ESTABLISHING THE EMPIRICAL RELATIONSHIP BETWEEN NON-SCIENCE MAJORING UNDERGRADUATE LEARNERS' SPATIAL THINKING SKILLS AND THEIR CONCEPTUAL ASTRONOMY KNOWLEDGE

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Abstract: The astronomy education community has tacitly assumed that learning astronomy is a conceptual domain resting upon spatial thinking skills. As a first step to formally identify an empirical relationship, undergraduate students in a non-major introductory astronomy survey class at a medium-sized, Ph.D. granting, mid-western US university were given pre- and post-astronomy conceptual diagnostics and spatial reasoning diagnostics, Instruments used were the "Test Of Astronomy Standards" and "What Do You Know?" Using only fully matched data for analysis, our sample consisted of 86 undergraduate non-science majors. Students' normalized gains for astronomy surveys were low at .26 and .13 respectively. Students' spatial thinking was measured using an instrument designed specifically for this study. Correlations between the astronomy instruments' pre- to post-course gain scores and the spatial assessment instrument show moderate to strong relationships suggesting the relationship between spatial reasoning and astronomy ability can explain about 25% of the variation in student achievement.

Keywords: Spatial reasoning; astronomy learning; astronomy education; correlational studies; undergraduate non-science majors.

ESTABELECENDO UMA RELAÇÃO EMPÍRICA ENTRE O RACIOCÍNIO ESPACIAL DOS ESTUDANTES DE GRADUAÇÃO EM CARREIRAS NÃO CIENTÍFICAS E SEU CONHECIMENTO CONCEITUAL DA ASTRONOMIA

Resumo: A comunidade da educação em astronomia tem suposto de forma implícita que o aprendizado da astronomia consiste em um domínio conceitual fundamentado no raciocínio espacial. Como um primeiro passo para identificar formalmente uma relação empírica entre estas duas coisas, utilizamos como amostra os estudantes de graduação de carreiras não científicas de um curso exploratório em uma universidade norte-americana do meio-oeste de médio porte com programa de Doutorado em andamento, onde estes estudantes foram submetidos a um diagnóstico de raciocino espacial e conceitos astronômicos antes e depois do mesmo. As ferramentas utilizadas foram o *Test Of Astronomy Standards* (TOAST) e o questionário *What do you know?* Utilizando somente dados completamente consistentes para esta análise, nossa amostra consistiu de 86 estudantes de graduação. As melhoras, depois de normalizadas, do desempenho dos estudantes nos dois quesitos foram pequenas, 0.26 e 0.13 respectivamente. O raciocínio espacial dos estudantes foi medido utilizando um instrumento específico desenhado para este trabalho. As correlações entre os resultados dos testes astronômicos e este instrumento específico antes e depois do curso mostraram uma relação entre moderada e forte, sugerindo que a relação entre o raciocínio espacial e o conhecimento astronômico pode explicar até um 25% na variação no desempenho dos estudantes.

Palavras-chave: Raciocínio espacial; aprendizado de astronomia; educação em astronomia; estudos de correlação; graduandos em carreiras não científicas.

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ESTABLECIENDO UNA RELACIÓN EMPÍRICA ENTRE EL RAZONAMIENTO ESPACIAL DE LOS ESTUDIANTES DE GRADUACIÓN DE CARRERAS NO CIENTÍFICAS Y SU CONOCIMENTO CONCEPTUAL DE LA ASTRONOMÍA

Resumen: La comunidad de educación en astronomía ha supuesto de forma tácita que el aprendizaje de la astronomía consiste en un dominio conceptual fundamentado en el razonamiento espacial. Como un primer paso para identificar formalmente una relación empírica entre estas dos cosas, utilizamos como muestra los estudantes de graduación de carreras no científicas de un curso experimental en una universidad norteamericana del medioeste de porte mediano con programa de Doctorado em curso, en el cual estos estudiantes se sometieron a un diagnóstico de razonamiento espacial y conceptos astronómicos antes e después del mismo. Las herramientas utilizadas fueron el *Test Of Astronomy Standards* (TOAST) y el cuestionario *What do you know?* Utilizando solo los datos completamente consistentes para este análisis, nuestra muestra consistió en 86 estudantes de graduación. Las mejoras, depués de normalizadas, en el desempeño de los estudiantes en estos dos asuntos foram pequenas, 0.26 e 0.13 respectivamente. El razonamiento espacial de los estudiantes fue medido utilizando un instrumento específico desarrollado para este trabaljo. Las correlaciones entre los resultados de los tests astronómicos y este instrumento específico, antes y después del curso mostraron una relación entre moderada y fuerte, sugiriendo que la relación entre el razonamiento espacial y el conocimiento astronómico puede explicar hasta un 25% de la variación em el desempeño de los estudiantes.

Palabras clave: razonamiento espacial, aprendizaje de astronomía, educación en astronomía, estudios de correlación, estudiantes de carreras no científicas

1. Introduction

A largely untested assumption across the astronomy teaching community is that novice astronomy students need to learn to visualize an enormous, complex and dynamic three-dimensional universe, observed from an Earth-bound spinning observation platform. The astronomy education research community generally refers to this type of cognitive process spatial thinking or spatial reasoning. In this context this means to be able to visualize three-dimensional spaces, even if we may only have a vantage point of two dimensions, such as when one is looking at the stars from Earth. Spatial thinking also means being able to shift one's point of view from a common one to one that is far outside of one's realm of everyday experience.

Few scholars would argue against the notion that successfully learning astronomy requires broadly defined spatial thinking abilities. Many of the objects and phenomena novice students encounter are not only unfamiliar, but are rarely able to be experienced directly. Some are too small, such as atoms. Some are too big, such as the Earth as a whole. Others are too far away, such as anything beyond Earth. Each of these requires students to be able to mentally visualize these phenomena, often guided by limited two-dimensional images and technical drawings. Because experienced teachers have long observed that some students seem readily able to do this, while others seem to find this highly challenging, this observation motivates us to wonder if there might be an important relationship between students' spatial thinking ability and the ability to successfully complete certain learning tasks in astronomy. If the astronomy education research community better understands relationships between astronomy learning and spatial thinking, specific pedagogical strategies could be employed to help a broader range of students be successfully in learning astronomy.

