Using Augmented Reality for Teaching Earth-Sun Relationships to Undergraduate Geography Students

Brett E. Shelton
College of Education
Program for Educational Transformation Through Technology
University of Washington
bshelton@u.washington.edu

Nicholas R. Hedley
Department of Geography
Human Interface Technology Laboratory
University of Washington
nix@u.washington.edu

Abstract

In this application-based paper we describe an ongoing research project in which we utilize ARToolkit to help teach undergraduate geography students about earth-sun relationships. We carefully examined over thirty students who participated in an augmented reality exercise containing models designed to teach concepts of rotation/revolution, solstice/equinox, and seasonal variation of light and temperature. We found a significant overall improvement in student understanding after the AR exercise, as well as a reduction in student misunderstandings. Further analysis implies that learning complex spatial phenomena is closely linked to the way students control "when" and "how" they are able to manipulate virtual 3D objects. We present some arguments for why it may be appropriate to use videotaped data gathering methods to accurately describe student understandings in future research.

1. Introduction

Many students have difficulty accommodating spatially related knowledge involving complex concepts and phenomena. As a result, instructors are challenged to find new ways of representing spatial systems that are more cognitively beneficial for student learning. This is a significant issue for teaching and learning in higher education and is well documented in current scientific research literature.

Traditionally, attempts to address the spatial learning problem have taken a 2D form in text and illustration, 2D digital media and animations, and most recently with 3D modeling through desktop interfaces. Numerous studies addressing the problem of students' conceptions regarding the dynamics of the earth-sun-moon systems further substantiate the significance of the spatial learning issue. The pedagogical challenge exists in many forms, perhaps none so apparent as illustrated in the film *A Private Universe* which shows Harvard University students and faculty inaccurately describing their understandings of basic astronomy and causes of seasons and moon phases [1].

Our research examines the advantages of the AR interface for viewing and manipulating 3D objects. We want to know how students' understandings of spatial content change through their physical interactions with virtual objects. Our hypothesis is that AR changes the way students come to understand certain concepts. Our analysis includes a careful examination of student physical movement and object manipulation during AR activity and reflection. Quantitative analysis of pre- and post-assessments, along with qualitative analysis of the videotaped AR exercise, allows us to measure learning outcomes. The findings demonstrate the potential benefits of using AR visualization interfaces in education and training.

2. Case study: earth-sun relationships

Geography 205 at the University of Washington aims to provide students with a working knowledge of the physical landscape and natural environmental processes. These phenomena exist at many different scales, are inherently spatial, and often require understanding their temporal development. The problem is that it is difficult for instructors to accurately represent explicit spatial phenomena using conventional 2D means. Part of the curriculum deals with earth-sun relationships and aims to help students understand how the spatial and temporal relationships between the sun and earth result in daily and seasonal variations in light and heat.

These principles are essential to an understanding of increasingly complex phenomena and processes in physical and human environments. A poor understanding of earth-sun relationships in introductory classes may propagate inaccurate understandings or difficulties when encountering more sophisticated physical and environmental concepts or in later undergraduate education.

Sometimes, even above-average learners find it difficult to make abstract visual connections between the

Shelton, B. E., & Hedley, N. R. (September 29, 2002). Paper presented at The First IEEE International Augmented Reality Toolkit Workshop, Darmstadt, Germany.
IEEE Catalog Number: 02EX632 ISBN: 0-7803-7680-3

position and tilt of the earth, the revolution of the sun, and the daily and seasonal conditions we experience on earth. Some instructors have attempted to use real 3D objects or props readily available in the room to demonstrate these relationships. This might involve holding an orange or a flashlight (the sun) in one hand, and an apple impaled on a pencil (earth with axis) on the other. Interactively, students can see how relative position along path of revolution interacts with the tilt of the earth's axis and the resulting effect when illuminated by the sun. However, students still struggle with bringing these relationships together as a complete understanding of a sophisticated system that operates in space and time.

But it is still just an apple and pencil. It is still just an orange. We are assuming all students understand the metaphor. We are assuming that students can visualize what we - as instructors - see in our minds.

