

Spatial Perception of the Moon Phases: Designing a Web-based Module for Middle-School Students

Rationale and Goals

Understanding of topics in earth science curricula, such as seasonal cycles and moon-phases, requires spatial perception. Research from the past decades indicate, that students at various ages have difficulties in understanding these basic astronomical phenomena and hold alternative conceptions (e.g.: Atwood & Atwood, 1996; Nussbaum & Novak, 1976; Trumper 2001b).

To assist students in dealing with the cognitive challenges inherent in such topics, several physical and computerized models have been 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.: Barab et al., 2000b; Gazit, Yair & Chen, 2005; Stahly, Krockover & Shepardson, 1999; Mualem, 2002), much remains to be revealed. Some questions that require more research include:

- What characterizes the specific spatial abilities involved in the understanding astronomical phenomena in general, and the moon-phases in particular?
- What kind of scaffolds are required to assist students develop these abilities?
- What are the 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 is intended to assist students to acquire the spatial abilities required for understanding the moon-phases. The pedagogical design of the unit is based on socio-constructivist design principles for computer-based learning environments found in the Design Principles

Database (<http://www.design-principles.org>) (Kali, 2006; Kali & Linn, in press).

Research goals were:

- 1) To explore middle-school students' spatial perceptions with regards to 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 learning, c) scaffolding the development of the spatial perception.

Theoretical Background

Students from various cultures and ages hold alternative frameworks, which they use for explaining their observations of astronomical phenomena (e.g.: Bakas & Mikropoulos, 2003; Callison & Wright, 1993; Trundle, Atwood & Christopher, 2002). Children can only observe these phenomena from earth and develop a geocentric perception of the universe (Keating, Barnet, Barab & Hay, 2002). Astronomical phenomena are three-dimensional, dynamic, and occur in large-scale space and time. Understanding these phenomena requires spatial abilities because the observer cannot observe the entire system contemporaneously. To understand astronomical phenomena one is required to build a mental model, and make complex mental manipulations on this model (Mualem & Nusbaum, 2002; Yair, Mintz & Litvak, 2001).

These issues make astronomy a challenging educational topic. Many textbooks fail to deal with the cognitive difficulties involved. Textbooks, due to their static two-dimensional nature, are in many cases insufficient for providing the scaffolds students need to understand astronomical phenomena (Barab et al., 2000a; Mualem & Nusbaum, 2002; Parker & Heywood, 1998).

Table 1 summarizes research findings from 12 studies that have explored the use and effect of physical and computerized models on student learning. The table shows that these instructional aids have the potential to develop student understanding of astronomical phenomena. However, it also shows that there are certain gaps which require further research in this field.

Table 1: Research findings from studies, that have explored the use and effect of physical and computerized models on student learning of astronomical phenomena.