The purpose of this study is to explore a possible relationship between spatial reasoning ability and students' ability to learn astronomy. The research questions driving this study to establish the relationship between non-science majoring undergraduate learners' spatial thinking skills and their conceptual astronomy knowledge are:

[1] Is there a relationship between students' spatial reasoning skills as measured by conventional mental rotation and spatial transformation tasks and students' abilities to learn astronomy concepts? and

[2] Do students with higher spatial reasoning ability make larger conceptual understanding gains in the most typical astronomy courses than their peers with lower spatial abilities?

The results of this study can provide astronomy instructors with a platform to develop more effective classroom activities, perhaps by promoting or scaffolding spatial reasoning skills in order to provide all students with the opportunity to learn astronomy content more effectively.

2. Literature Review

2.1 Understanding our current conceptions of the interplay between spatial reasoning and astronomy learning

The National Academies' comprehensive publication "Learning to Think Spatially" (National Academy of Sciences, 2006) provides one of the most widely read contemporary summary description of the various components of spatial thinking as related to teaching and learning, how education can foster it, and the larger implications for improved education and science learning. In terms of astronomy specifically, the authors describe at length how Eratosthenes measured the shadows thrown at midsummer's day by vertical poles in two cities and suggest that understanding this calculation requires students to utilize spatial reasoning. Although this is consistent with common sense, the authors provide no empirical evidence that this is true.

One can make the same hand-waving argument that observing planetary orbits from Earth probably requires spatial visualization. In the same way, studying objects beyond the Solar System, especially at very large extragalactic and cosmological distances, perhaps poses even further spatial thinking challenges. Various distance measurement techniques for increasing distances, also referred to as a "distance ladder," starting with parallax for nearer objects, and going to the stellar properties in the Hertzsprung-Russell Diagram, the Cepheid variable stars, and Hubble's relationship between galaxy motion and galaxy distance, enabled astronomers to find the distances, and thereby the spatial extent, of the Universe (Ch. 3.5 Spatial Thinking in Astronomy, National Academy of Sciences, 2006). Without spatial abilities, it might not be possible to translate these distance measurements into a three-dimensional view of our Universe.

All of these seem to require spatial reasoning from a common sense perspective, but no evidence in the literature confirms this suspicion.

Overall, the relationship between astronomy and spatial reasoning appears logical and compelling, but without actual data to indicate a relationship between spatial thinking ability and astronomy learning success, all of this amounts to well-educated guesswork. As a first step to improving teaching and learning of astronomy, our community needs to relate spatial thinking ability and astronomy learning empirically, in order to establish if spatial thinking ability does in fact have a positive effect on astronomy learning. Such an effort serves to help the community avoid wrong conclusions and teaching recommendations based on well-intentioned assumptions.

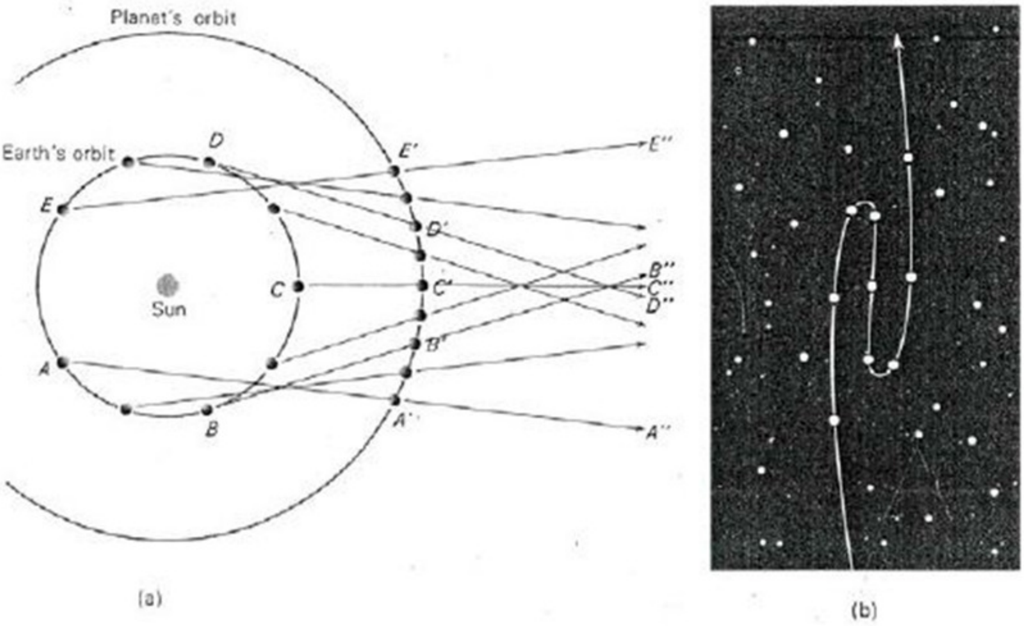
2.2 Defining Spatial Reasoning

Spatial thinking, or spatial reasoning, can be considered to be a way of thinking about spaces, orientations, rotations, movements and perspective. It can also be considered to be a set of skills that allow us to think about topics that involve distances, maps and models, both physical and digital. In this, spatial thinking involves a number of cognitive factors.

While a broad, general concept involving spatial thinking seems to be fairly uniform, the details of spatial reasoning, and therefore the ways and means to precisely and consistently measure it, differ considerably in the literature (Barnea; Dori, 1999; Carter; LaRussa; Bodner, 1987; Hegarty, 2011; Lord, 1990). Different researchers speak of spatial thinking, spatial reasoning, visual-spatial abilities, and many others. The definitions of each of these not only differ across the literature, but often a given construct definition incorporates several separate but related abilities, which makes it much more difficult to compare and contrast the various results in the literature.

