, which is painted half black and half white, representing the moon as viewed from earth. When rotating this model, students can see how phases of the moon can be formed from a half-illuminated ball. The computerized model (Figure 4) provides a view of the sun, earth and moon from space. Two linked views of the system are shown: one parallel to the ecliptic plane and the second perpendicular to the ecliptic plane (Figure 4). Figure 2 describes the five activities, and illustrates how we employed in them design principles from the Design Principles Database.

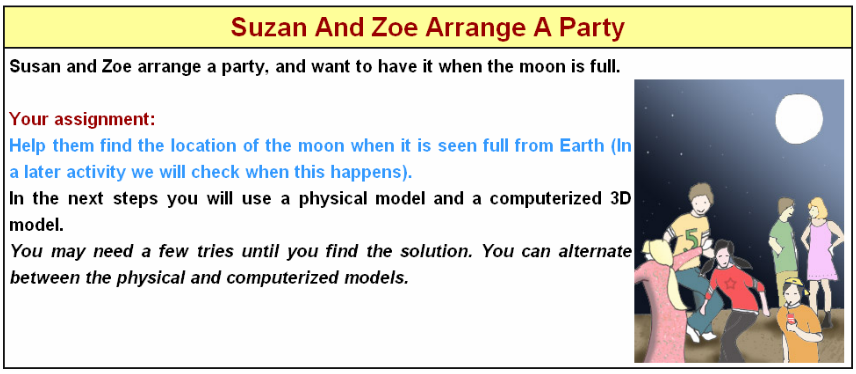
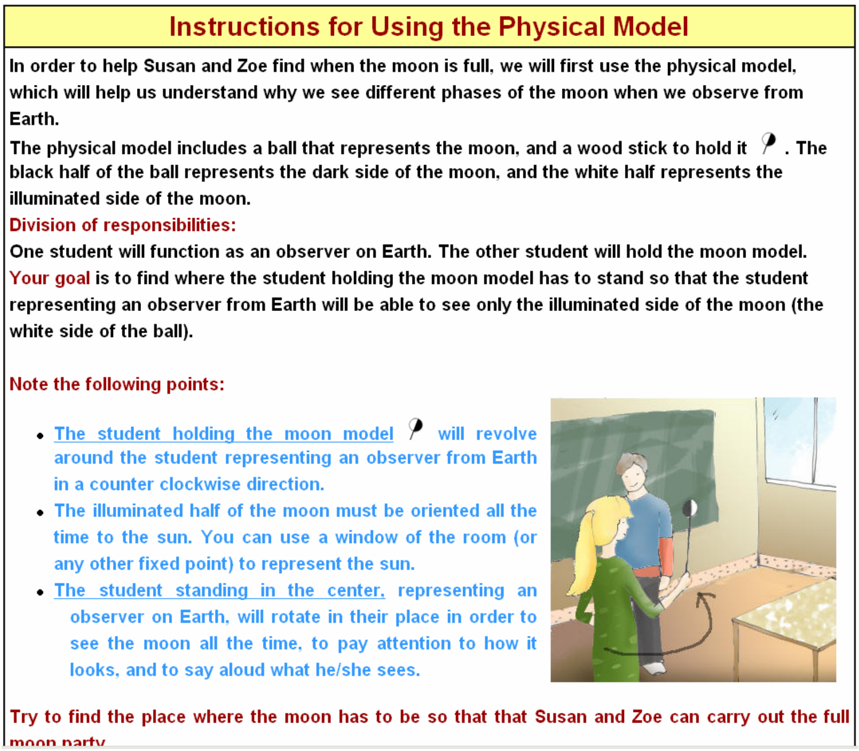


Figure 1. One of the "moon-phases stories" students select to explore

Sequence of activities	Design principles
Activity #1: Summary of our sky observations Students observe the moon-phases during one lunar month, arrange their findings in a digital calendar, and then discuss their initial ideas in an internet forum.	Provide visual representation tools of data collected by students
Activity #2: Let's explore one phase Students select one moon-phase to explore, by selecting one of the "moon-phase stories" in the activity. They use a physical and a computerized model (figures 3-4), scaffolded by guiding questions. At the end of the activity, they arrange their ideas using an interactive visualization tool.	* Provide dynamic visual aids and scaffolds for the perception of 3D phenomena
Activity #3: The moon-phases sequence Students explore additional moon-phases in a peer-instruction class activity. To summarize their findings they use a visual interactive tool (figure 5), in which they create an animation of the moon-phases sequence.	Provide knowledge representation and organization tools
Activity #4: Moon-phases and calendars Students explore how the Gregorian, Hebrew and Moslem calendars work, by finding the phase of the moon at their own birthday in the past six years. They use web-sites, which help them convert dates from one calendar to the other and find what the moon phase was in each.	Connect to personally relevant examples
Activity #5: Where did the moon disappear? Students explore sunrise and sunset, discuss initial ideas in an internet forum, and then use the computerized model with guiding questions to explore moonrise and moonset times.	Build on student ideas

* A design principle which emerged during the study, and was added to the database

Figure 2. The structure of the module and a design principle in each activity



Instructions for Using the Physical Model

In order to help Susan and Zoe find when the moon is full, we will first use the physical model, which will help us understand why we see different phases of the moon when we observe from Earth.