3. Methods

We investigated the potential of AR to improve education by studying thirty-four students enrolled in Geography 205 during summer 2002. The students experienced three-to-six animated 3D Earth and Sun models using AR. The models were designed to build an understanding of rotation and revolution, solstice and equinox, and seasonal variation of light and temperature of the northern and southern hemispheres.

3.1. Setting

The AR system was set up in one corner of a room dedicated to performing the exercise and videotaping the students in action. Users wore a lightweight Cy-Visor™ DH-440 head mounted display (HMD) with a Logitech QuickCam Pro 3000 video camera attached. The HMD and camera were connected to a computer Pentium 4 1.6 GHz laptop running Windows XP and ARToolkit version 2.52 software.

Students filtered through the AR station over a two-day period in which they completed a pre-assessment and post-assessment worksheet before and after the exercise. On a day following the AR exercise, a class discussion revolved around the content they experienced in which students had the opportunity to ask questions and clarify any issues they had.

The data collection focused on the students enrolled in Geography 205, with the goal of having at least 30 giving consent for the collection of their pre- and post-assessment worksheets. Because this class satisfies a university science requirement, there was a wide range of class standings and academic interests represented. All students who are enrolled in the class and are at least eighteen years of age were eligible to participate in the research. Students who did not wish to be part of the research still had the opportunity to take part in the AR exercise. The instructor replaced the traditional instruction covering earth-sun relationships with the AR exercise, and students received a grade for participating, although not for their accuracy on the pre- and post-assessment worksheets. An examination that, in part, covered the material in the AR exercise was administered the following week.

3.2. Procedure

The methods used for data collection included a variety of information gathering strategies. First, subjects were asked to complete a pre-assessment worksheet that helped determine their level of understanding of earth-sun relationships. One aim of this phase was to help students become aware of the assigned goals of the exercise and the nature of the content they experienced.

Subjects were then given a brief introduction of the components of the interface and how to manipulate virtual objects. We offered them a chance to view each model of the earth and sun, ask about the virtual representations, what interactions are taking place, and the results of those interactions. The sessions of the subjects were videotaped. The actions of the subject with the virtual objects and their physical manipulation of the objects from a “third” person perspective was recorded (Figure 1). The viewpoint of the subject with the object as it is viewed from the “first” person perspective (the view of the subject through the head-mounted display) was also videotaped (Figure 2).

Figure 1. Third person perspective of earth-sun AR exercise.

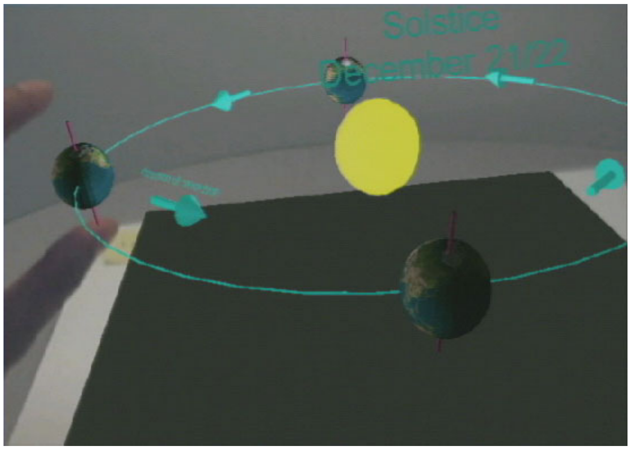

Figure 2. First person perspective of earth-sun AR exercise.

From these records it was possible to see and hear the interactions of the subject with the content (the 3D objects) and the interface. This data was necessary to provide insight into iterative student learning behaviors. After completing their interactions with the AR interface, students then filled out a post-assessment worksheet.