Physical/computerized	Learning aids	Research	Focus of research and participants	Main conclusions and implications	
Physical aids	3D aids such a ball representing the moon or the earth, and 2D aids such as diagrams	Mualem, 2002	<ul style="list-style-type: none"> The effect of learning with physical models on students' spatial abilities and on their conceptions with regards to the seasons phenomena. (middle school students) 	<ul style="list-style-type: none"> Instruction should use 3D aids in order to support students in developing significant understanding of astronomical phenomena. 	
		Callison & Wright, 1993; Stahly et al. 1999; Trundle et al., 2002	<ul style="list-style-type: none"> The connection between the use of physical models and the development of understanding of astronomical phenomena (elementary school students; teachers). 	<ul style="list-style-type: none"> Activities including physical models contribute to understanding compared with lectures, although some models may cause confusion. More research about the effect of these activities is needed. 	
Computerized aids	2D computerized simulation	Baxter & Preece, 2000	<ul style="list-style-type: none"> The effect of learning via a dome planetarium (a physical planetarium) versus learning via a computerized planetarium on student understanding of astronomical phenomena. 	<ul style="list-style-type: none"> Findings showed no significant differences between the effectiveness of the two planetaria; A computerized planetarium can be an effective alternative to a dome planetarium. More research is required for understanding the effect of interaction with computerized graphics on student understanding of topics that require spatial abilities. 	
	3D computerized interactive model	Barnet & Moran, 2002	<ul style="list-style-type: none"> Students conceptual change of astronomical phenomena when the curriculum engage them in discussing, reflecting and articulating their evolving understanding .(fifth grade students) 	<ul style="list-style-type: none"> Instruction should engage students in reflection and discussions about their understandings. 	
	Non-immersive virtual solar system	Gazit, Yair & Chen, 2005	<ul style="list-style-type: none"> Characterization studentns' learning processes while interaction with a computerized virtual solar system (tenth grade students) 	<ul style="list-style-type: none"> All participants developed a scientific understanding of the day-night phenomena, but students also developed alternative misconceptions of the earth-moon-sun system. Scaffolds and guided reflection are required for students learning with this environment. 	
			Bakas & Mikropoulos, 2003	<ul style="list-style-type: none"> The effect of the interaction with a virtual reality computerized solar system on understanding the day-night phenomenon (students years 12-13) 	<ul style="list-style-type: none"> Most of the students overcame their misconceptions about the day-night phenomena and the seasons.
			Barab et al., 2000a; Barab et al., 2000b	<ul style="list-style-type: none"> The effect of participatory learning via constructing computerized 3D models of the Solar System on understanding basic astronomical phenomena. Characterizing pedagogical issues of the learning process (role of teacher and technology; group dynamics; modeling process) 	<ul style="list-style-type: none"> 3D technologies should be integrated in the curriculum of science topics
			Keating et al., 2002;	<ul style="list-style-type: none"> Characterization of the type of conceptual understanding which can be developed by construction of 3D models. 	<ul style="list-style-type: none"> Students who learned in the VSS course improved their conceptual understanding of basic astronomical phenomena.
Virtual Reality learning environment for the construction of 3D computerized models (the VSS project for undergraduate students)	Hansen, Barnett, MaKinster& Keating, 2004a, 2004b	<ul style="list-style-type: none"> Comparison of the effect on learning between 20 graduate students who built computerized 3D models of astronomical phenomena, and 13 students who participated in a lecture-based course about the same topics. 	<ul style="list-style-type: none"> Construction of 3D models helped students develop spatial understandings, whereas traditional instruction helped students develop declarative knowledge. More research is needed to examine the potential of constructing 3D models on students' understanding of various scientific phenomena and in other situations 		