The physical model includes a ball that represents the moon, and a wood stick to hold it . The black half of the ball represents the dark side of the moon, and the white half represents the illuminated side of the moon.

Division of responsibilities:

One student will function as an observer on Earth. The other student will hold the moon model.

Your goal is to find where the student holding the moon model has to stand so that the student representing an observer from Earth will be able to see only the illuminated side of the moon (the white side of the ball).

Note the following points:

- The student holding the moon model will revolve around the student representing an observer from Earth in a counter clockwise direction.
- The illuminated half of the moon must be oriented all the time to the sun. You can use a window of the room (or any other fixed point) to represent the sun.
- The student standing in the center, representing an observer on Earth, will rotate in their place in order to see the moon all the time, to pay attention to how it looks, and to say aloud what he/she sees.

Try to find the place where the moon has to be so that that Susan and Zoe can carry out the full moon party

Figure 3. Instructions for using the physical model to explore the full moon phase

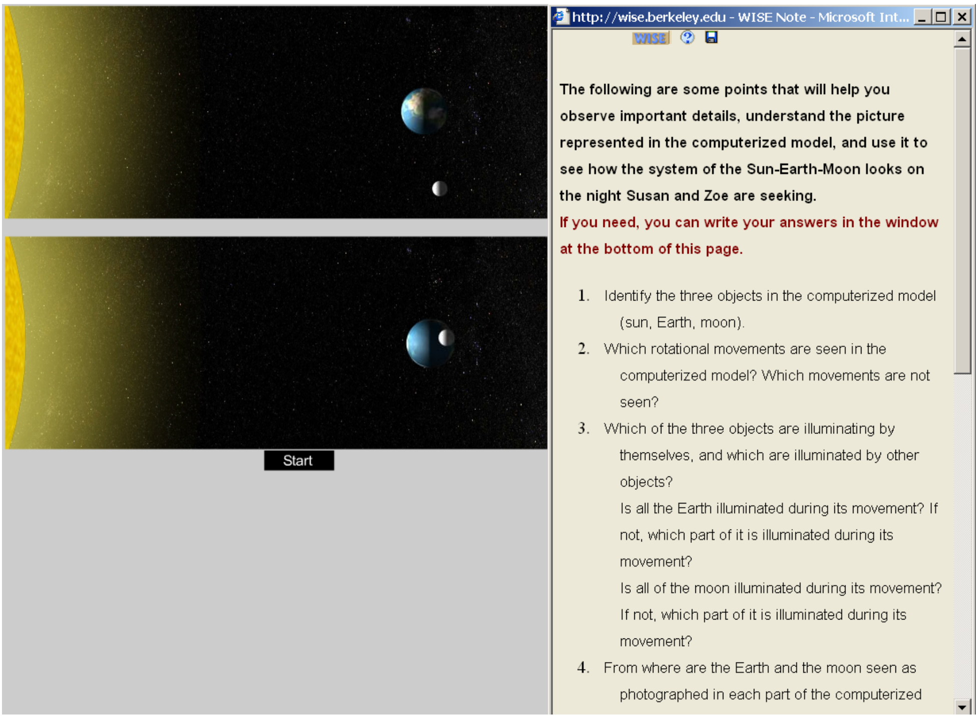


Figure 4. Guiding questions scaffolding the use of the computerized model

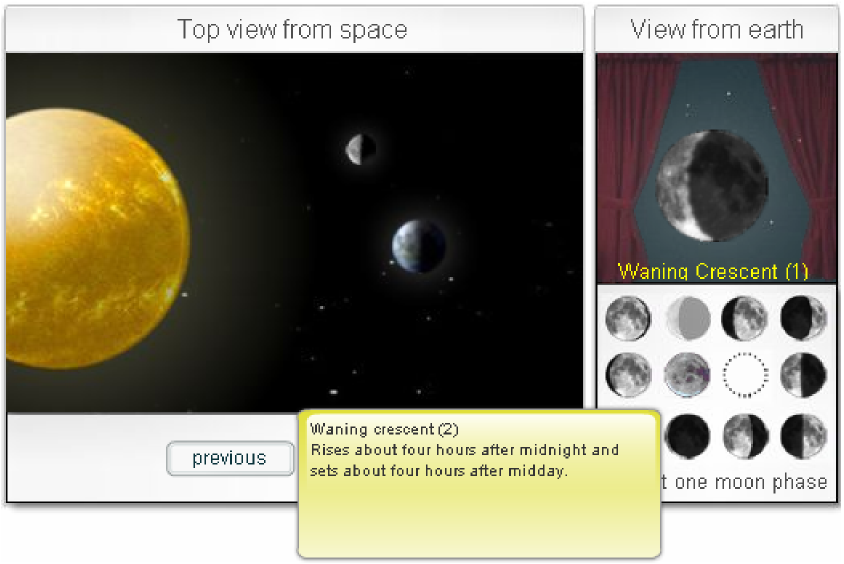


Figure 5. A visual interactive tool for the creation of an animation of the moon-phases sequence

Methods

The analysis was carried out using a mixed methods paradigm, which integrates quantitative and qualitative analyses (Morgan, 2007).

Sample

The research was conducted with 27 seventh-grade students, taught by a science teacher who volunteered to use the module. These students were the main resource for quantitative data collection (referred to as "classroom students"). The research also included four participatory observations of eight students (four pairs) from sixth to eighth grade, from various schools, who volunteered to study the module at our lab, from which we obtained rich qualitative analysis (referred to as "volunteer students"). During these observations, we were available to provide guidance, when needed, and asked questions to better understand the students' thinking process.

Data Sources and Tools

Table 1 summarizes the data sources and tools, the time when data was collected during the research, and participants from which the data was collected.

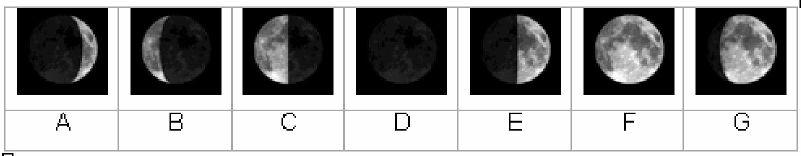
Table 1. Summary of the data sources and tools

Data Sources and Tools	Time collected	Participants
Pre and post tests with MPSAT. A Moon Phases Spatial Ability Test (MPSAT) consisting of two types of questions: three basic knowledge about the Sun-Moon-Earth system (For instance, which body revolves around the other), and six questions that require spatial perception of the moon phases phenomenon (e.g.: Figure 6). Paired T-tests were used for comparison between pre and post-tests, a two-sided alternative was taken, and the alpha level set at 0.05	Just before, and right after students' interaction with the module	All students