3.3. Pre- and post-assessment worksheets

In order to help understand what kinds of effects the augmented reality exercise had on student learning, we developed a measure in the form of pre-assessment, intervention, post-assessment. To build the assessment worksheet we drew upon two main resources. The first resource was a previous Geography 205 examination covering the earth-sun relationship topics being illustrated in the augmented reality exercise. The assessment consisted of three pages of open-ended questions asking students to explain their knowledge in three main categories:

1. rotation/revolution
2. solstice/equinox
3. seasonal variation in light and temperature

A second resource for building the worksheets was the previous research at Indiana University by the group led by Sasha Barab, in particular, two studies that described the implementation of similar earth-sun topics in a desktop 3D world [2][3].

The pre-assessment and post-assessment worksheets were identical, constructed so that questions were compared to each other as two related variables. Each question was formatted to be open-ended, using syntax such as “Explain the differences…” or “Describe the relationships and effects…” There were a total of three questions on each of the assessment sheets; each question dealing with a single topic of rotation/revolution, solstice/equinox, and seasons. Each question was evaluated by an expert in the subject matter, articulating a range of understanding for each question on a 0-to-5 ranking scale. The 0 represents a novice conceptual understanding of the material covered in the question, while a 5 represents a complete expert understanding of the material. Rankings of 2-4 represent incomplete understandings along the 0-to-5 spectrum, whose attributes were articulated independently for each question. Rankings also addressed issues of student alternative understandings and “missing” conceptions on each question topic. An independent expert in the field of earth-sun relationships assigned a rank from 0-5 for each question on the pre-assessment and post-assessment worksheets for each student. We collected and assessed the worksheets of over thirty of the participating students in the augmented reality exercise in order to attain statistical validity.

To help us measure the affect the augmented reality exercise had on the students’ understandings of earth-sun relationships, we proposed three questions:

1. How did students’ performance change from pre-assessment to post-assessment?
2. Which students improved, and which did not?
3. For which topics was student performance affected?

A Wilcoxon signed-rank statistical test that detects differences in the distributions of two related variables was used to measure overall student performance, student improvement based on their pre-assessment performance, and topic content what is most or least effective.

4. Results and Analysis

A Wilcoxon test for statistical significance for the combined scores, as well as for each individual score, is shown in Table 1. We look for 2-tailed significance values to be <.05 for 95% confidence interval. Thus, the “Combined”, “Question 1” and “Question 2” are deemed to show significant differences in performance from pre- to post-assessment.

Table 1. The Wilcoxon signed-rank results for pre- vs. post-assessments (N=28).

Test Statistics	**Combined** Pre-assessment and post-assessment	**Question 1**: Pre-assessment vs. post-assessment	**Question 2**: Pre-assessment vs. post-assessment	**Question 3**: Pre-assessment vs. post-assessment
Z	-4.029	-2.909	-2.145	-1.917
Asymp. Sig. (2-tailed)	.000	.004	.032	.055

Figure 3 visually represents student scores on a 0-5 scale from their pre- and post-assessments on a scatterplot. A line from (0,0) to (5,5) would represent the boundary for 'no change' in student score.

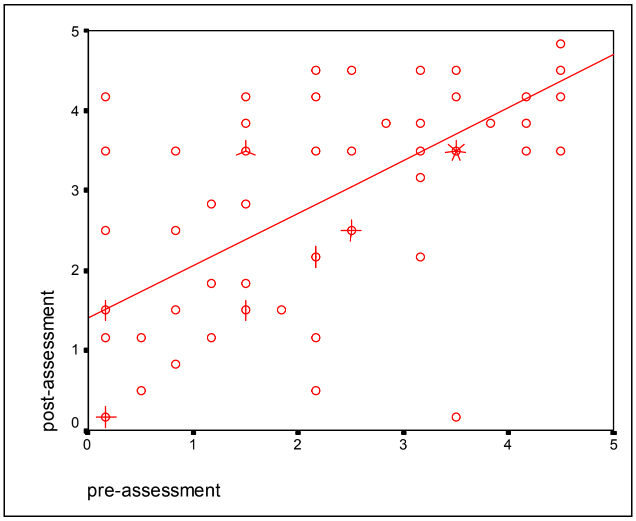

Figure 3. Combined pre- and post-assessment results for all three questions. The line shown here represents the linear regression of the data.

