AN INTERACTIVE SIMULATION TO EVALUATE STUDENT UNDERSTANDING OF MOON PHASE FORMATION

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ABSTRACT
The development of student understanding of phases of the moon is notoriously difficult due to the spatial reasoning requirements posed by the relative motion of three celestial bodies. We have used the Greek version of Physics by Inquiry to develop two alternative three-body models with a class of prospective elementary teachers. At the end of the semester we used a computer-based evaluation instrument that we developed in order to assess student understanding of the formation of the phases of the moon as well as the evidence on which students base their models. In this paper, we discuss the design of the simulation software and the interpretation of the assessment results we obtained in the context of this application.

KEYWORDS
Simulations, moon phases, evaluation, inquiry, astronomy

1. INTRODUCTION

Natural science is the process of understanding the real world. This understanding can be developed through information processing, experimentation and application of scientific reasoning. Formal teaching of the natural sciences aims to develop students' understanding of the natural phenomena in the real world and to enable students to develop scientific thinking skills and autonomous learning habits. It is well documented that currently the teaching of science does not always help students to achieve these goals. One possible cause of this failure is the poor understanding on the part of the teachers themselves of scientific concepts and the mechanisms underlying physical phenomena.

In order to improve their knowledge, pre-service and in-service teachers take science courses that are designed to help them develop scientific models of the natural world and effective teaching approaches. Shulman believes that an effective teacher is not only familiar with, but also understands thoroughly the fundamental scientific concepts [1]. Understanding comes through individual construction of meaning, and is based on first hand observations obtained through experimentation with the real world. Using a combination of evidence and logical thinking, the science learner constructs models that have the ability to explain the phenomenon and to make valid predictions. Such models are not static, but they change dynamically according to new evidence the learner receives from the real world.

Astronomy appears in many science curricula worldwide. The topics that are most commonly emphasized are the following: the earth's shape, the day/night cycle, the phases of the moon, the formation of the seasons, naked eye observation of the stars. In the Cypriot educational system, basic astronomical topics appear in the national curriculum in the context of both science and geography from grade 4 (10 year olds) upwards. The science teacher preparation program at the University of Cyprus includes two compulsory science content courses, one science methods course and three optional science specialization courses, including one in communication and information technology tools in science. The compulsory science content courses currently implement the Greek version of *Physics by Inquiry* [2]. In the first content class one of the modules that is taught is *Astronomy by Sight* and this includes a unit on *Phases of the Moon*. The course is taken by around 70 pre-service elementary teachers at any one time. In the context of this unit, they construct models about the Earth's shape, the phenomenon of the day/night cycle and the phases of the moon. In this article, we describe the design of a simulation environment for evaluating student understanding of moon phase formation.

2. BACKGROUND

2.1 STUDENT UNDERSTANDING OF MOON PHASE FORMATION

Moon phases is the name given to the different shapes of the moon as they appear in the sky over a period of roughly one month. The causal mechanism of this variation in the apparent shape of the moon is the amount of the illuminated part of the moon that is visible from the earth at any one time.

The moon is an externally illuminated celestial body that orbits around the earth once every twenty-nine days. During the whole of this orbit, which has the same sense as the earth's rotation around its axis, only half of the moon is illuminated, always by the sun. An observer from earth can see a varying portion of the illuminated half of the moon each day. In this way, the position of the moon relative to the earth and the sun gives rise to the phenomenon we call phases of the moon.

The relative motion of the moon and the earth is such that if someone is observing the moon from the north pole, s/he believes that it is moving counterclockwise, but if s/he is observing it from the south pole he/she believes that it is moving clockwise. The times for moonrise and moonset differ according to the moon phase. For example, at new moon, the moon forms an angle of about 180 degrees with the sun and the earth and moonrise is at around 6:00 a.m. (Figure 1).

Previous research with elementary school students, has identified the following alternative models described by children in their effort to come up with an explanation of the formation of the phases of the moon [3,4]:

1. Clouds in the sky hide the moon, or a part of the moon, so we cannot see it.
2. The sun's or some planets' shadow hides the moon, or a part of the moon, so we cannot see it.