2.2.1 Spatial Visualization

Spatial visualization is most often defined as the aspect of spatial reasoning describing the ability to build and manipulate mental representations of three-dimensional objects from two-dimensional image representations or from textual descriptions (Barnea; Dori 1999). Perhaps the most widely cited definition comes from Carter, LaRussa, and Bodner (1987). The authors propose that spatial visualization specifically involves the mental manipulation of a picture (two dimensions) through a process which requires recognizing and remembering a configuration that moves as a whole or in parts (three dimensions). Of the many components available, we judge that spatial transformation and mental rotation hold the most immediate promise to be related to learning astronomy. An example of visualization in astronomy would be the ability to perceive both the objects and, simultaneously, the motions in the Solar System in three dimensions, simply from the information obtained from the pictures and text in a text book. As Figure 1 illustrates on the left, an astronomy textbook might have a graphic illustrating the orbits of Earth and a more distant planet, showing how Earth as an interior planet overtakes the exterior planet in its orbit. Straight lines connecting the two planets in the graphic are meant to show the effect of retrograde motion, i.e. the appearance of the exterior planet going backwards in the sky from the point of view from the surface of the interior planet Earth (Figure 1 right). In order to be able to visualize how this would look if one saw it over time in the sky, requires the ability to mentally manipulate this motion in three dimensions over time.



(a)

(b)

Figure 1 - Outer planet's orbit as seen from Earth (National Academy of Sciences, 2006).

Spatial transformation is the particular aspect of spatial reasoning describing the ability to perceive, remember, and analyze the dynamic properties of objects and the relationships between objects. This includes mental manipulation of objects, such as rotation, reflection and inversion (Ben-Chaim; Lappan; Houang, 1988). This aspect differs from spatial visualization in that the object is not only seen from different points of view, but is mentally manipulated in order to perceive it in different ways. An astronomical example is shown in Figure 2. The left side shows a traditional text book view of the phases of the Moon from a vantage point above Earth's North Pole — a typical representation of the Solar System. The right side shows Earth as seen from lunar orbit. When posing to students a question as to the phase of the Moon the people on Earth would see at the moment this picture was taken, only students with strong spatial transformation skills would likely be able to answer this without getting confused.

In contrast, mental rotation involves mentally manipulating objects in order to perceive them from different perspectives (Barnea; Dori, 1999). An example of this might be to mentally look at stick-like representations of chemical molecular bonds in order to understand the three-dimensional structure of the molecule (Pribyl; Bodner, 1987).

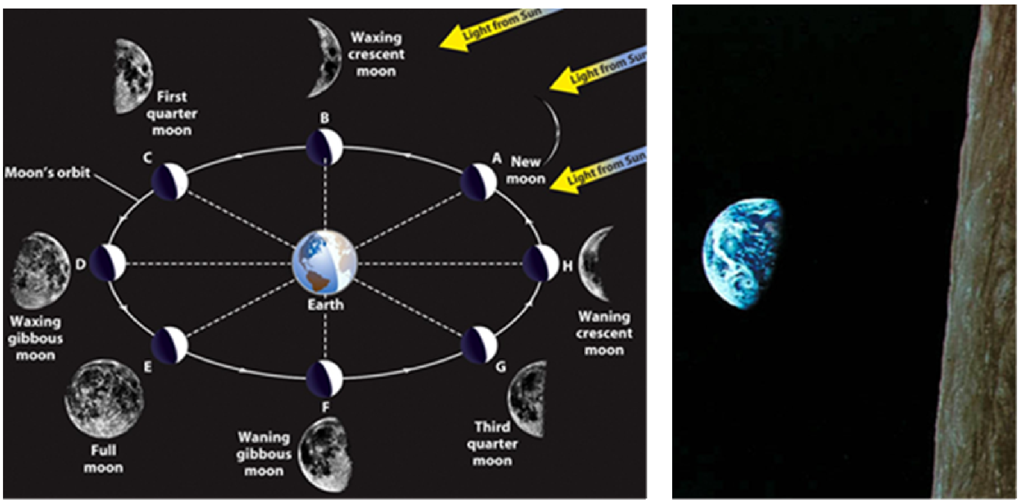


Figure 2 - The Earth-Moon system from a typical top-down text book perspective (Slater; Freedman, 2011); on the right we see Earth from the vantage point of the Moon (NASA).

2.3 Spatial Reasoning Constructs in the Context of this Study

It would be pragmatically impossible to study all of the types of spatial reasoning and astronomy thinking in the scope of the present study. Therefore, this study limits its investigation to [i] spatial transformations and [ii] mental rotations. Because of a clear lack of community consensus, studies have used a wide array of tests from different sources to investigate varied aspects of spatial reasoning. For one, the ability to mentally transform spatial configurations has been most frequently tested by several instruments. One instrument most often used is the Paper Folding Test (Baker; Talley, 1972). In this study spatial transformations will be measured using a subset of items from the Paper Folding Test, which is also referred to as the Thurstone Paper Folding Test (from "Punched Holes" by Thurstone; Thurstone, 1938, 1941). A thorough inspection of the literature indicates that this is a frequently used test and a reasonable instrument to use. These items were chosen because they have been used extensively not only in the literature, but have also been in continuous use by the Educational Testing Service (Ekstrom; French; Harman, 1976).

The ability to mentally rotate spatial configurations has also been widely tested by various instruments. The instruments most often used are the Purdue Visualization of Rotations Test (PVOR, Bodner; Guay, 1997), card rotation (Lord, 1990), and the Vandenberg Mental Rotation Test (Cohen; Hegarty, 2007). In this study mental rotation is being measured using a subset of the Vandenberg Mental Rotation Test. This instrument, which was first developed by Shepard and Metzler (1971), is being used because it has been described extensively in the literature and has shown to be consistently reliable.

2.4 Previous Correlational Studies in the Natural Sciences

An exhaustive review of the literature reveals that undergraduate students' astronomy knowledge and spatial reasoning skills have never been correlated. In fact, few studies exist at all regarding astronomy and spatial reasoning, with notable exceptions of work by Julia Plummer (2009) and Aaron Price (2011). As a result, we must look outside astronomy to better understand previous work relating spatial thinking and science overall.

To date, few studies of spatial reasoning with undergraduates studying astronomy have been published. Rudman (2002) found that spatial ability is somewhat positively correlated with problem solving performance in astronomy, regardless of the causal beliefs of subjects. In response, some curricula have been developed using a more constructivist approach by having students use and build models, using 3-D and VR technology (see for example, Barab et al. 2000), but it is still somewhat unclear how these materials specifically address spatial reasoning hurdles.

In a comprehensive review paper Hegarty (2011) examines a variety of spatial thinking issues across scientific disciplines taught in undergraduate college science courses. She reports that spatial thinking is likely a central component of scientific thinking, and that spatial ability is correlated with performance in college science courses, such as chemistry, physics, biology, medicine, and geology. As alluded to earlier, astronomy was notably absent across the literature. Hegarty also points out, that while it is tempting to believe that dynamic (animated), 3-D and interactive visualizations might compensate for lack of internal visualization ability, research to date suggests that science learners often depend on internal visualization ability for their use.

