Using the Lunar Phases Concept Inventory to Investigate College Students' Pre-instructional Mental Models of Lunar Phases

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The Lunar Phases Concept Inventory (LPCI) is a twenty-item multiple-choice inventory developed to aid instructors in assessing the mental models their students utilize when answering questions concerning phases of the moon. Based upon an in-depth qualitative investigation of students' understanding of lunar phases, the LPCI was designed to take advantage of the innovative model analysis theory to probe the different dimensions of students' mental models of lunar phases. As part of a national field test, pre-instructional LPCI data was collected for over 750 students from multiple post-secondary institutions across the United States and Canada. Application of model analysis theory to this data set allowed researchers to probe the different mental models of lunar phases students across the country utilize prior to instruction. Results of this analysis display strikingly similar results for the different institutions, suggesting a potential underlying cognitive framework.

Introduction

Individuals begin forming a concept of lunar phases at a quite early age. [1] This conceptualization may not be scientifically correct and may be ineffective in explaining lunar phases [2]; however, these alternative conceptualizations may be so deeply entrenched that they prove a deterrent to learning the scientifically accepted understanding of lunar phases. [3]

According to cognitive theory, to encourage the development of a scientific understanding, instructors need to first be aware of students' pre-existing cognitive frameworks, as well as how deeply rooted these frameworks are prior to designing effective instruction.[4]

Individuals' conceptual understanding of lunar phases may well be the most researched area of astronomy education research; however, the majority of studies at the post-secondary level have been quantitative in nature with only a few questions concerning lunar phases. [5] This data is simply not rich enough and does not provide detail on individuals cognitive frameworks. Some researchers have utilized qualitative methods to investigate college students pre-existing understanding of lunar phases [6]; although these studies provide rich detail, they should not be generalized.

A new alternative, that provides the richness of a qualitative investigation with the ease of a quantitative study, is to combine a research-based multiple-choice instrument with the innovative Model Analysis Theory (MAT).[7] This theory purports that by performing a mathematical analysis of individuals' responses to different items on an instrument, their mental models, as well as how consistently they use these mental models will be revealed.

The Lunar Phases Concept Inventory (LPCI) has been designed to utilize MAT to assess college students' understanding of lunar phases.[8] As part of a national study, the LPCI was administered to over 750 college students prior to instruction on lunar phases. The goal of this study was to determine the similarities and differences of pre-instructional cognitive frameworks among post-secondary astronomy students. This paper will discuss the preliminary results from the national study of eight institutions across the United States and Canada.

Model Analysis Theory

According to Model Analysis Theory, an individual's conceptual understanding can be represented as a series of concept dimensions [9] relating to the phenomenon, with each dimension having multiple possible models. In this theory a model is defined as a layer of knowledge that forms a stable functional package.[10] This set of models represents the scientifically acceptable understanding, as well as alternative conceptions uncovered by detailed qualitative interviews.

If multiple-choice questions are carefully designed, the results from the responses can be analyzed using Model Analysis Theory. An appropriate set of questions consists of multiple items for each of the different dimensions, with each item addressing only one dimension and the item distracters correspond to the different models of the dimension. By studying the patterns of individuals' responses to these questions, the probabilities of an individual utilizing each of the alternative models can be mathematically calculated. [11]

The LPCI

The LPCI is a twenty-item multiple choice instrument based on a detailed qualitative investigation.[12] This investigation yielded detailed information about the different dimensions and models of post-secondary students' understanding of lunar phases. Additional models were taken from the alternative understandings previously uncovered by the literature. Table I shows the LPCI's concept domain with the correct model listed as the first response under each dimension. Item reliability and validity was previously reported.[13]

National Sample

The LPCI was administered prior to instruction in the introductory astronomy course at eight different volunteer institutions during the 2002-03 academic year. These schools represented a variety of different sizes and geographical locations: two large state universities (AZ and Canada), three intermediate state universities (IL, KY, WA), two small private colleges (IL and IA) and one community college (AZ). Table II summarizes these sites.

Table I: Lunar Phases Concept Domain

1. Period of the Moon's orbit around the Earth
   - Approximately One month
   - Less than one month
   - More than one month
2. Period of the Moon's cycle of phases
   - Approximately One month
   - Less than one month
   - More than one month
3. Direction of the Moon's orbit around the Earth as viewed from a point above the north pole
   - Counter-clockwise
   - Clockwise
   - Random
4. Motion of the Moon
   - Moves like the Sun (East to West)
   - Moves opposite the Sun (West to East)
   - Random
5. Phase and Sun-Earth-Moon positions
   - Correct relationship
   - Opposite relationship
   - Incorrect relationship
   - No relationship
6. Phase - location in sky - time of observation relationship
   - Correct relationship
   - Incorrect relationship
   - No relationship
7. Cause of Lunar Phases
   - Alignment of Earth-Moon-Sun
   - Obstruction by the Earth's shadow
   - Obstruction by the Sun's shadow
   - Obstruction by Object
   - Combination
8. Effect on lunar phase with change in location on Earth
   - No change in Moon's shape
   - Moon's shape appears larger
   - Moon's shape appears smaller

Table II: Summary of Field Test Sites Pre and Post Average Test scores. Maximum score = 20. Differences between schools significant at $\alpha = 0.05$.

