Measuring Conceptual Change in College Students' Understanding of Lunar Phases

Rebecca S. Lindell

Physics Astronomy Chemistry Biology Education Research Group
Southern Illinois University Edwardsville

Abstract. To determine the overall effectiveness of instruction at producing a scientifically correct understanding, researchers need to be able to assess conceptual change. This paper details how using Model Analysis Theory (MAT) in conjunction with the Lunar Phases Concept Inventory (LPCI), provides researchers a more detailed picture of college students conceptual change with regards to lunar phases than traditional methods alone. A review of MAT is provided along with a detailed example of its application before and after instruction to determine conceptual change.

INTRODUCTION

Researchers now know that students do not enter the classroom as blank slates, but rather with pre-existing mental models of how they believe the world works. If rooted deeply enough alternate mental models may actually impair an individual's ability to learn a particular concept. To determine the effectiveness of instruction at overcoming these alternative mental models, researchers need a method by which to assess conceptual change.

While this can be accomplished qualitatively, it is not practical for the average university instructor. Quantitatively, researchers often employ a pre-test/ post-test design using a research-based concept inventory. Traditional statistics, such as gain or effect size, if used for assessing conceptual change are quite limited and do not provide an in-depth information necessary to measure conceptual change.

A new alternative is to employ Model Analysis Theory (MAT) [1] in conjunction with an appropriate research-based instrument to determine what mental models students possess and how consistently students use said mental models.

This paper is designed to provide a brief overview of MAT and provide a detailed example of how MAT was used to probe conceptual change in college students' understanding of lunar phase. The concept inventory utilized in this study was the Lunar Phases Concept Inventory (LPCI) [2], the first concept inventory specifically designed to be used with MAT.

MODEL ANALYSIS THEORY

According to Model Analysis Theory (MAT), an individual's conceptual understanding can be represented as a series of concept dimensions [3] 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. 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 MAT. 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. [3]

To help visualize the consistency of use of a particular model, researchers can plot the probability of students answering with the correct model versus the most common incorrect model. [4] Depending on where the concept dimension model points fall on the model plot, one can determine how deeply rooted a model is for a particular concept dimension.

If the concept dimension point lies in the lower right of the plot (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 plot (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 plot, the class will utilize neither model consistently.

By producing model plots for each of the concept dimensions both before and after instruction, researchers can determine the effectiveness of the instruction at producing conceptual change.

THE LPCI

The LPCI is a twenty-item multiple-choice instrument based on a detailed qualitative investigation. [5] 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 dimensions with the correct model listed as the first response under each dimension, and the most common alternate model listed as the second response. Table II provides an overview of the 20 items on the LPCI. Item reliability and validity was previously reported. [2]

EXAMPLE

The LPCI was administered to a class of 200 students enrolled in a primarily non-science major introductory astronomy course at a large public American university. Students took the LPCI at the beginning of the semester, completed a twenty-minute inquiry-based tutorial [6] on lunar phases several weeks later and then took the LPCI again six weeks after completing the tutorial. Lecture was kept to a minimum during this tutorial and very little additional class time was spent covering lunar phases.

Table 1: 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
    - Other relationship
    - No relationship
6. Phase - location in sky - time of observation relationship
    - Correct relationship
    - Other 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

The total scores and standard deviations for the LPCI are shown in Table 3.

Data from the LPCI was analyzed using MAT. 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. Figures 1 and 2 show the model plots of the concept dimension model points pre- and post-instruction respectively.

DISCUSSION

By studying the plots, we observe several interesting results. Prior to instruction, the plot points for dimensions 1, 2 and 4 show that probabilistically the majority of the students will use neither the correct model nor the most common alternative model consistently, while for dimensions 3, 5, 6, 7 and 8 the plots show that the majority of the students will utilize the alternative model to answer questions concerning these concept dimensions. After instruction, the plot shows that the majority of students will answer questions using the correct model for all concept dimensions, except for dimensions 6 and 7.