Physics is a field that may require spatial reasoning ability in order to understand concepts and solve problems. For one, Kozhevnikov and Thornton (2006) report that non-science majors' spatial visualization scores were significantly lower than those of students from the other groups. Perhaps similarly, in chemistry, Bodner & McMillen (1986) examined 600 high- and low-spatial ability students on plausibly highly spatial concepts in chemistry, finding, to their great surprise, that stoichiometry problems were highly correlated to spatial reasoning scores. Prior to this, researchers did not think that this problem would be related to spatial thinking. This critically important result calls attention to the notion that science concepts not normally associated with spatial reasoning might be so.

One might naturally assume that astronomy could be a field for which all spatial reasoning abilities could play an important role. Many phenomena seemingly require visualization, rotation, and transformation in order to make sense of them. However, there is a paucity of evidence to support this gut-level assertion. Given the limited but highly promising findings above, there is strong warrant to empirically investigate these assumptions.

Taken together, this analysis strongly suggests that researchers haven't sufficiently explored the relationship between spatial thinking and learning astronomy. A correlational study testing for both a variety of spatial abilities as well as astronomy learning specifically in spatially related domains could provide an important step forward in helping instructors at all levels to identify where and why their astronomy students experience learning difficulties.

3. Methodology

3.1 Research Context and Participants

In order to answer our research questions, we adopted a single-group, multiple measures, matched student pre/post design in an undergraduate introductory astronomy survey course held on the campus of a medium-sized, mid-western, Ph.D.-granting, research-extensive university. Known across the US as ASTRO 101, this class is usually taken by a large number of undergraduate non-science majors and future teachers to satisfy their general education science distribution requirements.

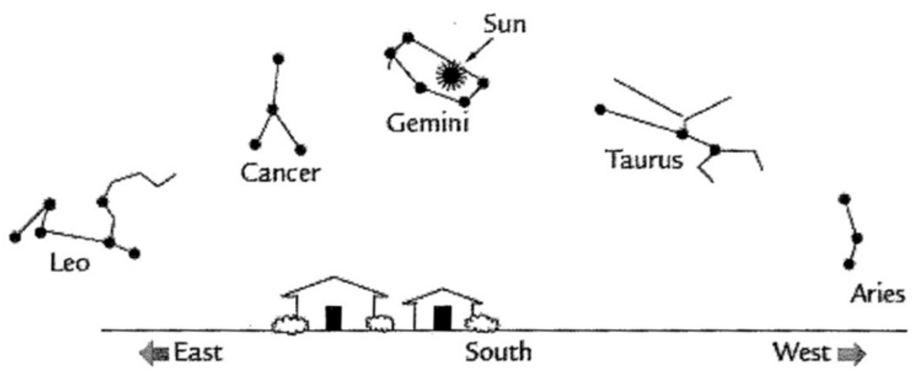
154 students were enrolled in the class, which met for three hours each week for traditional lecture and two hours each week for a laboratory-style class meeting The participant demographics mirrored the larger population at the university (82% white/Caucasian, 4% Hispanic, 1% Asian, 1% black, 1% native American, 11% other; source: University Office of Institutional Analysis). Informed consent was implemented as per IRB guidelines.

3.2 Assessment Instruments

Three instruments were used to measure conceptual astronomy knowledge and spatial thinking abilities of the student-participants.

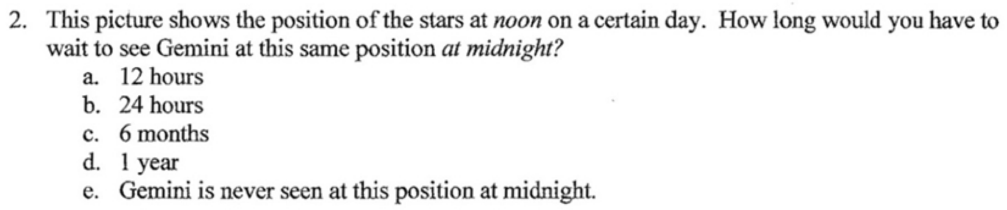
To measure astronomy content knowledge, we administered two surveys, the Test Of Astronomy STandards (TOAST, Slater et. al, 2011) and the What Do You Know (WDYK, Morrow, 2000, 2004; Parker, 2007), both pre- and post-course. These tests have been widely used and cited in the literature, and within the astronomy education community (Figures 3 to 6).

Use the drawing below to answer the next <u>two</u> question.



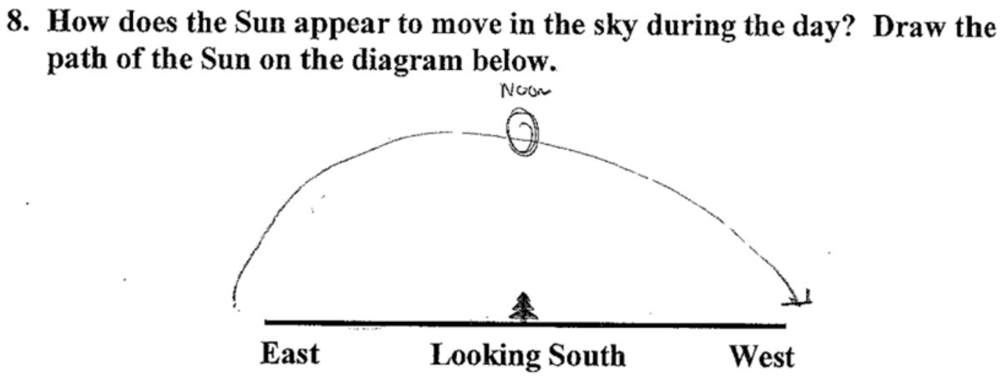
1. If you could see stars during the day, the drawing above shows what the sky would look like at *noon* on a given day. The Sun is at the highest point that it will reach on this day and is near the stars of the constellation Gemini. What is the name of the constellation that will be closest to the Sun at sunset on this day?
   a. Leo
   b. Taurus
   c. Aries
   d. Cancer
   e. Gemini

Figure 3 - Example items from the TOAST.



