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Stellar Ideas: Exploring Students' Understanding of Stars

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Abstract

In this study, high school and first-year undergraduate students were asked about their understanding of stars. The hypothesis guiding this research posits that high school students who have taken a semester-long astronomy course will have an understanding of stars most related to scientific knowledge, compared with high school students enrolled in an earth science course and undergraduate students who have not received formal astronomy instruction. This study uses semistructured interviews to investigate students' ideas about the relationship between the Sun and stars, the nature of stars (What is a star?), and the distances between stars. The results indicate that astronomy instruction at the high school level can be effective at developing students' knowledge about stars in a short period of time. Specifically, students' knowledge about stars is enhanced through their understanding of nuclear fusion as the process of energy production in stars. Students who are not enrolled in astronomy at the high school level tend to focus on secondary characteristics of stars, such as size and color.

1. INTRODUCTION AND LITERATURE REVIEW

1.1. Research Addressing K-12 Astronomy Instruction

The memorable video *A Private Universe* (Schneps 1989) documents the responses of Harvard graduates and faculty members who were asked about the cause of seasonal changes on Earth. As the filmmakers explain, the topic of the Earth's seasons is covered in most K-12 science classrooms. This topic is often studied at the middle school level as recommended by the *National Science Education Standards* (National Research Council 1996). Nonetheless, *A Private Universe* reveals that 21 of 23 interviewed participants did not know the correct explanation for seasonal change. Most participants incorrectly cited the changing Earth-Sun distance as the factor that determines seasonal change, instead of the correct factor: the tilt of the Earth's axis. The researchers in this study continued their interviews in a nearby high school classroom and questioned students about their understanding of the seasons and the phases of the Moon. The study focuses on students' misconceptions--ideas that disagree with scientific knowledge. *A*

Private Universe encourages science educators to consider students' initial ideas about astronomical content and to ask the "right" questions in order to understand their students' ideas.

In the field of astronomy education, many researchers have considered ideas held by students in order to inform educators and curriculum developers. There is a growing body of research concerning students' ideas about astronomical topics covered in the national K-12 curricula. Much of this research has focused on the relationship between the Sun, the Earth, and the Moon, concepts recommended for instruction in elementary and middle school by the *National Science Education Standards* (National Research Council 1996). Quite a few studies have focused on the concept of the Earth's shape and gravity (Butterworth et al. in press; Nussbaum & Novak 1976; Nussbaum 1979; Mali & Howe 1979; Nobes et al. 2003; Sneider & Ohadi 1998; Sneider & Pulos 1983; Samarapungavan, Vosniadou, & Brewer 1996; Schoultz, Saljo, & Wyndhamn 2001; Vosniadou & Brewer 1992) and have followed the paradigm initiated by Jean Piaget for investigating students' ideas, known as the clinical interview method (Piaget 1951). Astronomy education researchers have also explored K-12 students' understanding of the day/night cycle (Vosniadou & Brewer 1994), phases of the Moon (Barnett & Morran 2002; Dai 1992; Rider 2002; Schneps 1989; Stahly et al. 1999), and the causes of seasonal change (Schneps 1989).

Few astronomy education studies have considered K-12 students' ideas about stars, galaxies, and the Universe (Bailey & Slater 2003), topics central to the high school earth and space science *National Science Education Standards* (National Research Council 1996) and central to the work of most professional astronomers. Adams & Slater (2000) pointed out this gap in the research literature: "For the upper grades, almost no work has been done on student concepts of the origin, characteristics, and evolution of the solar system, the stars, or the Universe. This research focus will have to start from a very small knowledge base." In addition to this shortage of research, high schools throughout the country regularly lack programs that provide formal instruction in astronomy (Barstow et al. 2002). The purpose of the current study is to add to the "knowledge base" in astronomy education by exploring high school and undergraduate students' ideas about stars, and considering the impact of an astronomy course taught at the high school level.

Neil Comins (2001) offered some examples of misconceptions that undergraduate students hold about stars in his book *Heavenly Errors*. He noted, "the most commonly cited incorrect astronomical beliefs" include the following ideas about stars:

- Stars really twinkle.
- Polaris, the North Star, is the brightest star in the sky.
- A shooting star is actually a star falling through the sky.
- The Sun is a unique object, not a star.
- The Sun/stars will last forever.
- The Sun shines by burning gas or from molten lava.
- The Sun doesn't rotate.
- The Sun is solid.
- All stars are yellow.
- There are many stars in the Solar System.