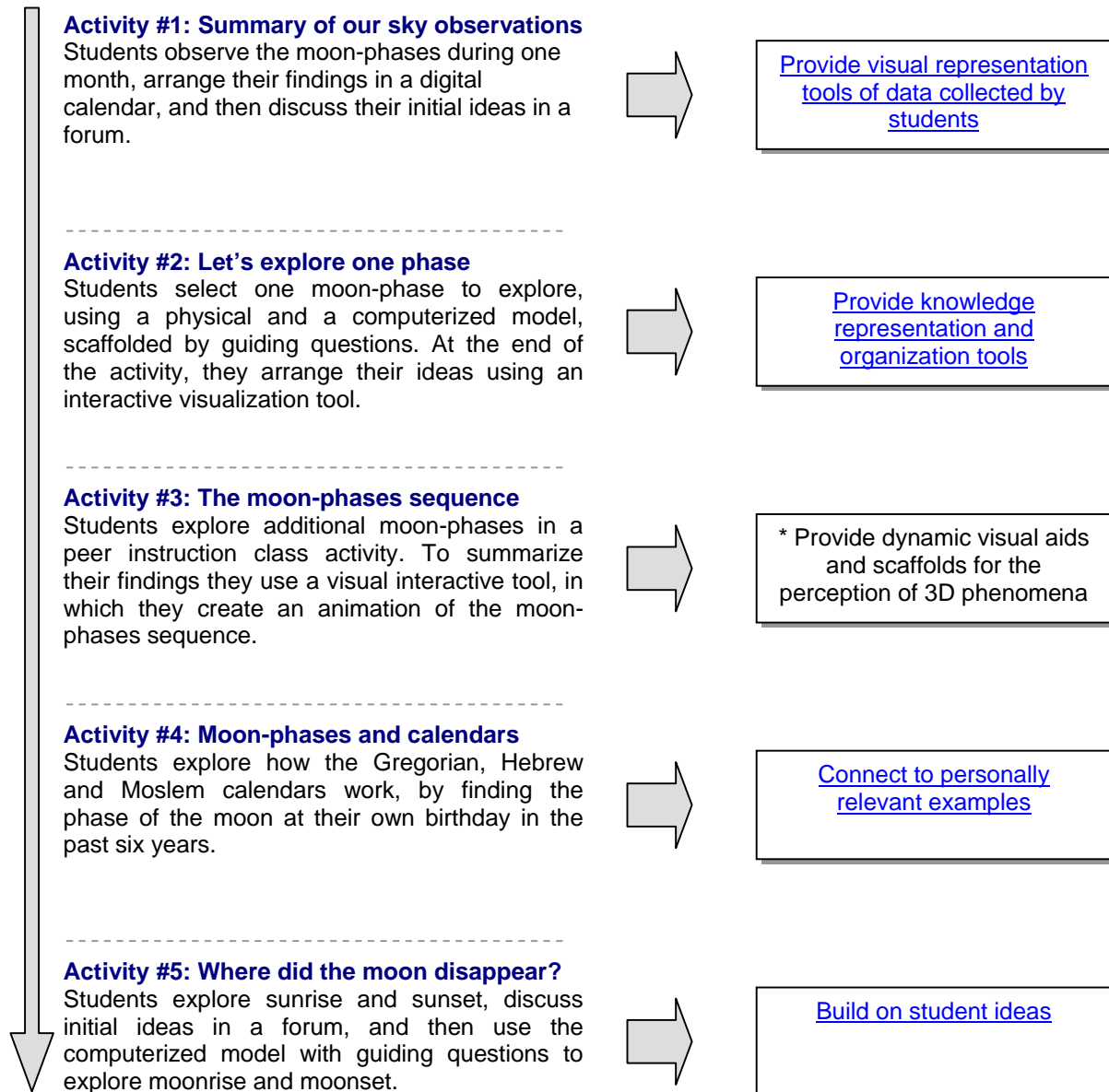
Pedagogical Design of the Module

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 in their own pace, while the teacher serves as a guide. In this section, we describe the five activities, and illustrate how they employ design principles from the Design Principles Database. Figure 1 summarizes the structure of the module and one design principle in each activity.

Sequence of activities

Design principles



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

Figure 1: The structure of the module and a design principle in each activity

First Activity: Summary of our Sky Observations

Students observe the moon-phases during one month, arrange their findings in a digital calendar (Figure 2). Following this stage, students discuss their initial ideas in a forum.

One design principle employed in this activity is “[Provide visual representation of data collected by students](#)”. This principle calls for creating tools that enable students to represent data they collect in ways that can assist them to recognize patterns in their data. Such tools can decrease the workload and help students focus on the contents.