Table 2: Summary of questions in current LPCI (Corresponding Dimension)

1	Where to see Waxing Crescent Moon at Sunset (6)
2	Time to complete one orbit (1)
3	Moon orbits in which direction (3)
4	Cause of New Moon (7)
5	Frequency of New Moons (2)
6	Phase of Moon for Solar Eclipse (5)
7	Appearance of Full Moon in Australia (8)
8	Orbital period vs. phase period*
9	Time to observe 3^{rd} quarter Moon setting (6)
10	Direction of 3^{rd} quarter Moon Rising (4)
11	Earth-Moon-Sun geometry for Full Moon (5)
12	Time until Moon appears same (2)
13	Moon's appearance half-way around world (8)
14	Direction of Moon rising at sunset (4)
15	Phase of Moon rising at sunset (6)
16	Alignment between Sun/Earth/ Moon to produce Waxing crescent Moon (5)
17	Time difference between different phases (2)
18	Cause of phases (7)
19	Orbital period – time difference between observations (1)
20	Direction of Moon's orbit (3)

*Question 8 not used for Model Analysis Theory

Table 3: Summary of Average LPCI scores and standard deviations

	N	Average Score	Standard Deviation
Pre	194	6.54	2.43
Post	223	13.74	3.24

As a comparison to traditional methods for determining conceptual change, we can calculate the normalized gain [7]:

$$< g >= \frac{< Post\% > - < Pre\% >}{100 - < Pre\% >} \tag{1}$$

The normalized gain for this data set is 0.54, which is fairly high compared to other gains previously reported. [2]

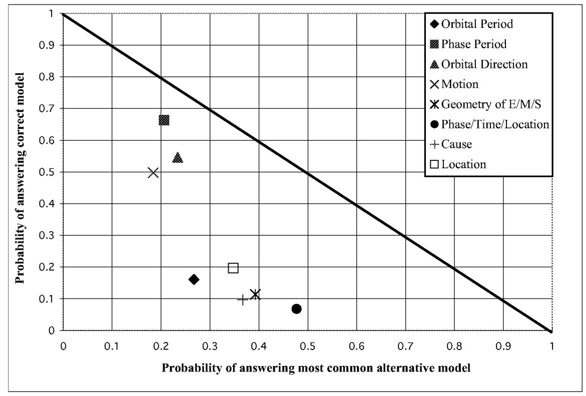

FIGURE 1. Pre-instructional probability of using different models for each concept dimension

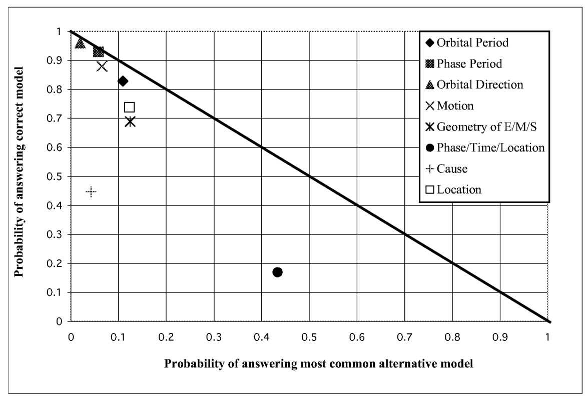

FIGURE 2. Post-instructional probability of using different models for each concept dimension

CONCLUSIONS

If we look at the normalized gain alone, we may have concluded that this instruction was fairly successful at promoting conceptual change. However, when we look at the results from MAT, we see that this may not be the case. The instruction on dimensions 1, 2, 3, 4, 5 and 8 was quite successful. We can conclude that the instruction on dimension 6 (cause of phases) was only moderately successful and on dimension 7 (relationship between time, phase and location) was a complete failure. It is interesting to note that these two concept dimensions' pre-instructional plots showed the most deeply rooted alternative models. In addition, these two concept dimensions are the only two that are typically assessed when evaluating instruction on lunar phases. This suggests that lunar phases instruction may indeed be more successful than was previously reported for the other dimensions. [8]

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[3] Also referred to as Physical Features in [1]

[4] Note that by making model plots of other probabilities, other research questions can be addressed

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