Institution		N	Score	SD
University of Alberta		200	8.73	3.00
University of Arizona		194	6.54	2.43
Augustana College		35	7.60	2.60
Estella Mountain CC		20	6.20	2.17
SIUE	Fall 02	74	6.86	2.41
	Spring 03	64	7.20	2.55
Western Kentucky		59	6.53	1.78
Western Washington		77	7.58	2.38
Wittenberg University		43	8.37	2.55

Results

For each of the different concept dimensions, the probability of students answering with the correct model, as well as the most common incorrect model were calculated and plotted. Due to space considerations, only the most common incorrect model was plotted. Figures 1 through 8 shows the model plots for each of the different concept dimensions.

Depending on where the class model points fall on the model graph, one can determine how deeply rooted a model is for a particular class. If the class model point lies in the lower right of the graph (probability of utilizing correct model <0.3), the majority of the class will utilize the incorrect model consistently. While if the class model point lies in the upper left of the graph (probability of utilizing correct model >0,7), the majority of the class will consistently utilize the correct model. If the class model point lies in the middle of the graph, the class will utilize neither model consistently.

By studying the plots, we observe several interesting results. First, for dimensions 2, 4, 5, 6 and 7, all of the class model points appear to be clustered together. Showing that probabilistically that students will utilize the correct model primarily for Period of Lunar Phases, incorrect models for the following dimensions: Earth/ Moon/ Sun and observed phase relationship; the phase, time of observation and location in the sky relationship and the cause of lunar phases, and no dominant model for the dimension of moon motion. Dimension 8 appears to also be one cluster with no dominant model, although it is so widely dispersed that it might be a random distribution.

For dimensions 1 and 3, we observe multiple clusters on the plots. It is interesting that for dimension 1, that the clusters seemed to be determined by score on the test, with top scoring schools utilizing the correct model primarily, the middle scoring schools mixing the models and the lower scoring schools utilizing the incorrect model primarily. Dimension 3 differs from Dimension 2 in that there is not cluster utilizing the incorrect model primarily.

Figure 1:
Probability of Using Different Models:
Moon's Orbital Period

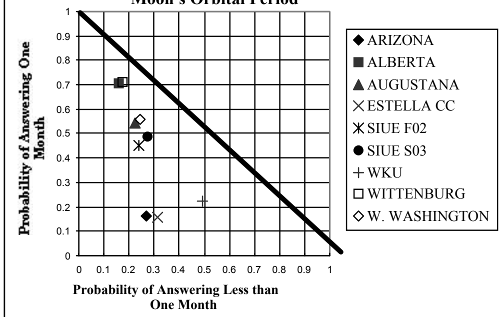


Figure 2:
Probability of Using Different Models:
Period of Lunar Phases

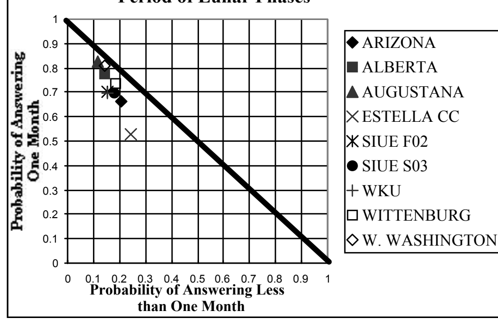


Figure 3:
Probability of Using Different Models:
Direction of Lunar Orbit

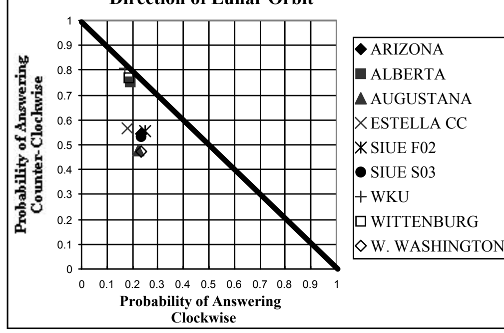


Figure 4:
Probability of Using Different Models:
Motion of the Moon

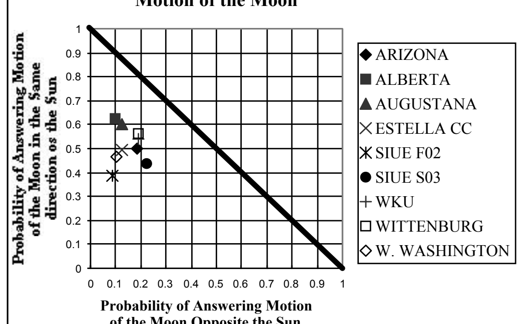


Figure 5:
Probability of Using Different Models:
Earth-Moon-Sun Position and Observed Phase