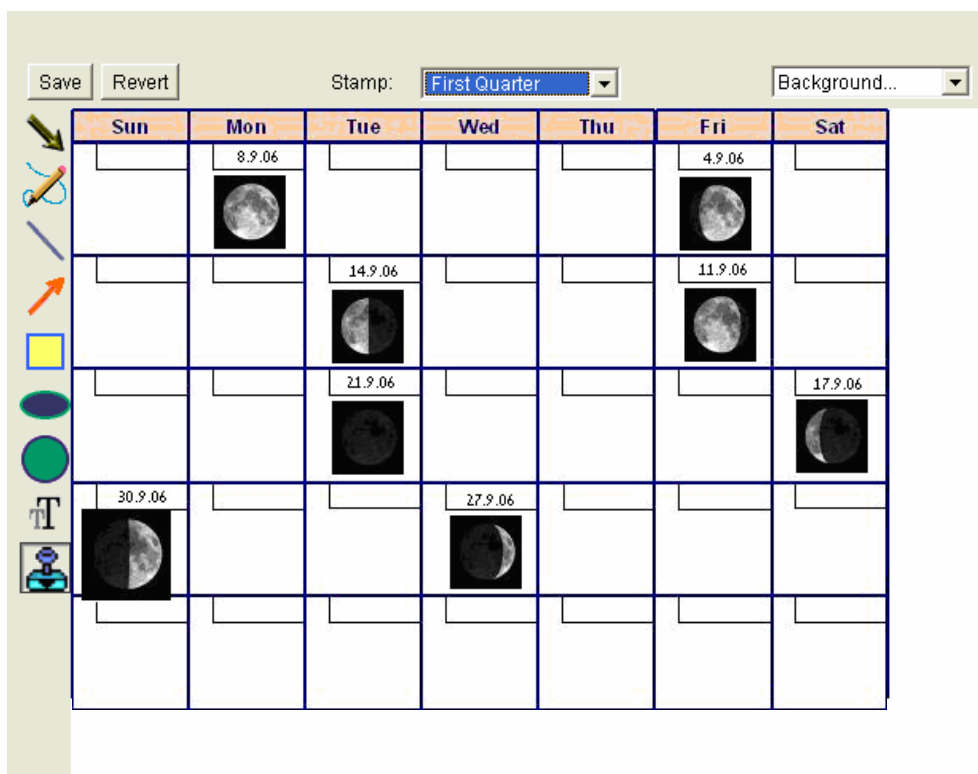


Figure 2: A digital calendar for arranging students observations of the moon

Second activity: Let's Explore One Phase

Students select one moon-phase to explore, by selecting one of the “moon-phase stories” in the activity. For instance, they can choose to “Help

Suzan and Zoe find when they can have a full-moon party”. The exploration is conducted using two models, one physical and the other computerized. Each of the models is a different representation of the Sun-Earth-Moon system, and represents the phenomenon from a different perspective. The use of the models is scaffolded by guiding questions (Figure 3).

A design principle this activity uses is “**Provide dynamic visual aids and scaffolds for the perception of 3D phenomena**”. Visual aids, physical and computerized, have the potential to assist students understand three-dimensional phenomena. However, in many cases, especially when complex phenomena are involved, these aids are hard to use (Gazit, Yair & Chen, 2005). This design principle emphasizes the importance of providing scaffolds for supporting students with various spatial abilities to use these aids.

The following are some points that will help you observe important details, understand the picture represented in the computerized model, and use it to see how the system of the Sun-Earth-Moon looks on the night Susan and Zoe are seeking.

If you need, you can write your answers in the window at the bottom of this page.

1. Identify the three objects in the computerized model (sun, Earth, moon).
2. Which rotational movements are seen in the computerized model? Which movements are not seen?
3. Which of the three objects are illuminating by themselves, and which are illuminated by other objects?
Is all the Earth illuminated during its movement? If not, which part of it is illuminated during its movement?
Is all of the moon illuminated during its movement?
If not, which part of it is illuminated during its movement?
4. From where are the Earth and the moon seen as photographed in each part of the computerized

Figure 3: Guiding questions scaffolding the use of the computerized model

Third activity: 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, in which they create an animation of the moon-phases sequence (Figure 4).

A design principle applied in this activity is “[Provide knowledge representation and organization tools](#)”. To integrate pieces of knowledge, students need tools, which can help them represent and organize their ideas. Such tools enable students to make their thinking visible to themselves, their peers and instructors, and promote knowledge integration (Linn & Hsi, 2000).