The findings were recorded through Comins's role as an astronomy professor, and they serve to exemplify possible ideas that students have about stars. However, Comins did not explore these ideas through further questioning, and he did not compare responses between students of different educational backgrounds or ages. Clearly, systematic research on student understanding of stars could add to the research literature and guide curriculum development in this subject area.

1.2. Understanding Students' Ideas

Insofar as the research reported here identifies concepts common to students' understanding of stars, the present study mirrors Nussbaum & Novak's (1976) early research into students' ideas about the Earth's shape and gravity. In this seminal work, these researchers employed semistructured interviews and identified different notions or concepts that students seemed to hold prior to developing a scientific understanding of the Earth's shape and gravity. Vosniadou, Brewer, and their colleagues further developed this work by identifying mental models related to the notions that Novak and Nussbaum described (Samarapungavan, Vosniadou, & Brewer 1996; Vosniadou 1992, 1994; Vosniadou & Brewer 1987, 1992, 1993, 1994). These mental models, or complete ideas, were based on presuppositions that Vosniadou described as concepts formed from everyday experience and observation (Vosniadou 1994). Vosniadou and Brewer's research suggested that children progress through a sequence of mental models in their understanding of the Earth's shape and gravity, starting with an initial model based on presuppositions defined as "empirically acquired domain-specific constraints, products of an inferential process based on everyday experience" (Vosniadou 1994). Specifically, presuppositions related to the concept of the Earth's shape and gravity include the ideas that the Earth is flat, and things fall downward. As children are exposed to scientific knowledge that the Earth is shaped like a sphere, they will attempt to reconcile their former presuppositions with new scientific information, thereby forming a synthetic model to explain the shape of the Earth. An example of a synthetic model related to the shape of the Earth that Vosniadou and Brewer identified is the "dual-Earth" model, in which a child considers the ground below to be part of the flat Earth, while a separate spherical Earth exists in space. In this example, the child retains the presupposition that the Earth is flat, and synthesizes it with the information that the Earth is shaped like a ball. Finally, children abandon the use of presuppositions and develop a scientific model of the Earth's shape that is based on scientific knowledge.

Vosniadou and Brewer's research supports their conclusion that the transition to new models in students' understanding requires either a suspension or a revision of presuppositions, and may result in various synthetic models of understanding depending on how the presuppositions are addressed (Vosniadou 1994). The present study identifies possible presuppositions that students may use in their understanding of stars (see Table 1). With the understanding that these presuppositions are empirically acquired, this article uses the interview responses of the research participants as evidence for presuppositions related to stars. The ideas that students have about stars may be determined by the relationship between these presuppositions, by concepts formed from everyday experience and observation, and through scientific knowledge learned from a textbook or teacher. Presuppositions related to students' ideas about stars are considered throughout the results section, and possible mental models tied to this topic are explored in section 5.

Table 1. Presuppositions Related to the Nature of Stars

Presupposition 1: The Sun is bigger than other stars.
Presupposition 2: A star is made of fire or lava.
Presupposition 3: Stars and planets differ primarily because of their composition or size.
Presupposition 4: Stars are small, nearby objects.
Presupposition 5: A star's distance relates to its apparent brightness in the sky.

The present study represents an initial exploration of students' understanding about stars through an analysis of three distinct groups of students: first-year high school students with no formal astronomy instruction, first-year undergraduate students with no formal astronomy instruction, and fourth-year high school students with one semester of astronomy instruction, including instruction about stars. Because of the small sample of participants (17 students total), this study must be considered exploratory. The hypotheses that guide this work are (1) that first-year high school students with no formal astronomy instruction will have an understanding of the nature of stars that relies most heavily on presuppositions (ideas based on everyday experience) and is furthest from current scientific understanding; (2) that first-year undergraduate students with no formal astronomy instruction may have an understanding of the nature of stars that is closer to current scientific knowledge than first-year high school students' understanding, but these undergraduate students may lack some specific astronomical content knowledge; and (3) that fourth-year high school students with a semester of astronomy instruction will have an understanding of the nature of stars that is closest to current scientific knowledge. Difference in content knowledge between the latter two groups can best be explained by educational experience rather than developmental ability because the students interviewed here are close in age (the fourth-year high school students are generally only one year younger than the first-year undergraduate students). Because astronomy is not a required content area in many high schools, a sample of first-year undergraduates does not guarantee any specific educational background in astronomy. An alternative possibility is that the undergraduate students will have the best understanding of the nature of stars because they attend college and may represent a select sample with more academic success.