3. The sun moves around the earth and the moon and the earth are in the same line. As the sun's position changes, the earth casts its shadow on the moon, hiding all or part of it.

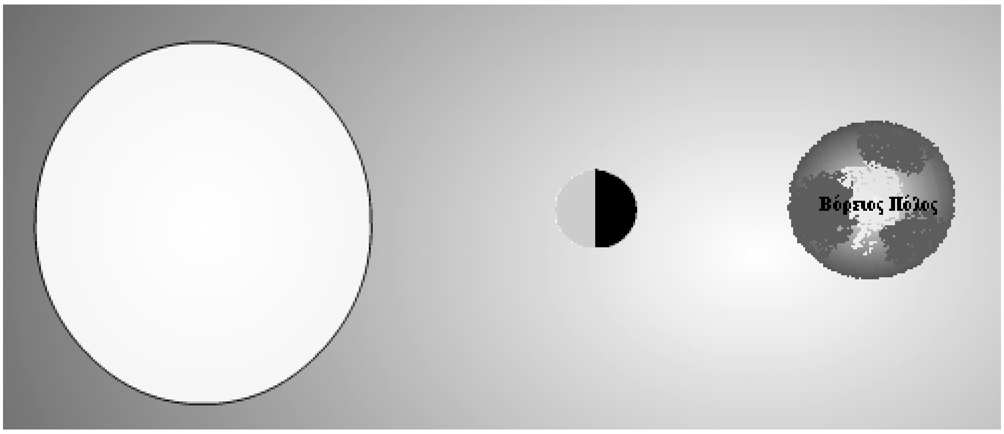

Figure 1
The relative positions of the earth, moon and sun at the time of new moon (two-dimensional projection).

Such alternative models are also often held by teachers [5]. Parker and Heywood [1] ascribe this to conceptual and reasoning difficulties, particularly with spatial representation, encountered by teachers in their effort to make meaning about the phases of the moon. Teachers find it particularly difficult to visualize in three dimensions the relative motion of the moon, the sun and the earth.

According to Parker and Heywood [1], very few of the pre-service teachers they worked with demonstrated understanding that approached the scientific model of moon phases (9.8%), some did not show evidence of any understanding (12,2%), and the rest (78%) could provide some response to the tasks without being in a position to explain their reasoning. In another study, Trumper [5] found that 51% of pre-service teachers gave a correct response, but 31% answered that the phases are caused by the moon entering the earth's shadow. In this latter work, explanations of reasoning were not required.

2.2 PHYSICS BY INQUIRY

Physics by Inquiry [2] is a set of laboratory-based modules that provide a step-by-step introduction to physics and the physical sciences. *Physics by Inquiry* has been designed for courses in which the primary emphasis is on discovering rather than on memorizing and in which teaching is by questioning rather than by telling. During implementation, we allow time for open-ended investigations, dialogues between the instructor and individual students, and small group discussions. A major goal is to help students think of physics not as an established body of knowledge, but rather as an active process of inquiry in which they can participate [6]. Through in-depth study of simple physical systems and their interactions, students gain direct experience with the process of science. Starting from their own observations, students develop basic physical concepts, use and interpret different forms of scientific representations, and construct explanatory models with predictive capability. All the modules have been explicitly designed to develop scientific reasoning skills and to provide practice in relating scientific concepts, representations, and models to real world phenomena.

Physics by Inquiry is not meant to be passively read. The modules do not provide all the information and reasoning included in a conventional text. There are gaps that are expected to be bridged by the student. The underlying rationale assumes that the process of science cannot be learned by reading, listening, memorizing, or problem-solving. Effective learning requires active mental engagement.

Students always work in groups and the curriculum materials rather than the instructors offer the main guidance. Students maintain notebooks in which they record observations, do exercises and problems, and reflect on how their understanding is evolving. In this way, they create an indispensable reference that complements the curriculum materials and serves as an individualized study guide.