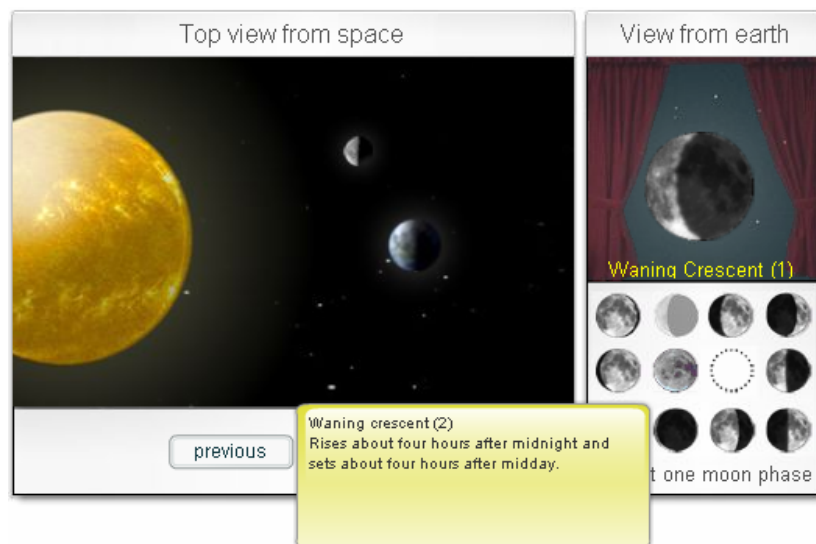


Figure 4: A visual interactive tool for the creation of an animation of the moon-phases sequence

The fourth activity: 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 (Figure 5).

This activity realizes the design principle “[Connect to personally relevant examples](#)”. Relevant examples encourage students to connect new concepts to their everyday lives. Such connections promote understanding rather

than rote learning (Linn & Hsi, 2000; Linn, Davis & Bell, 2004; Bransford, Brown & Cocking, 1999).

Let's check whether the same moon phase has appeared every year on your birthday according to the Gregorian calendar

Does the same moon phase reappear every year on your birthday? In order to find out, go back to NASA's site (check if the site is already open on your screen)
<http://liftoff.msfc.nasa.gov/Academy/UNIVERSE/MOON.html>

This time check the moon phases on your birthday for the last five years (this year, last year, and the three years before that).

Fill in the moon phases in the table below (scroll down the page if needed).
 Use the phases names that you learned in the first activity:



New Moon Waxing crescent First Quarter Waxing Gibous Full Moon Waning Gibbous Last Quarter Waning Crescent

After you finish filling in the table, save your work by clicking on the "Save and Do Calculations" button.
 Leave the site open after you finish this task.

Were the moon phases on your birthdays identical for the last five years?

A	B	C
1	Year	Moon phase on my birthday in Gregorian calendar
2	When I was born	<input type="text"/>
3	last year	<input type="text"/>
4	2 years ago	<input type="text"/>
5	3 years ago	<input type="text"/>
6	4 years ago	<input type="text"/>
7	5 years ago	<input type="text"/>

Figure 5: Students explore the Gregorian calendar by finding the moon-phases at past birthdays

Fifth activity: Where did the moon disappear?

Students explore sunrise and sunset, discuss initial ideas in a forum, and then use the computerized model with guiding questions to explore moonrise and moonset.

A design principle used here is "[Build on student ideas](#)". This principle is one of the basic principles of constructivism. It emphasizes the importance of encouraging students to build on their own ideas, and to connect new information to existing knowledge (Linn et al., 2004). The forum encourages students to discuss their initial ideas before they begin to study the topic.

Methods

This research is conducted in a design-based research approach, which emphasizes lessons learned from an iterative design process (Barab & Squire, 2004; Bell, Hoadly & Linn, 2004; Collins, Joseph & Bielaczyc, 2004; The Design-Based research Collective, 2003). In this spirit, the current research involved three iterations of design, implementation, analysis, and refinement. The analysis was carried out using a mixed methods paradigm, which integrates quantitative and qualitative analyses (Morgan, 2007). We report here on the first iteration of the study.

Sample

The first iteration 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”). This iteration 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, one of the researchers was available to answer students’ questions. The researcher also occasionally stopped the students to provide guidance, when needed, and asked questions to better understand students’ thinking.