2. METHODOLOGY

2.1. Sample

The research presented here is based on the responses of eight high school freshmen ages 14 and 15 who have received minimal astronomy instruction as part of an earth science course (Group 1: ES); five first-year undergraduate students ages 18 and 19 (Group 2: UN) who have not received formal astronomy instruction at college or high school levels; and four high school juniors and seniors ages 16 to 18 (Group 3: AS) who were completing a semester-long astronomy class at the time of the study. The high school freshmen were completing a nine-week earth science class at the time of the study.

The earth science and astronomy high school students shared a classroom and a teacher at a public high school in a suburban area of southeastern Massachusetts. The school's population is racially mixed with a majority of white students, and the area includes primarily middle-income families. The teacher's academic background includes an undergraduate major in geology, and he is currently an avid amateur astronomer. In fact, he developed the astronomy course at the high school, and he created and advises the students' extracurricular astronomy club. The classroom in which he teaches the earth science and astronomy courses is well decorated with scientific and cultural posters, including posters identifying different types of spacecraft, posters of astronomical objects like nebulae and galaxies, and posters of popular movies. The astronomy club's telescope is stored in one corner of the classroom, and a few lab benches on the sides of the room house supplies, including globes of the Earth, the Moon, Venus, Mars, and the celestial sphere. The classroom environment is filled with astronomical information. Thus, even though the earth science course offers limited instruction in astronomy, the students in this course had access to a wealth of astronomical information and materials.

The earth science course covers the following topics: scientific skepticism, the difference between scientific laws and scientific theories, the formation of the Solar System (material including the identification of the Sun as a star, but no exploration of stars or stellar evolution), plate tectonics (including earthquakes and volcanoes), mapping and GPS, glaciers, and rivers. All students are required to take this earth science course or a similar physical science course.

The astronomy course covers the following topics: the history of astronomy, the tools of the astronomer, planetary astronomy, stellar evolution, and cosmology. Students learn that stars produce their own energy, although the teacher does not explore the details of nuclear fusion. The astronomy course is an elective for juniors and seniors, and many of the students enrolled have taken the earth science course with this teacher in previous years.

The undergraduate students interviewed as part of this study attended a private liberal arts college in southeastern Massachusetts. Approximately 65% of the students in this college receive some form of financial aid. Of the five students who participated in this study, three were enrolled in a year-long introductory physics course that covered the following topics: kinematics (laws of motion), sound, electricity and magnetism, and optics. The two other undergraduate students had not yet taken a science course at the college level. None of the five students reported receiving any formal instruction in astronomy during high school.

2.2. Data Collection

Each student was interviewed for 15 to 30 minutes. The high school students were interviewed during their astronomy or earth science courses throughout May in a nearby office. All of these semistructured interviews were audiotaped and included directed questions and discussion. The interview questions used in this study are listed in Table 2. These questions may be modified for future research so that any impact on the students' responses can be minimized (see section 5).

Table 2. Interview Questions

1. What is a star?
2. How do stars shine?
3. What is the difference between a star and a planet?
4. Where do stars come from/how are they formed?
5. Do stars change over time?
6. Is there anything left after a star stops shining?
7. How do stars differ from one another?
8. What is the difference between the Sun and stars?
9. What's the nearest star to the Earth?
10. What are the distances to stars? If the Earth were 1 inch in diameter, how far away would the Sun/nearest star be?

2.3. Method of Analysis

The purpose of the interview questions was to identify elements of the students' understanding and investigate their ideas. Specifically, students were questioned about the relationship between the Sun and stars, the nature of stars (i.e., What is a star?), and the distances between stars. An analysis of student responses focuses on the interview questions related to each concept, the consideration of possible guiding presuppositions, the scientific understanding of stars, and a comparison between the three participant groups. The scientific understanding of stars considered in this article acts as a comparison for student responses.

3. RESULTS

3.1. The Sun as a Star

The identification and description of the Sun as a star was explored through interview questions 8 (What is the difference between the sun and stars?) and 9 (What is the nearest star to the Earth?).