Graphs for student performance, pre- vs. post-assessment for each individual question are depicted in Figure 4, Figure 5 and Figure 6. The lines representing linear regression shows greater improvement by those who performed very poorly on the pre-assessment. Question 3 representing seasonal variation was the most difficult for students to grasp.

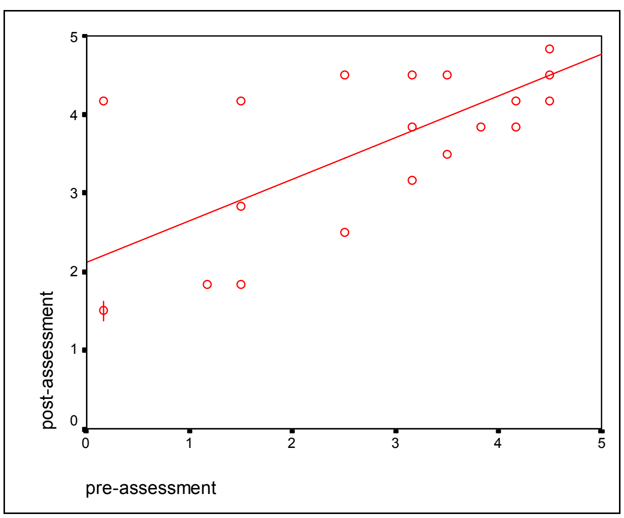

Figure 4. Question 1 (rotation/revolution) pre-assessment vs. post-assessment.

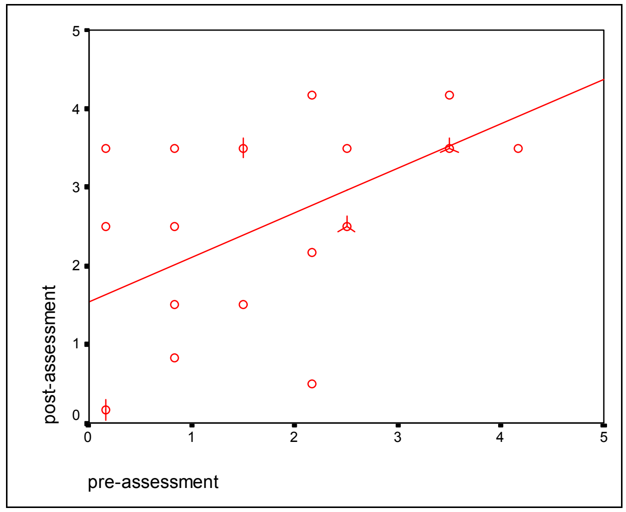

Figure 5. Question 2 (equinox/solstice) pre-assessment vs. post-assessment.

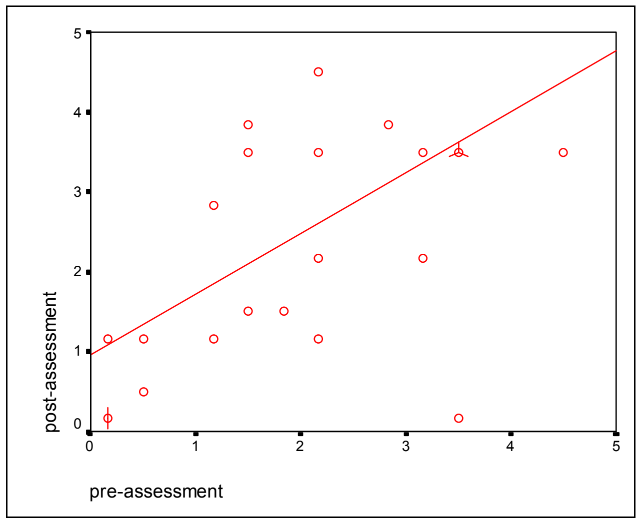

Figure 6. Question 3 (seasonal variation) pre-assessment vs. post-assessment.

The following are some general trends supported by artifact analysis of the pre- and post-assessment worksheets, along with some of the descriptive statistics:

- Students' expressions of their conceptual and factual understanding generally improved in all cases following AR intervention.
- In all but one case, misrepresentation of factual information was reduced after the intervention. The exception occurred where the same misrepresentation remained from pre- to post-assessment.
- The largest increases in improvement were registered for those with lower pre-assessment scores.