Data Sources and Tools

Table 2 summarizes the data sources and tools, the time when data was collected during the research, and participants from which the data was collected.

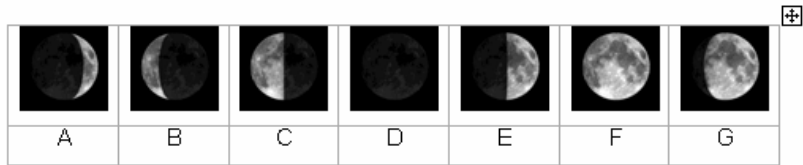
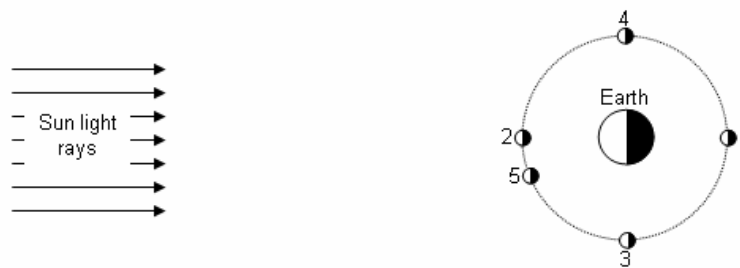
Table 2: Summary of the data sources and tools

Data Sources and Tools	Time collected	Participants
<p>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</p>	<p>Just before, and right after students' interaction with the module</p>	<p>All students</p>
<p>Observations</p>	<p>While working with the module in the classroom run</p>	<p>Classroom students</p>
<p>Video records of the participatory observations</p>	<p>While working with the module at our lab.</p>	<p>Volunteer students</p>
<p>WISE embedded notes and forums</p>	<p>Automatically saved on WISE servers while students work with the module.</p>	<p>All students</p>
<p>Reflective survey consisting of 11 questions about the extent to which students felt that the various features of the unit contributed to their understanding;</p>	<p>Few days after students' interaction with the module</p>	<p>Classroom students</p>
<p>Interviews that were intended to verify our interpretations of students' answers in the WISE embedded notes, and in the MPSAT.</p>	<p>The same day or few days after students' interaction with the module, and completing the post MPSAT.</p>	<p>2 students from the classroom students and 2 students from the volunteer students</p>

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

Preliminary Outcomes

Quantitative analysis

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

- Following their work with the module, students significantly improved in questions 1, 3 (basic knowledge), and 4, 5 (spatial perception of the moon-phases). The improvements 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 improvements in question 4 and 5 as far more important. These finding 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. The difficulty is because understanding the phenomenon requires understanding the connection between the observer position relative to the sun and his position relative to the moon.

Some of the above findings can be explained by the qualitative analysis:

Quantitative analysis of the pre and post tests of the volunteer students, that these students significantly improved their spatial perception of the moon-phases following the interaction with the module. The qualitative analysis shows the following:

- 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 did not read and answer 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. Students needed more scaffolds in order to make correct observations and promote their understanding.
- 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.