Observations	While working with the module in the classroom run	Classroom students
Video records of the participatory observations	While working with the module at our lab.	Volunteer students
WISE embedded notes and forums	Automatically saved on WISE servers while students work with the module.	All students
Reflective survey consisting of 11 questions about the extent to which students felt that the various features of the unit contributed to their understanding;	Few days after students' interaction with the module	Classroom students
Interviews that were intended to verify our interpretations of students' answers in the WISE embedded notes, and in the MPSAT.	The same day or few days after students' interaction with the module, and completing the post MPSAT.	2 students from the classroom students and 2 students from the volunteer students

Question #4:

The picture below shows a top view of the Sun-Earth-Moon system, showing 5 different positions of the moon orbiting around Earth.

For each position (1,2... 5), match one of the figures below (A,B... G), showing how the moon would be viewed from Earth in that position.



Do it by filling in the statements:

When the position of the moon is 1, the moon phase will be ____. (Write the correct letter).

When the position of the moon is 2, the moon phase will be ____.

When the position of the moon is 3, the moon phase will be ____.

When the position of the moon is 4, the moon phase will be ____.

When the position of the moon is 5, the moon phase will be ____.

Figure 6. Example question from the MPSAT which requires spatial perception

The findings and analysis

Quantitative analysis

The comparison between the pre and post MPSAT tests, obtained from 20 of the 27 classroom students who completed both the pre and post tests, indicates the following (Figure 7):

- Following their work with the module, students significantly improved their performance in questions 1, 3 (basic knowledge), and 4, 5 (spatial perception of the moon-phases). The improvement in questions 1 and 3 indicates that students gained basic knowledge about the sun-earth-moon system, required as a first step in understanding the moon-phases. However, we consider the improvement in question 4 and 5 to be far more important. These findings indicate that students developed their ability to make the mental manipulations required for understanding the connection between the moon phase, as seen from earth and the relative position of the sun, earth and moon. We view this ability as the core spatial ability required for understanding the phenomenon of the moon-phases.Students' understanding of the more complex aspects of the moon-phases phenomenon, i.e. moonrise and moonset, as indicated from question 8 and 9, did not improve in a significant manner.