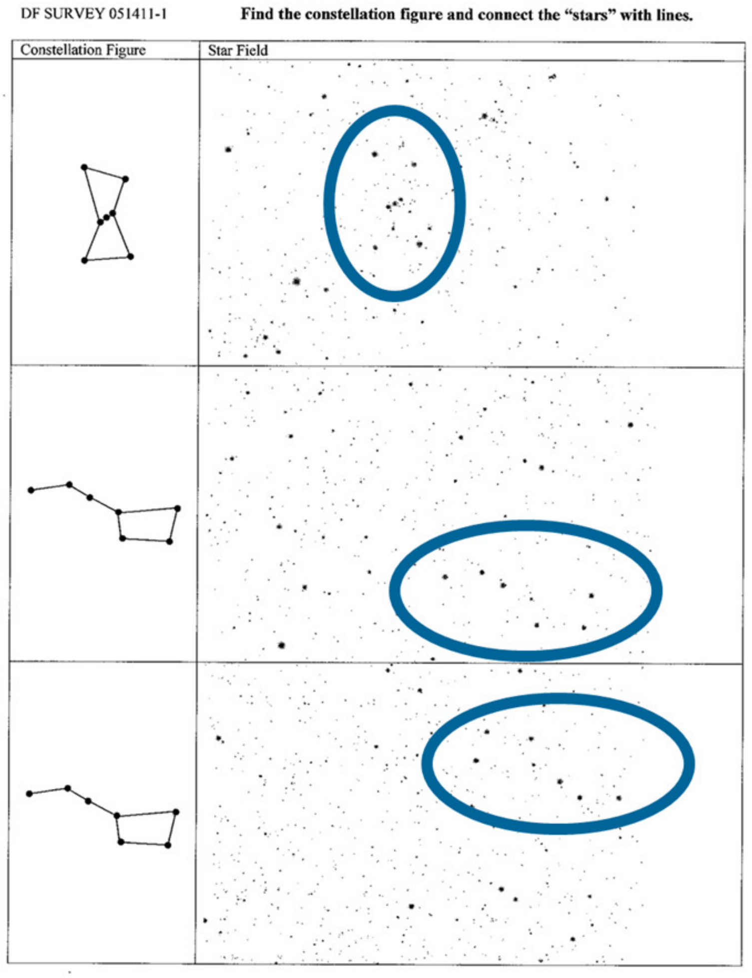
2. This picture shows the position of the stars at *noon* on a certain day. How long would you have to wait to see Gemini at this same position *at midnight?*
   a. 12 hours
   b. 24 hours
   c. 6 months
   d. 1 year
   e. Gemini is never seen at this position at midnight.

Figure 4 - Example items from the TOAST.



8. How does the Sun appear to move in the sky during the day? Draw the path of the Sun on the diagram below.

Figure 5 - Example student response for a WDYK question.



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Find the constellation figure and connect the "stars" with lines.

Figure 6 - Example item (with illustrative answer) from the TOAST.

To quantitatively measure spatial thinking abilities, we administered a single two-part spatial reasoning instrument adapted by the second author from three well known spatial abilities assessments. This survey was only given once to purposefully avoid the test-retest gains that often occur with these sorts of spatial reasoning instruments as student scores improve slightly each time they take the test. The first component comes from the Vandenberg Mental Rotation Test, designed to measure spatial rotation. It was originally developed by Shepard and Metzler (1971) and adapted by Vandenberg and Kuse (1978). The images were redrawn more recently due to deterioration of the originals (Peters et. al, 1995) (Figure 7). The second component comes from of The Paper Folding Test-Vz-2, taken from "Punched Holes" by Thurstone and Thurstone (1938; 1941). The original has been adapted and is used by the Educational Testing Service (Ekstrom; French; Harman, 1976) (Figure 8).

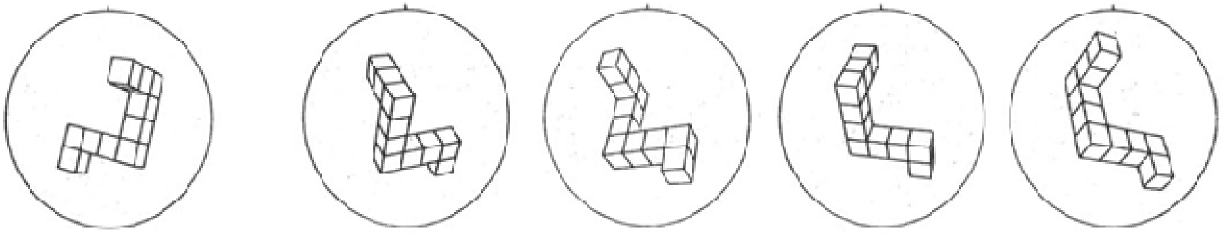

Figure 7 - Sample item from the Vandenberg Mental Rotation Test.

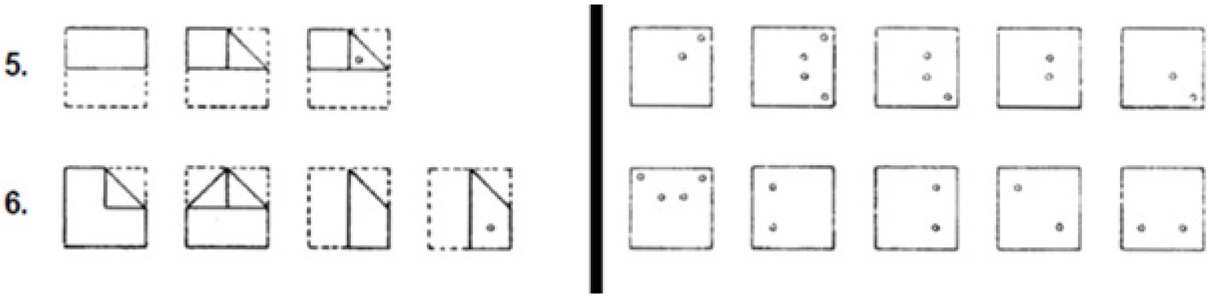

Figure 8 - Sample items from the Thurstone Paper Folding Test (spatial transformation).