The instructor-student interaction is limited to brief semi-socratic dialogues that are designed to help students evaluate their understanding and find ways of obtaining feedback by conducting more experiments and observations.

2.3 THE ROLE OF SIMULATIONS IN PHYSICS LEARNING

Educational software has become increasingly powerful, interactive and hence more likely to contribute to the learning environment in an effective manner. Dynamic modeling constitutes one of the capabilities that have only become a possible part of the learning process and its evaluation as a result of the advent of computers in the classroom.

There is a wide range of software that can support the learning process and its evaluation. For the purposes of this article we will concentrate on the utilization of simulation tools in the science classroom.

A simulation is a working model of a phenomenon usually designed and operating on the computer. Simulation software gives the student the opportunity to interact with a simplified representation of the physical phenomenon, isolate, explore and investigate particular aspects of the phenomenon and use the results to compare with the functionality of the phenomenon in the real world. Simulations are particularly useful in cases where observations from the real world are difficult to obtain. Astronomical phenomena are one case in point. Students can make observations about the simplest of these phenomena, including phases of the moon. However observations are time consuming and, while they are important to make through one cycle of the phenomenon, it is difficult to expect students to go back and forth to the observation deck. Rather, it is more realistic to expect students to make an initial round of observations and then to offer them the support and the tools they need to use these observations in order to develop valid models. Simulation is an effective tool for use in this process because it provides a means of visualizing particular models and exploring their implications which can then be compared against the observations for validation purposes.

2.4 DESCRIPTION OF THE SIMULATION AND THE EVALUATION INSTRUMENT

Our simulation software was developed in Macromedia Director 8. Director is an object-based authoring environment that uses theatre as its metaphor [7]. For example, multimedia elements become cast members on the stage. Likewise, all the windows and elements in this program use the theatrical metaphor. The program also enables the creation of videos that include objects moving around on the screen. The videos can be interactive and non-linear. In other words, the end user can modify the sequence of the exploration in any Director application and s/he can also interact with objects comprising the application.

The moon phase simulation that we developed uses three basic elements: a picture of the sun, a picture of the moon and a picture of the earth. The earth and sun images were created using Windows Paint and the pictures of the moon were photos taken from a satellite camera. All pictures presented "top" views of the celestial bodies.

The evaluation instrument is a software sequence that is based on this simulation. For the sake of clarity and conciseness, we will present an abbreviated version of the evaluation instrument. The sequence in this abbreviated version begins by displaying six pictures of different phases of the moon and posing the following question:

"Below you can see pictures of various phases of the moon. Starting from full moon, place the pictures in the same order as they appear when they are observed in the northern hemisphere during the period of one month."

The user can move the pictures around the screen until they settle on a particular sequence that they believe to correspond to the observations they have already made. Once the user settles on a sequence, the software poses a second question:

"Look at each of the videos listed below. Which of these videos demonstrate a valid representation of the movement of the moon relative to the earth, as observed from the north pole, that agrees with the sequence of observations that you specified in your last answer?"

The user has to choose one of many videos and to explain their reasoning. Every video plays a view of the earth from the north pole as it moves counter-clockwise, the moon as it circles around the Earth (in one video the movement is counter-clockwise and in another it is clockwise) and the sun that remains idle. Another video shows a top view of the sun and the moon but a side view of the earth. A fourth shows the earth orbiting clockwise around the sun.

The evaluation instrument finally poses a third question:

"Look at each of the videos of the relative motion of the moon, the earth and the sun. In each case, what do we have to change in order to have a valid simulation of the evolution of the moon phases? Explain your reasoning."

It should be mentioned that at each question users have the opportunity to go back and change their responses to the previous questions. All responses, either initial or modified are recorded.

3. PILOT TESTING OF THE EVALUATION INSTRUMENT

3.1 PURPOSE

The purpose of this pilot program was to refine the development of the evaluation instrument and the simulation software that it is based on by obtaining feedback through using it to evaluate the understanding of a small number of students, who had already been taught *Astronomy by Sight*.