- A majority of students chose to draw sketches to help illustrate their understandings of earth-sun relationships on both pre- and post-assessment worksheets. This could indicate their preference for explaining spatially-related information through pictorial descriptions rather than written word descriptions.

Using Atlas TI we also coded the transcripts of the students as they engaged in discussion with us during the exercise. We combined and cross-referenced these with hand-written notes during video analysis. The codes and notes attempted to reflect the research question by addressing "what is happening", then further "is learning happening" by describing student actions and commentary.

The following is an excerpt of a student transcript with some coding and analysis following each portion. The student "S" is discussing Model #2 with the investigator "I". Model #2 contains two earth models representing the earth's position at equinox are on the left and right side of the card he is holding. Two additional earth models representing the earth's position at solstice are on the front and back sides of the card. Other models present include annotations describing the path and direction of rotation and revolution and a model of the sun, as seen in Figure 2. Our commentary is enclosed in brackets <>.

I: What can you say about the amount of light that's reaching both the north and the southern hemispheres [of the earths at equinox positions]?

S: They're almost equal. The amount of lights, yeah, they're about the same if considering, yeah because well there's still slight differences but they'll be a little bit, they're a less –

<The student is considering (or expecting) that the northern and southern hemispheres are receiving equal amounts of light. The student changes the position of the earths left-and-right, forward-and-back, during this inspection.>

I: That slight difference might be because the perspective that you're looking at it, so if you looked at it, like move it over here, it's difficult because of the angle but if you bring up that equinox a little bit closer to you. Actually it is equal, it should be equal, thus the term equinox.

<The investigator attempts to encourage the student to inspect the equinox earth more closely, from an angle that reduces the amount of distortion caused by the artificial vanishing point of the models in interface.>

I: So when the southern and northern hemispheres are at those points they're receiving equal amounts of sun.

S: Got it.

I: You might also notice that the axes on all four figures are pointing in the same direction at all times, in other words it's revolving with the axis being stable as far as its position relative to the sun, which is what creates those four distinct points. Does that make sense or did that confuse you?

S: That confused me. So you mean the poles are just, they're supposed to be straight up and down, right?

I: Uh huh.

<The student expects that "North Pole" should be perpendicular to the surface he is holding, at least at some point during revolution. His understanding is that the earth "wobbles" during revolution so that the tilt of the earth changes with respect to its position to the sun.>

S: But how do they turn -

I: Actually straight up and down, I'm not sure what you mean there. They're actually tilted with the earth 22 1/2 degrees at all times.

S: Oh, are they?

I: Yes. So if you notice, if you look at each one –

<The student now changes the angle which he is viewing the models. He brings all 4 earths (2 solstices, 2 equinoxes) into view in a more top-down kind of perspective. He inspects the angle of the axis in each of the earths. He then changes the perspective back to more of a "flat" one to examine the angle of the axes at the equinoxes again. He focuses on the equinox to his left.>

S: All right, this one, yeah, if I look at this angle this one is more straight up and down, but how are they tilted? Oh wait, I see it, because they're tilted that way but if I'm looking -

I: Right, it's tilted away from you instead of to the right to left.

<Student actually holds the card in one hand as he uses his own finger to mimic the angle that the axis is at. He sees that at equinox the axis angle still exists, but it is titled away from him. At a "flat" angle, the axis appears vertical or as he says, "Up and down." This was previously misconstrued as a 0 degree axis angle because of his viewing perspective. As he changes the viewing perspective by tilting the card, however, he sees that the axis angle remains.>

S: I see it, so it's always going that way. All right, I see it. That's interesting.

I: You might also notice that the -

S: Yeah, they're all the same angle, if I look at it this way all of poles are exactly the same angle. That's cool.