During the following four days after the post-course astronomy tests were administered, 14 student volunteers (compensated with $20) completed parts of the astronomy and spatial tests again, but this time using a talking aloud protocol describing their thinking processes. The purpose of these 45-minute interviews was to further validate the interpretation of student thinking processes during the tests (Figure 9).

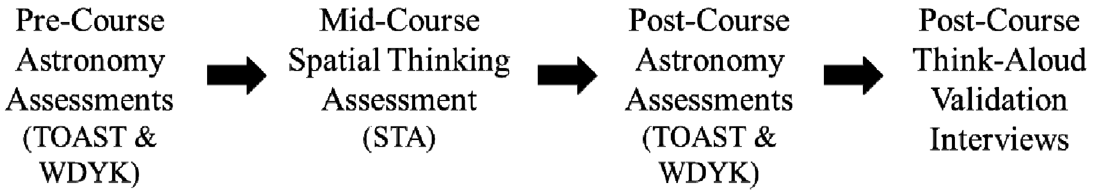

Figure 9 - Methodology sequence.

4. Results

4.1 Astronomy Scores

To determine the participants' level of conceptual knowledge, we administered the TOAST and the WDYK instruments pre-course and post-course. Using only fully matched data for analysis, 86 undergraduate non-science majors (49 males & 37 females), students' normalized gains for astronomy surveys were low at .26 and .13 respectively. During the middle of the term, students' spatial thinking was measured using an instrument designed specifically for this study.

	Pre-test (%)	Post-test (%)	Normalized gain (<g>)
TOAST	37.2%, SD: 16.0	53.5%, SD: 18.5	0.263, SD: 0.229
WDYK	61.4%, SD: 14.1	68.0%, SD: 14.7	0.126, SD: 0.361

Table 1 - Average scores and normalized gain for the two astronomy assessment instruments.

As summarized in Table 1, we found that overall the gains in the astronomy scores measured by the two instruments (TOAST, WDYK) were quite low. This means that students leave this class not being able to answer questions on about a third of the material. This result foreshadows that any correlations involving the gains are going to be correspondingly small.

The Cronbach's α reliability scores for our astronomy assessment instruments were 0.75 for the pre-course TOAST, 0.81 for the post-course TOAST, 0.54 for the pre-course WDYK, and 0.64 for the post-course WDYK. Ideal values are between 0.7 and 0.8, while values below 0.3 would indicate problems with the instrument (Field, 2009).

The effect size for the TOAST is 1.02, and the effect size for the WDYK is 0.47. An effect size of 0.20 is considered small, 0.50 is medium, and 0.80 is large (Ary; Jacobs; Sorensen, 2010).

4.2 Spatial Thinking Scores

To determine the level of participants' spatial reasoning ability, we investigated the scores on spatial thinking instruments both combined as well as separately. The average mental rotation score was 66.3% correct (SD: 26.8). The average spatial transformation score was 60.1% correct (SD: 18.9). The average total (rotation and transformation) score was 63.1% correct (SD: 18.8).

4.3 Correlations between Astronomy Scores and Spatial Thinking Scores

In order to investigate possible relationships between the astronomy scores and the spatial thinking scores we performed Pearson r correlations between the pre- and post-course astronomy scores of the two instruments and the two spatial thinking scores, both combined and separate.

Table 2 summarizes the correlation coefficients found. '*' indicates a P-value of $p < .05$, '**' indicates a P-value of $p < .01$, and 'n.s.' indicates that the correlation is not statistically significant. The number of participants comprised 86 students; therefore the number of degrees of freedom was 84. 'ROT' refers to mental rotation, and 'TRANS' refers to spatial transformation.

Examining the correlations between the astronomy gains and the spatial thinking scores, we find statistically significant relationships between the TOAST normalized gain and mental rotation scores (r(84) = .26, p < .01). We also find a statistically significant relationship between the WDYK normalized gain and spatial transformation scores (r(84) = .18, p < .05). All other relationships appear not to be statistically significant.

	ROT	TRANS	SPATIAL TOTAL
TOAST pre	.40 **	.36 **	.46 **
TOAST post	.48 **	.37 **	.52 **
TOAST <g>	.26 **	.17 n.s.	.27 **
WDYK pre	.31 **	.19 *	.31 **
WDYK post	.43 **	.36 **	.49 **
WDYK <g>	.13 n.s.	.18 *	.19 *
ROT	---	.37 **	.87 **
TRANS	.37 **	----	.78 **
SPATIAL TOTAL	.87 **	.78 **	---

Table 2 - Pearson r correlations between astronomy pre-course, post-course, and normalized gain scores for the TOAST and WDYK astronomy tests and the two spatial thinking tests.

We see moderate to strong relationships between both pre- and post-course astronomy scores and the rotation (cubic worms) and transformation (paper folding) spatial tests. We see statistically significant, strong relationships between the TOAST pre- course and mental rotation score (r(84) = .40, p < .01), as well as the TOAST pre-course and spatial transformation score (r(84) = .36, p < .01). Similarly, WDYK pre-course and post-course scores show significant, moderately to strong relationships to the mental rotation and spatial transformation scores.

The statistical correlations of .49 and .52 between the astronomy post-scores and the spatial thinking score seems to indicate that the relationship between spatial reasoning and astronomy ability explains about 25% of the variation in the data.

4.4 Interviews

During the open coding of the student participant interviews, three common themes and issues emerged. The first theme involves the mental rotation task (cubic worms). When asking the students about the spatial rotation task, some of them described rotating the figure as a whole in their heads, whereas others described rotating it in parts.

A second theme speaks to the paper folding (origami) task. All students described unfolding the paper in their heads, and marked the holes on the figures as they unfolded. Some used their hands or folding the test paper to help demonstrate to the interviewer how they visualized the folding.

The third theme involved one of the astronomy tasks. Everyone found the TOAST task addressing the stellar spectra the most difficult. Many swore their professors had not covered this in class, while all instructors assured us independently that this was covered in both lecture and laboratory exercises (Figure 10).