The simplest observation for one to make about the relationship between the Sun and stars is that the Sun is visible in the daytime, while stars are visible at nighttime. This observation may support the idea that the Sun and stars are different types of objects altogether, an idea that Neil Comins (2001) documented in *Heavenly Errors*. However, students in the present study did not offer evidence for this idea, so it was not identified as a presupposition. Nonetheless, the recognition of observable differences between the Sun and stars did impact students' ideas and led to the identification of a related presupposition. The Sun appears much bigger in the sky than stars, so a likely idea may be that the Sun is, in fact, bigger than other stars. Astronomers recognize the Sun as a low-mass star on the main sequence (a classification that designates hydrogen fusion as the primary energy source of the star). The Sun has been identified as one of approximately 300 billion stars in the Milky Way galaxy, which is one of approximately 50 billion galaxies in the Universe. The Sun is the center of our Solar System and the closest star to the Earth (the next closest star, Proxima Centauri, is located some 4.2 light years away). Astronomers estimate the Sun's age (and, therefore, the Solar System's age) to be 4.5 billion years, with a remaining 4.5 billion years before the Sun stops fusing hydrogen in its core.

3.1.1. Group 1: ES

None of the earth science students identified the Sun as the closest star to Earth when asked in the interview. For example,

> LA: Do you have an idea what the nearest star to the Earth is?
> ES6: Can I take a guess? Is it the North Star?

However, the students' responses to the comparison between the Sun and stars (question 8) revealed their knowledge that the Sun is a star. The inconsistency of the answers to the two different questions illustrates clearly that students often have multiple conflicting conceptions because they compartmentalize information.

All of the earth science students described the difference between the Sun and other stars as related to the Sun's bigger size (presupposition 1), while only one student directly commented on its closer distance to the Earth. A typical answer differentiating the Sun from other stars follows. Note that this same student did not identify the Sun as the nearest star to the Earth in the transcript above. The researcher did not point out the conflict between such responses during the interviews.

> LA: What's the difference between the Sun and stars?
> ES6: The Sun's way, way bigger. I think maybe it's composed of different, of slightly different, not very big--it's just a bigger star.

Two students in this group indicated that stars were dispersed throughout the Solar System (see section 3.2.1).

3.1.2. Group 2: UN

In the undergraduate group, the three students with stronger science backgrounds identified the Sun as the star nearest Earth, while the other two students did not. These two students incorrectly cited the North Star as the closest star to the Earth. This identification may be related to the common "misconception" documented by Comins (2001) that the North Star is the brightest star in the sky (Sirius is the brightest star, besides the Sun, visible from the northern hemisphere). It seems reasonable for students to hypothesize that the brightest star is closest to Earth. For example, UN 5: The closest star? I have no idea. I’ve only heard of the North Star or whatever, but I don’t know.

Distinctions between the Sun and other stars were not explicitly questioned with this group, although one student regularly referred to the Sun as "our local star," clearly indicating the similarities between the Sun and stars. The undergraduate students were not asked question 8 (see Table 2) because of changes in the semistructured interview questions (this question was added to the interviews after some research had been completed). Therefore, presupposition 1 was not identified in this group.

3.1.3. Group 3: AS

Three students in the astronomy group identified the Sun as the nearest star to the Earth, and described the main difference between the Sun and other stars as the Sun’s small distance from us. For instance,

LA: What is the difference between the Sun and the stars that we see at night?
AS3: Nothing, really, their magnitudes [brightness] are different but this is just the closest star to us.

The student who did not identify the Sun as the nearest star identified Proxima Centauri instead. The responses from this group most accurately matched the scientific understanding of the Sun as a star, and did not reflect the presuppositions related to this concept.

3.1.4. Summary: The Sun as a Star

Earth science students did not identify the Sun as the nearest star to the Earth, although they did recognize that the Sun is a star, holding presupposition 1 as an explanation for the difference between the Sun and other stars. Some first-year undergraduate students identified the Sun as the nearest star to the Earth, while others did not. The astronomy students generally identified the Sun as the nearest star to the Earth, and described the Sun’s relationship to stars in correct scientific terms.

3.2. The Nature of Stars

A number of interview questions led to the description of the nature of stars in student responses because this was the central purpose of the study. Interview questions that allowed students to identify stars in broad terms included questions 1 (What is a star?) and 2 (How do stars shine?). Question 3 (What is the difference between a star and a planet?) gave the students an opportunity to choose qualities that distinguish stars from other astronomical objects, namely planets. Questions 4 (Where do stars come from/how are they formed?), 5 (Do stars change over time?), 6 (Is there anything left after a star stops shining?), and 7 (How do stars differ from one another?) add to the student’s description of stars.

Images of stars reveal surface characteristics that appear similar to fire and lava flow on the Earth, so it is likely that students will describe stars in these terms (presupposition 2). Both stars and planets "shine" (even though a planet’s light is actually reflected starlight), so distinctions between planets and stars may focus on other characteristics that are observable in certain science textbook images, such as composition or size (presupposition 3).