<Student holds his finger at a 22.5 degree angle, and moves his hand in a wide circle mimicking the path of the earth during revolution. The student is using a spatial and physical strategy using his hands to show me that he now understands how the earth is tilted as it revolves.>

Later, this same student had a chance to reflect on the exercise.

S: I thought it was really, really good because it's actually giving me a perspective, a three-dimensional perspective versus like a two-dimensional reading from a book because I really don't know like if I see a diagram in the book and there's like several diagrams, which makes it a little bit hard to understand…

<The student is making a comparison to previous educational methods he has experienced that covers similar types of concepts. He specifically denotes the advantage of having a single "diagram" under his control as being advantageous over several static ones.>

S: …But when you see all that in 3-D with this full motion you actually can see like the, I think you can absorb it a lot faster. And especially I didn't know like the poles stayed the same, I thought they just, you know, I thought around the sun - rotate it's a different way but they were, if I looked at a different angle I actually saw like they were all the same angle and that's kind of neat. That's interesting. I liked that.

The qualitative analysis of the first- and third-person videotapes of the students performing the exercise yielded some interesting trends:

- Less complex content seemed to be an effective way of introducing the AR interface. The time it took to get used to the interface was very little for most students, and no one seemed in awe of the way it worked, although we think a couple of people never did get too comfortable with the set-up. We suspect that this is due both to being able to see the natural environment through the HMD, and to the nature of undergraduate students to be familiar with complex 3D objects through their previous experiences with media and gaming.
- Some people preferred to do very little "exploring" of the content, preferring instead to choose a perspective while keeping the 3D objects steady. Others rotated the objects quickly and consistently, sacrificing the fidelity of the objects at times but perhaps gaining a more worldly spatial understanding. Our initial observation is that those who felt comfortable with the content (as opposed to being comfortable with the interface) tended to be the "explorers" while those more unsure of the content were "static perspective viewers." However, utilizing the "body as rubric" for manipulating 3D objects has been difficult to both monitor and measure.
- Being able to change perspectives (90 degrees) of the Solstice/Equinox models multiple times and in succession was the most common and successful way students gained an appreciation of how the earth's axis and position around the sun caused variation in light and temperature.
- For the more advanced concepts, physical inspection of the content was a key to understanding how multiple elements involved in the earth-sun relationships worked together. For example, seeing how the axis tilt of the earth remained consistent during revolution about the sun coupled with the earth's position at solstices and equinoxes seemed to be the way students were able to understand seasonal variation in light to the northern and southern hemispheres. Students were able to switch their attention to different things happening in the same model. In order to accomplish this, students often physically maneuvered the content, but in certain cases (depending on the angle of viewing) students only had to change their area of focus.
- An interesting finding is the issue of "control" over the content. Few students are able to articulate very effectively this idea when asked, but it seems to pervade many of the experiences of the students whether they could pinpoint this idea or not. In other words, they appreciated that they could use a "diagram" in a way that they could control what they were looking at, and when they wanted to look at it. This also ties in directly with having a 3D object to inspect, as this 4th dimension was a key to making the breakthrough for understanding spatially what was going on. (Note: "Control" in this sense is much different than other kinds of "control over content" normally referred to in constructivist mulitmedia applications.)
- The tangibility of the virtual objects was so real, for some students, that they pointed and referred to the virtual objects during the exercise as if other people could see them the same way that they could. We surmise that they "forgot" that they were virtual, and an HMD was needed to see them. In other words, they thought very quickly that the virtual objects were part of the real environment and their belief was temporarily suspended.
- The mixed vanishing-point of the 3D content with the real-world background caused confusion for

some people (although none of the students were able to articulate that this indeed was the problem they were having). This was especially the case when inspecting the angle of the axis at different revolution locations. This is exemplified in the following figures. Figure 7 shows the top view without perspective of a model of the earth with axis during equinox, positioned toward the edge of the card, with the appropriate 22.5 degree of angle. Figure 8 shows how the artificial vanishing point, mismatched with the real environment's vanishing point, created an artificial "angle" misinterpreted by some students. Figure 9 shows that the correct angle axis can be seen if the card is positioned differently, however, the pattern is difficult to keep in the field of view.