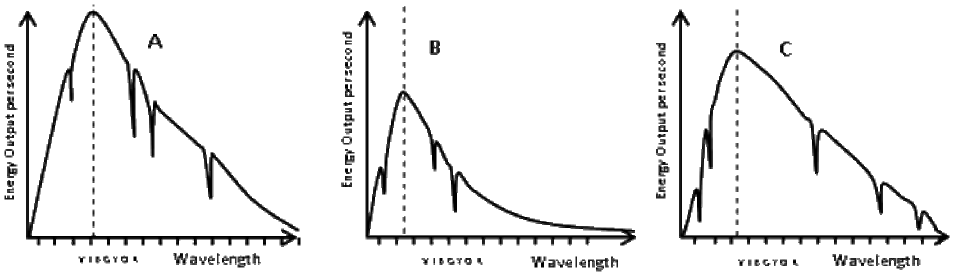

Figure 10 - Stellar spectra comparisons from the TOAST.

Taken together, the interview data strongly suggests that the astronomy and spatial reasoning items were valid in eliciting student thinking. The interviews revealed that students understood what the questions were asking in the way the research team intended. Furthermore, the interviews demonstrated that students were selecting the responses they did for the reasons we believed they were.

5. Discussion

In looking at the test results in more detail, it becomes clear that the students entered this course with many preconceptions. Frequently they did not realize that the Solar System only has one star, or that the number of times they have gone around the Sun equals their age in years. And more than half believe the seasons are caused by a varying distance of the Earth to the Sun.

Considering results overall, students came out not knowing 30% to 50 % of the material. Consulting their test papers again, we still see the same prevailing misconceptions documented in the literature (Bailey; Slater, 2004).

While the astronomy score gains may have been low and therefore not conducive to producing meaningful correlations in and of themselves, the relationships found between the separate pre-course and post-course astronomy scores and the spatial thinking scores appears to be much more revealing. The two spatial thinking scores (rotation and transformation) showed a moderate to strong relationship to the astronomy scores. With statistically significant ($p < .01$) correlations mostly between .3 and .5, we suggest that there exists a measurable relationship between spatial thinking ability and astronomy content knowledge.

It seems clear that, much as suggested by the literature describing other scientific disciplines, there is a connection between spatial thinking ability and the facility to learn astronomy content.

It would be most illuminating to administer the astronomy learning and spatial thinking assessment instruments to a class taught not in the traditional lecture format, but in a more modern, learner-centered format, such as inquiry. As was suggested in some of the literature for other scientific disciplines, it would be interesting to know if high spatial thinkers achieve more in astronomy courses, but it was not visible in the context of this study due to the lack of large gains.

The establishment of a relationship between students' spatial reasoning skills and their ability to learn astronomy concepts by this study further motivates the astronomy education research community to systematically determine which of the many available astronomy concepts are directly tied to spatial reasoning. For example, specifically how does understanding or misunderstanding Solar System dynamics or Big Bang cosmology depend on spatial reasoning? Astronomy is ripe for a systematic deconstruction of astronomy concepts along this line of research.

If spatial reasoning is indeed teachable and retainable as suggested by Ben-Chaim, Lappan and Houang (1988), then faculty might enhance student learning of astronomy by including spatial skills tasks early in the semester. As suggested by many studies summarized by Hegarty (2011), it would benefit all students, but especially the weaker spatial thinkers, to include activities, in both lecture and laboratory sections, that promote enhanced spatial thinking. Ideally, students should engage in spatial reasoning activities starting in elementary school, but given that university faculty could hardly influence that, we can at least give our students spatial training as early in their university science careers as possible.

What type of training could be used to help students improve their spatial reasoning abilities, or at least better perform in spatially dependent contexts? Slater et al. (2011) and Morrow (2000; 2004) have advocated various kinesthetic astronomy activities teaching constellations and the seasons. To be clear, these activities do not enhance students' spatial reasoning; rather, they provide cognitive scaffolding to help students solve complex problems rich in spatial reasoning characteristics.

Figure 11 illustrates an example of another student astronomy activity facilitating spatial reasoning (activity developed by the author). On the left is a classic text book graphic of the constellation Orion. The stick-figure-like representations of constellations are like maps of the sky, showing the locations and two-dimensional distances of the stars. The dimension of distance is not one we perceive looking up from Earth, at least not without the assistance of instrumentation. This is the real distance of these various stars. From a table of distances in the star catalogue, a student constructed a three-dimensional model of the Orion constellation, as shown on the right in Figure 3. In this task, she had to create the three-dimensional layout of the constellation from the directions and distances given. The end result is a three-dimensional model that demonstrates the actual differing distances among the stars.

There are some specific ideas professors can use to help students understand concepts we are currently trying to teach across STEM, but there is still a large knowledge and experience gap regarding spatial reasoning intervention for all levels of education. The current studies certainly help, but are admittedly insufficient. Researcher and teachers are well poised to close the spatial reasoning gap between high and low spatial reasoners much earlier in their student careers. If the gap is closed earlier, the students appear to have much broader choices available later regarding high school classes and college majors. Pallrand and Seeber (1984) concluded that, while the students will likely not be conscious of it, their choices to take science vs. humanities classes are influenced by their spatial ability. We're not advocating every student should become a scientist, but learners should be able to have wide choices, instead of being constrained from the outset by moldable spatial abilities.

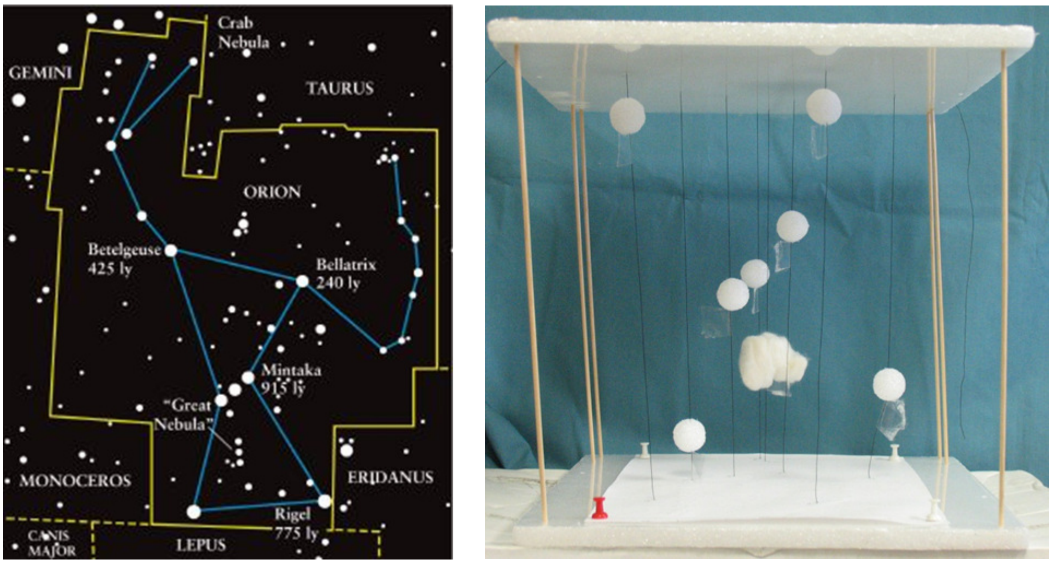

Figure 11 - The Orion constellation in 2-D from a text book (Slater; Freedman, 2011) and in 3-D as a student-made model (author).