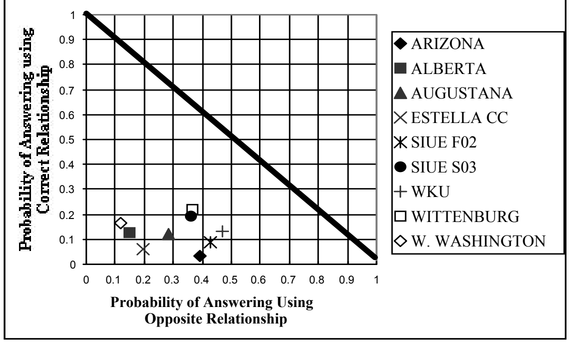


Figure 6:
Probability of Using Different Models:
Phase, Location and Time Relationship

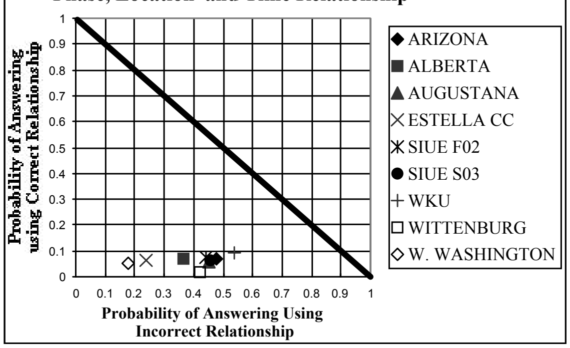
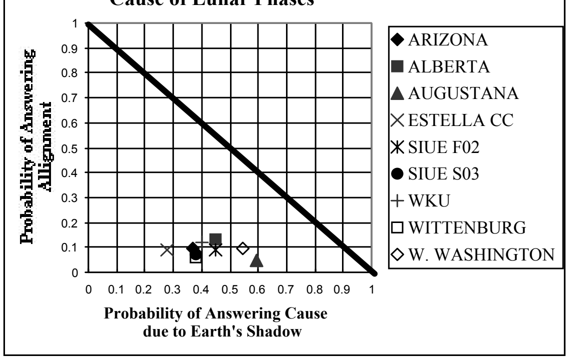


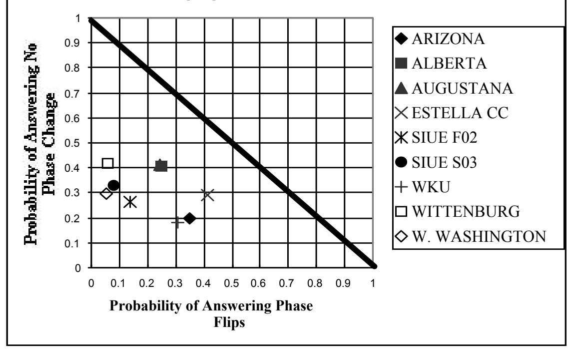
Figure 7:
Probability of Using Different Models:
Cause of Lunar Phases



Conclusions

For all concept dimensions, except for location, there appears to be a clustering of the model points, with more than one cluster for orbital period and motion of the moon. This suggests that there may be an underlying pre-instructional understanding for these dimensions that can be assumed by instructors. To determine if this indeed the case, data needs to be collected from more institutions.

Figure 8:
Probability of Using Different Models:
Effect of Changing Location on Earth



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2. See for example: M. Zeilik & W. Bisard, "Conceptual change in introductory-level astronomy courses: Tracking misconceptions to reveal which-and how much-concepts change", *Journal of College Science Teaching*, 29(4), 229-232, (2000).
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6. R. Lindell, *Enhancing college students' understanding of lunar phases*. Unpublished Dissertation. University of Nebraska-Lincoln (2001).
7. L. Bao, *Dynamics of student modeling: A theory, algorithms and application to quantum mechanics*, Doctoral Dissertation, University of Maryland (1999).
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9. Also referred to as Physical Features
10. Note that this is slightly different from how some cognitive psychologists and scientists use the term model.
11. See ref. 7.
12. See ref. 6.
13. See ref. 8.