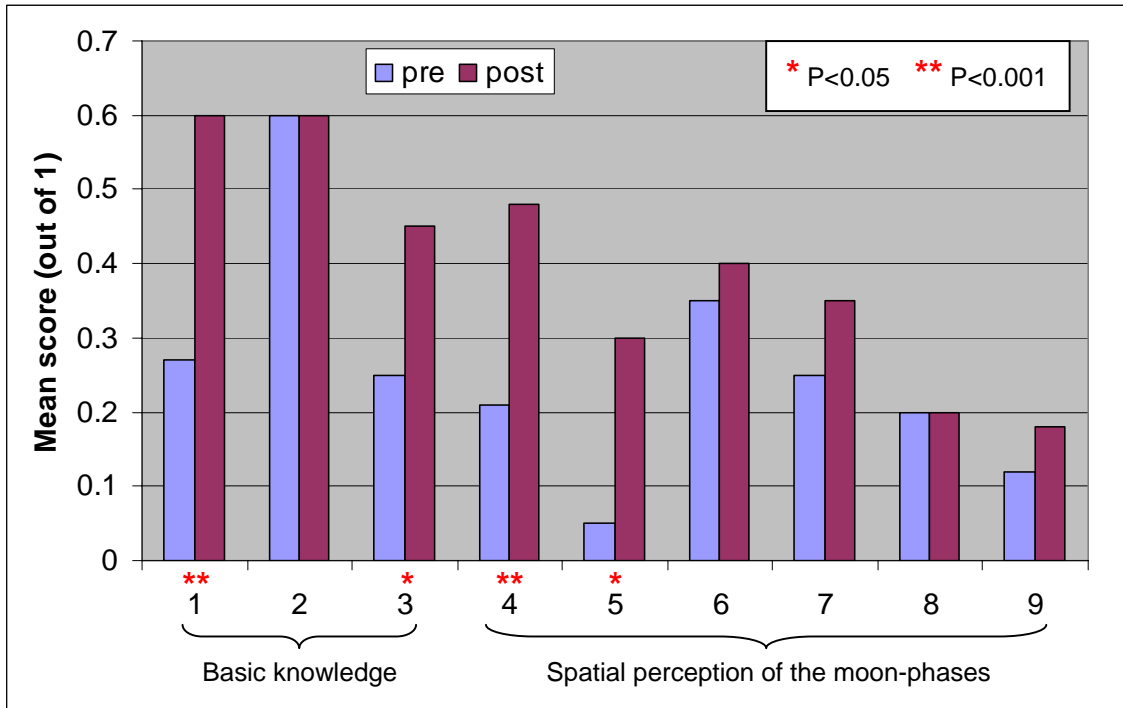


Figure 7: Comparison between pre and post tests with MPSAT

Theoretical and Practical Implications

This research 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.

References

- Atwood, R.K., & Atwood, V.A. (1996). Preservice elementary teachers' conceptions of the causes of seasons. Journal of Research in Science Teaching, 33(5), 553-563.
- Bakas, C., & Mikropoulos, T.A. (2003). Design of Virtual Environments for the Comprehension of Planetary Phenomena Based on Students' Ideas. International Journal of Science Education, 25(8), 949-967.
- Barab, A.B., Hay, K.E., Barnett, M., & Keating, T. (2000a). Virtual Solar System Project: Building Understanding through Model Building. Journal of Research in Science Teaching. 30(7), 719-756.
- Barab, S. & Squire, K. (2004). Design-based research: Putting a stake in the ground. Journal of the Learning Sciences, 13(1), 1-14.
- Barab, S.A., Hay, K.E., Squire, K., Barnett, M., Schmidt, R., Karrigan, K., Yamagata-Lynch, L. & Johnson, C. (2000b). Virtual Solar System Project: Learning Through a Technology-Rich, Inquiry-Based, Participatory Learning Environment. Journal of Science Education and Technology, 9(1), 7-25.
- Baxter, J.H. & Preece, P.F.W. (2000). A comparison of dome and computer planetaria in the teaching of astronomy. Research in Science and Technological Education, 18(1), 63-69.
- Bell, P., Hoadley, M.C., Linn, M. Design-based Research in Education. In: Linn, M., Davis, E.A., & Bell, P. (Eds) (2004). Internet Environments for Science Education.
- Bennett, M. & Morran, J. (2002). Addressing Children's Alternative Frameworks of the Moon's Phases and Eclipses. International Journal of Science Education, 24(8), 859-79.
- Bransford, J.D., Brown, A.L. & Cocking, R.R. (1999). How People Learn: Brain, Mind, Experience, and School. National Academy Press, Washington, DC.
- Callison, Priscilla, L., and Wright, Emmett L. (1993) The effect of teaching strategies using models on Preservice elementary teachers' conceptions about Earth-Sun-Moon Relations. Paper presented at the Annual meeting of the National Association for Research in Science Teaching, Atlanta.
- Collins, A., Joseph, D. & Bielaczyc, K. (). Design Research : Theoretical and Methodological Issues. Journal of the Learning Sciences, 13(1), 19-32.
- Gazit, E., Yair, Y. & Chen, D. (2005). Emerging Conceptual Understanding of Complex Astronomical Phenomena by Using a Virtual Solar System. The Journal of Science Education and Technology, 14(5-6), 459-470.
- Hansen, J.A., Barnett, M., MaKinster, J.G. & Keating, T. (2004a) The Impact of Three-Dimensional Computational Modeling on Students Understanding of Astronomy