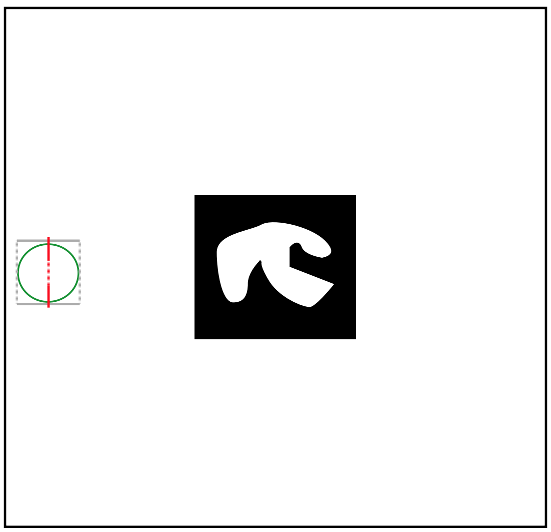

Figure 7. Top view without perspective.

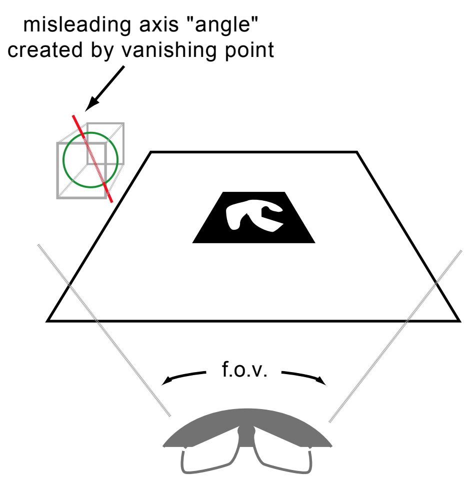

Figure 8. Front view with perspective, card positioned with the pattern directly in front of the student.

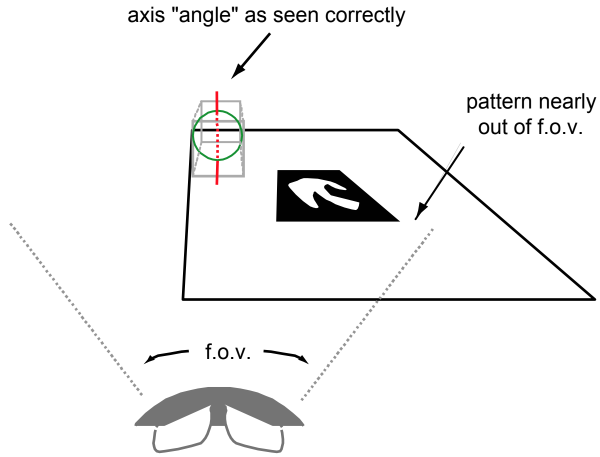

Figure 9. Front view with perspective, card positioned with the earth model directly in front of the student.

5. Discussion

We believe that AR has the potential to transform instruction and learning of complex spatial concepts and content. Building on theory and development in the cognitive and applied attributes of AR, we used AR to teach students earth-sun relationships as part of an undergraduate class curriculum. Our research addresses the effects the interface has on learning.

Further, this research explores the potential of AR to advance visualization tools in education and for the design and development of learning technologies. AR interfaces do not merely change the delivery mechanism of instructional content. They may fundamentally change the way that content is understood, through a unique combination of visual and sensory information that results in a powerful cognitive and learning experience.

In regard to our experimental method, we believe there might be the assumption on the part of the students that their responses to the post-assessment were to be considered an addition to their pre-assessment responses. Some of the wording in post-assessment responses seems to hint at the existence of this. Only in five or six cases do people explicitly state: "same as before, plus…" If this is indeed the case, post-assessment scores would likely be much higher than our current form of ranking would indicate. In the future, we are planning an alternate method of pre- and post-assessment methods of data gathering which would help to eliminate this factor for the next phase of research, as discussed in Future Work.