3.2 SAMPLE

The pilot test was conducted at the University of Cyprus at the end of spring semester 2000. The sample involved three students of the primary education program at the Department of Education. The students had just complete a compulsory science content course in which they had been exposed to the first five sections of the *Astronomy by Site* module in *Physics by Inquiry* [1]. The evaluation was conducted in interview format. In each case one student was interviewed by one researcher in front of the computer. For triangulation purposes, data was collected both through audio taping and through the software described in section 2.4 above.

3.3 RESULTS

In order to evaluate the students' responses, we used Waheed & Lucas's [8] criteria. Each response was categorized in one of the following categories:

- Correct answer with explanation
- Correct answer with no or with partial explanation
- Wrong answer and wrong explanation.

When the students did not answer a question their response was categorised as "Did not know/answer". The answers that students gave to each of the three questions are discussed below.

The first question concerned the sequencing of the various moon phases. A correct response was the following: full moon, waning gibbous, 3rd quarter, waning crescent, new moon, waxing crescent, 1st quarter, waxing gibbous.

Student 1 sequenced the pictures correctly but started with the new moon rather than the full moon as was requested. Since the student had been prompted to do otherwise without any success and this was the sequencing that had been used in class, we believe that student 1 likely did not construct a model that would allow her to arrive at an answer independently of the observations made.

Student 2 gave a wrong response: she could not place the pictures in an appropriate sequence but she could give a correct name to each of the moon phases. This seems to indicate that student 2 did not understand the formation of the phases of the moon and she had resorted to learning by heart the names and shapes.

Student 3 gave a correct response as described above.

The second question concerned the information that can be inferred from the sequencing of the phases concerning the relative motion of the moon, the earth and the sun. Students were given an opportunity to reflect on their own sequencing and if they could not modify it appropriately they were then prompted by questioning to do so. Even after settling on appropriate sequencing of the phases and after repeated prompting, none of the students could relate the sequencing to the relative motion of the two celestial bodies. One example of an appropriate response is the following: since the third quarter appears before the new moon and the new moon appears before the first quarter as observed from the northern hemisphere, it follows that with respect to an observer at the north pole, the moon rotates counter-clockwise around the earth.

This result demonstrates two possible difficulties in constructing an appropriate model that can account for the phases of the moon:

- Many students tend to find prohibitive the spatial reasoning that is required to relate rotational movement of one body around another to the appearance of that body from a specific location on the other.
- Students tend to find it difficult to formulate coherent explanations of reasoning that describe a causal mechanism for sequenced observations.

The existence of both of these difficulties seems to provide an explanation for the apparent inability of students to provide appropriate responses to the second question irrespective of whether they had succeeded or not on the first question.

4. DISCUSSION

The use of simulation software as evaluation instruments has a number of advantages over traditional paper and pencil tests.

Firstly, more realistic renditions of the situation can be achieved in simulation format as compared to paper depictions. In our case, the pictures used were readily available satellite images. If they had been printed, the result would probably have been much different.

Secondly, time dependent phenomena, such as the relative motion of the moon and the earth, cannot be projected on paper. Additionally, the reconstruction of the movement helps us to visualise better than corresponding symbolic representations such as arrows.

Thirdly, the software prevents students from making easy mistakes, which some would probably do if they tried to draw the representation of the illuminated part of the moon, or the size of the moon with reference to the size of the Earth and the Sun. Hence, the use of the software enables the evaluation to focus on interesting and more productive aspects of student understanding.

Fourthly, there are additional more minor advantages that emerge from the novelty of the approach and from the opportunity to use colour and more realistic renderings of the situation.

In the pilot testing of the evaluation that we described above, even though we included a very small unrepresentative sample, we were able to analyze the variation in the responses and, based on this analysis, to identify specific reasoning difficulties that presented insurmountable obstacles to the students attempt to construct meaning. In this light, these preliminary results are very promising and suggest that the evaluation instrument could be fruitfully refined and used productively with larger samples to implement reliable assessments of their conceptual models.

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