- Concepts: A Qualitative Analysis. International Journal of Science Education, 26(13), 1555-1575.
- Hansen, J.A., Barnett, M., MaKinster, J.G. & Keating, T. (2004b) The Impact of Three-Dimensional Computational Modeling on Students Understanding of Astronomy Concepts: A Quantitative Analysis. International Journal of Science Education, 26(11), 1365-1378.
- Kali, Y., & Linn, M.C. (in press). Technology-enhanced support strategies for inquiry learning, in Spector, J. M., Merrill, M. D., van Merriënboer J. J. G., & Driscoll, M. P. (Eds.) (in progress). Handbook of Research on Educational Communications and Technology (3rd ed.). Lawrence Erlbaum Associates.
- Kali, Y., (2006). Collaborative knowledge-building using the Design Principles Database. International Journal of Computer Support for Collaborative Learning, 1(2), 187-201.
- Keating, T., Barnett, M., Barab, S.A. & Hay, K.E. (2002). The Virtual Solar System Project: Developing Conceptual Understanding of Astronomical Concepts Through Building Three-Dimensional Computational Models. Journal of Science Education and Technology, 11(3), 261-275.
- Linn, M.C. & Hsi, S. (2000). Computers, Teachers, Peers: Science Learning Partners. Lawrence Erlbaum Associates, Inc., Publishers, Mahwah, NJ.
- Linn, M.C., Clark, D. & Slotta, J.D. (2003). Wise Design for Knowledge Integration. Science Education 87(4), 517-538.
- Linn, M.C., Davis, E.A., & Bell, P. (2004). Internet Environments for Science Education. Mahwah, NJ: Erlbaum.
- Morgan, D.L. (2007). Paradigms Lost and Pragmatism Regained – Methodological Implications of Combining Qualitative and Quantitative Methods. Journal of Mixed methods Research, 1(1), 2007.
- Mualem, R. & Nusbaum, Y. (2002). Earth in Space: Activities and Conceptions, Teacher Manual. Weizmann Institute of Science.
- Mualem, R. (2002). Development and implementation of an astronomy learning unit “Earth in space”, and examination of its effect on understanding of the seasons of the year. Unpublished thesis. Weizmann Institute of Science (In Hebrew).
- Nussbaum, J. & Novak, J.D. (1976). An Assessment of Children’s concepts of the Earth Utilizing Structured Interviews. Science Education, 60(4), 535-550.
- Parker, J. and Heywood, D. (1998). The Earth and beyond: Developing primary teachers’ understanding of basic astronomical events. International Journal of Science Education, 20, 503-520.
- Stahly, L., Krockover, G.H. & Shepardson, D.P. (1999). Third Grade Students’ Ideas

- about the Lunar Phases. Journal of Research in Science Teaching, 36(2), 159-177.
- The Design-Based Research Collective (2003). Design-Based Research: An Emerging Paradigm for Educational Inquiry. Educational Researcher, Vol. 32, No. 1, pp. 5–8.
- Trumper, R (2001b). A Cross-Age Study of Junior High School Students' Conceptions of Basic Astronomy Concepts. International Journal of Science Education, 23(11), 1111-1123.
- Trundle, K.C., Atwood, R.K & Christopher, J.E. (2002). Preservice elementary teachers' conceptions of moon phases before and after instruction. Journal of Research in Science Teaching, 39(7), 633-658.
- Yair, Y., Mintz, r. & Litvak, S. (2001). 3D-virtual reality in science education: An implication for astronomy teaching. Journal of Computers in Mathematics and Science Teaching, 20(3), 293-305.