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References

ARY, D.; JACOBS, L. C.; SORENSEN, C. **Introduction to Research in Education**. 8. ed. Belmont, CA: Wadsworth, 2010.

BAILEY, J. M.; SLATER T. F. A Review of Astronomy Education Research. **Astronomy Education Review**, v.2, n.2, p.20, 2004.

BAKER, S. R.; TALLEY, L. The relationship of visualization skills to achievements in freshman chemistry. **Journal of Chemical Education**, v.49, n.11, p.775, 1972.

BARAB, S. A. *et. al*. Virtual solar system project: Building understanding through model building. **Journal of Research in Science Teaching**, v.37, n.7, p.719, 2000.

BARNEA, N.; DORI, Y. J. High-school chemistry students' performance and gender differences in a computerized molecular modeling learning environment. **Journal of Science Education and Technology**, v.8, n.4, p.257, 1999.

BEN-CHAIM, D.; LAPPAN, G.; HOUANG, R. T. The effect of instruction on spatial visualization skills of middle school boys and girls. **American Educational Research Journal**, v.25, n.1, p.51, 1988.

BODNER, G. M.; GUAY, R. B. The Purdue visualization of rotations test. **The Chemical Educator**, v.2, n.4, p.1, 1997.

BODNER, G. M.; MCMILLEN, T. L. Cognitive restructuring as an early stage in problem solving. **Journal of Research in Science Teaching**, v.23, n.8, p.727, 1986.

CARTER, C. S.; LARUSSA, M. A.; BODNER, G. M. A study of two measures of spatial ability as predictors of success in different levels of general chemistry. **Journal of Research in Science Teaching**, v.24, n.7, p.645, 1987.

COHEN, C. A.; HEGARTY, M. Individual differences in use of external visualisations to perform an internal visualisation task. **Applied Cognitive Psychology**, v.21, n.6, p.701, 2007.

EKSTROM, R. B.; FRENCH, J. W.; HARMAN, H. H. **Manual for kit of factor-referenced cognitive tests**. Princeton, NJ: Educational Testing Service. 1976.

FIELD, A. **Discovering Statistics Using SPSS**.3. ed. Thousand Oaks, CA: Sage Publications. 2009.

HEGARTY, M. The Role of Spatial Thinking in Undergraduate Science Education. **Commissioned paper by the National Research Council**. 2011. Available at <http://www7.nationalacademies.org/bose/DBER_Hegarty_December_Paper.pdf>.

KOZHEVNIKOV, M.; THORNTON, R. Real-time data display, spatial visualization ability, and learning force and motion concepts. **Journal of Science Education and Technology**, v.15, n.1, p.111, 2006.

LORD, T. R. Enhancing learning in the life sciences through spatial perception. **Innovative Higher Education**, v.15, n.1, p.5, 1990.

MORROW, C. A. Kinesthetic Astronomy: The Sky Time Lesson. **Physics Teacher**, v.38, n.4, p.252, 2000.

MORROW, C.; ZAWASKI, M. **Kinesthetic Astronomy**. Space Science Institute: Education: Instructional Materials. 2004. Available at: <http://www.spacescience.org/education/index.html>.

NATIONAL ACADEMY OF SCIENCES. **Learning to Think Spatially**, National Academies, 2006.

PALLRAND, G. J.; SEEBER, F. Spatial ability and achievement in introductory physics. **Journal of Research in Science Teaching**, v.21, n.5, p.507, 1984.

PARKER (SLATER), S. J. **The Impact of a Kinesthetic Astronomy Curriculum on the Attitudes, Self-efficacy and Content Knowledge of High School Students, Master's Thesis**. Montana State University, Bozeman, 2007.

PETERS, M. *et. al.* A Redrawn Vandenberg and Kuse Mental Rotations Test: Different Versions and Factors That Affect Performance. **Brain and Cognition**, v.28, n.39, 1995.

PLUMMER, J. D.A cross-age study of children's knowledge of apparent celestial motion. **International Journal of Science Education**, v.31, n.12, p.1571, 2009.

PRIBYL, J. R.; BODNER, G. M. Spatial ability and its role in organic chemistry: A study of four organic courses. **Journal of Research in Science Teaching**, v.24, n.3, p.229, 1987.

PRICE, A. **Scientific Literacy of Adult Participants in an Online Citizen Science Project**. Dissertation, 2011. Available at: <http://udini.proquest.com/view/scientific-literacy-of-adult-pqid:2295835721/>.

RUDMANN, D. S. Solving Astronomy Problems Can Be Limited by Intuited Knowledge, Spatial Ability, or Both. **Paper Presented at the Annual Meeting of the American Educational Research Association** (New Orleans, LA), 1. 2002.

SHEPARD, R. N.; METZLER, J. Mental Rotation of Three-Dimensional Objects. **Science (new series)**, v.171, n.3972, p.701, 1971.

SLATER, S. J. *et. al.* **Discipline-based Education Research**: A Scientist's Guide. New York, NY: W. H. Freeman, 2011.

SLATER, T. F.; FREEDMAN, R.A. **investigating astronomy**. New York, NY: W. H. Freeman, 2011.

THURSTONE, L. L. **Primary Mental Abilities**. Chicago: Chicago University, 1938.

THURSTONE, L. L.; THURSTONE, T. G. **Factorial Studies of Intelligence**, Chicago: Chicago University, 1941.

VANDENBERG, S. G.; KUSE, A. R. Mental Rotations: A group test of three-dimensional spatial visualization. **Perceptual and Motor Skills**, v.47, n.2, p.599, 1978.