Some of the above findings can be explained by the **qualitative analysis**. The data from the video records and observations of the volunteer students show that: .

- The physical and computerized model complement each other: students choose to use different models in different situations and use them intertwiningly. For instance, in several cases, students stopped the computerized model at a certain point, and checked what the phase of the moon would be using the physical model. We noticed several “aha!” points when students worked with both models.
- The scaffolding questions are critical for understanding the computerized model. Students who initially skipped these questions had difficulties to solve problems using the model. However, after answering the guiding questions, which served as scaffolds, they were more able to solve these problems.
- Students found it difficult to verbalize the moon-phases phenomenon. They tended to use drawings, hand waving and gestures to explain their ideas.
- The module encouraged peer learning: in many cases students negotiated their understanding with each other. This process was, to a large extent, supported by the guiding questions.
- The guidance provided by the researchers, which to a large extent resembles the way a teacher might guide students, was crucial.
- The different "moon-phases stories" motivated students to explore the phenomenon, and supported diverse learners. For instance, boys tended to choose the “Roy and Eli go to the pool at night” story, while girls tended to use the “Suzan and Zoe Arrange a Party” story.

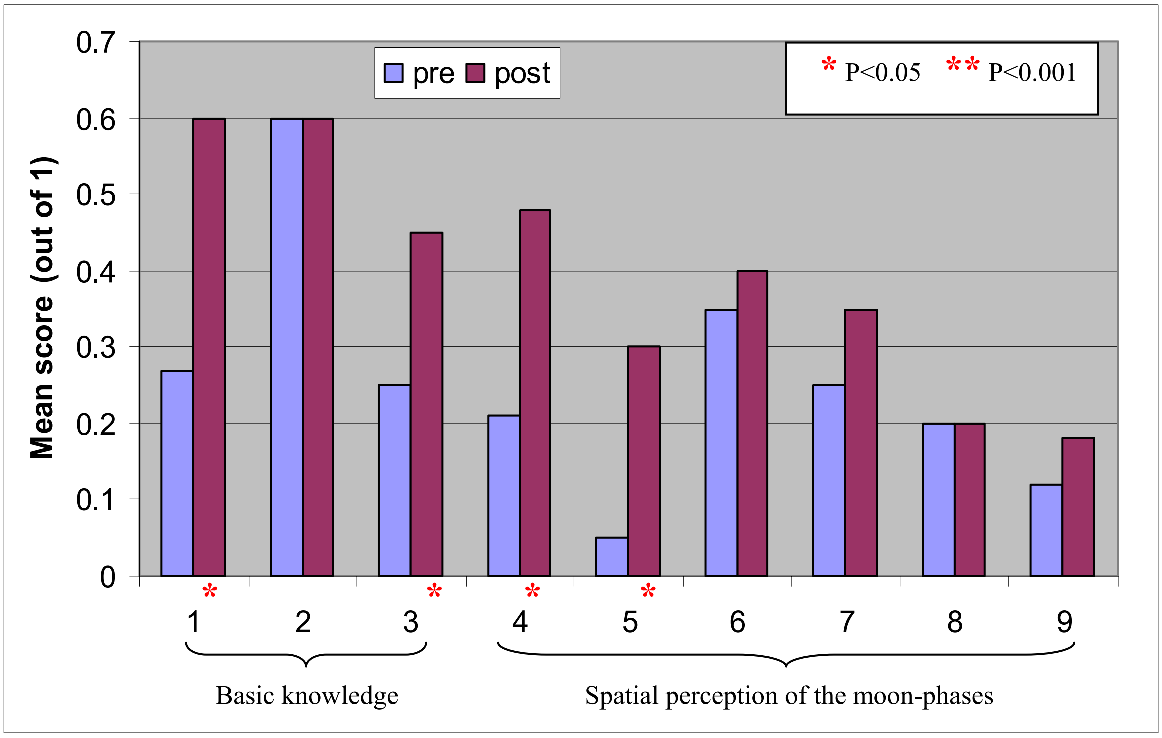


Figure 7. Comparison between pre- and post-tests with MPSAT

Theoretical and Practical Implications

This research may advance the body of knowledge about the way we can help middle-school students understand the moon phases phenomenon. In addition this research contributes to the current body of knowledge about the characterization of the specific spatial abilities required for understanding the moon-phases phenomenon. More research is required for understanding the relationship between these abilities, and more general, non-context-related spatial abilities. On the practical side, we have developed an effective learning tool, open for public use via WISE, which can serve students and teachers around the world. Additionally, by contributing new features and design principles to the Design Principles Database, this study may serve computer-based curriculum designers in other areas that require spatial abilities.

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