Perhaps the largest confounding factor in the way the pre- and post-assessments were given is that the students knew they were not being graded for accuracy, and the considerable time (~15 minutes) it took to completely answer the post-assessment exam many students found undesirable. For the students who performed well during the intervention (through review of the video) yet did not make a reasonable effort on the post-assessment we eliminated from the statistical analysis. We eliminated four cases out of thirty-two, however, upon inspection of certain other outlying cases we probably could have eliminated more.

AR provides an efficient, powerful tool that allows students to view and interact with sophisticated phenomena while providing flexibility to allow query and exploration of component parts of this system such as time, position, angles, rotation, and revolution. Augmented reality allows us to present any three-dimensional phenomenon we wish, scaled to dimensions that are convenient for classroom observation and manipulation.

Put another way, instead of looking "through a window" of static sketches, linear animations or movies, we can look at these phenomena as 3D entities in our own 3D spaces. And by using this technology we can leverage the power of virtual objects, that is, represent anything we like all at once.

With AR, there is no need for students to pretend an apple is the earth, nor an orange the sun. There's the sun! Right there, positioned as an object before the students' very eyes, with the earth following a path around it. And as they look at it, important annotations appear showing dimensions, labels, and illumination. Manipulating these 3D objects provide the necessary information needed to make the connections of how earth-sun relationships operate. By bringing AR interfaces into classrooms, we believe that there may be significant benefits to the quality in which curriculum involving complex 3D spatial phenomena and concepts are taught in geography, astronomy and other disciplines.

6. Future Work

Additional phases of this research will take into specific account of how to properly address students' understandings of earth-sun relationships both before and after the exercise. We plan to use an elicited pre- and post-exercise interview in which students will be videotaped while describing their understandings of how earth-sun relationships work. They will be offered props such as styrofoam balls and drawing tools to help them fully explain themselves. Videotape analysis of their answers by independent experts will then better help us interpret their changes in understanding than did the paper-and-pencil worksheet method. This data will be pivotal in helping us explore how the behavior with virtual objects in an augmented reality environment leads to changes in student understandings.

In addition, after the exercise we will contact the participating students to request an interview. We will use the time between intervention and interview to review the videotapes of student interactions, and choose a small representative sample for the semi-structured interview portion of the study. Students who agree will participate in an interview where students get the opportunity to see themselves using the AR interface. The discussion will center on how the content was represented and the subject's impressions of how the interface may have affected the understanding of that content. Questions will also address what understandings the subject has obtained through the activity, and the role of their manipulation of the 3D objects played in the process. This data will help provide us with student reflections of their own learning through the interface after some time has passed.

Because this is part of the first study to address learning in a real-world context using this interface, we did not know at the outset how to measure student learning through their activity with the interface. As part of this ongoing research, we hope to discover how to methodologically tie student activity with the interface to their changes in understanding. Discussion topics during the interviews with the student will cover emergent goals throughout the exercise and the intended goal prior to beginning the exercise. We believe gathering information about student goals will help us create the methodological ties. In addition, focusing on student learning strategies in virtual environments may help illuminate certain patterns in students' behaviors [4]. This kind of interaction analysis will complement other types of statistical analysis to help measure learning outcomes [5].

References

[1] A private universe. An insightful lesson on how we learn [Film], Pyramid Film & Video, Santa Monica, CA, 1988.

[2] S.A. Barab, K.E. Hay, M. Barnett, and T. Keating., "Virtual Solar System project: Building understanding through model building", *Journal of Research in Science Teaching, 37*(7), 2000, pp. 719-756.

[3] S.A. Barab, K.E. Hay, M. Barnett, and K. Squire, "Constructing virtual worlds: Tracing the historical development of learner practices", *Cognition and Instruction, 19*(1), 2001, pp. 47-94.

[4] W. Winn and M. Windschitl, "Strategies used by university students to learn aspects of physical oceanography in a virtual environment", paper presented at the American Educational Research Association, New Orleans, LA, April 2002.

[5] B. Jordan and A. Henderson, "Interaction analysis: Foundations and practice", *The Journal of the Learning Sciences, 4*(1), 1995, pp. 39-103.