Astronomers define stars by their ability to fuse lighter elements into heavier elements to create energy. Stars are distinguished from several other types of objects: (1) planets, which are not massive enough to fuse elements in their core; (2) protostars, which are still accumulating material and will become stars after accretion stops and they become hot enough at their centers to support fusion of hydrogen; and (3) stellar remnants, including white dwarfs, neutron stars, and black holes, which are no longer fusing elements and have collapsed under the force of gravity. The distinguishing characteristic of "stardom," then, is the ability to fuse elements and create energy. This ability depends on a star’s mass and is related to a star’s radius and surface temperature, but these latter features are secondary to a star’s nature. In other words, a star’s mass determines how much energy the star generates, but that a star creates energy at all is most significant to its nature.

3.2.1. Group 1: ES

Sixty-three percent of the earth science students (five) described a star as a "ball of gas" or a " ball of fire" (presupposition 2) in their initial answer to the question, What is a star? However, few of these students were able to provide an effective explanation for the mechanism by which stars shine. One student (ES8) correctly cited fusion as the source of a star’s light. When considering the differences between a star and a planet, the characterizations used by this group of students addressed descriptive secondary qualities, such as size and composition (presupposition 3), and often confused the relative sizes of stars and planets.

> LA: What is a star, what do you think a star is?
> ES4: Like a burning gas or ball or something like that.
> LA: So what’s the difference between a star and a planet to you?
> ES4: A star is smaller and the planets are bigger.

3.2.2. Group 2: UN

All of the undergraduate students also described stars as balls of burning gas, and one student particularly spoke of stars in terms of lava (presupposition 2).

> LA: When you say chemicals burning up, do you have an idea of what chemicals are in the star?
> UN2: Some sort of gas. I imagine. . . I don’t know. . . I just imagine something like a volcano [pause] but a lot harder.

Two responses related to the distinction between stars and planets in this group focused on the burning action of a star, although all of the undergraduate students also discussed the material difference between the two objects (presupposition 3).

> UN4: Well, planets I’m not really sure what the makeup is, like, I guess, like Earth, mass and water. In some cases, I know that stars are burning balls of gas.

3.2.3. Group 3: AS

In contrast to the responses of the earth science students and the undergraduate students, all of the responses from astronomy students included an immediate recognition of the production of energy as a defining feature of stars.

> AS1: Ooo, my own words, um, it's basically [laughs] just a, like, uh [laughs], it has just a big thing of energy and fusing going on inside and a lot of activity going on in a large space.

This attention to the energy production in stars is in marked contrast to the responses of the other groups, which focused on a star's descriptive qualities, such as size and composition. Furthermore, the focus on function continues in the astronomy students' differentiation of stars and planets. Two of the four students in this group distinguished stars from planets by a star's energy production.

> AS3: And uh a star also has uh, a uh, what was I going to say? They create their own energy, like they make it, that they burn stuff, and the planets don't actually burn anything. . .

3.2.4. Summary: The Nature of Stars

The earth science students and the first-year undergraduate students held presuppositions 2 and 3, describing stars in general terms based on surface appearances and differentiating stars from planets through descriptive features such as size, temperature, and composition. In contrast, the astronomy students mostly described and qualified stars in terms of energy production.

3.3. The Distances Between Stars

A student's understanding of the distances between stars is a difficult concept to gauge, especially in the context of a verbal interview. The particular question that targeted students' ideas about distances between stars and other objects asked students to consider a scale in which the Earth is 1 inch in diameter, and relate the distance between it and another object, be it the Sun or the "nearest star" (Question 10: What are the distances to stars? If the Earth were 1 inch in diameter, how far away would the Sun/nearest star be?)

The distances to stars cannot be determined using the eye alone, so an initial presupposition claims that stars are small objects that are relatively close to the Earth (presupposition 4). Observations of stars reveal different magnitudes of brightness that could correlate to different distances (presupposition 5) if it is assumed that all stars have the same absolute brightness (luminosity).

The vast distances between stars are difficult for astronomers to discuss in common language. Many astronomy educators use scale models to provide a sense of the distances between stars. For instance, if the Sun were 1 inch in diameter, the nearest star would be nearly 500 miles away. A formal measurement of astronomical distances, the light year, is the distance that light travels in one year, approximately six trillion miles. The nearest star to the Sun, Proxima Centauri, is roughly 4.2 light years away.

3.3.1. Group 1: ES

Four students in the earth science group indicated that stars were dispersed within the realm of the Solar System and were relatively small objects (presupposition 4). Two of these responses corresponded to the students' description of the Solar System as including more stars than just the Sun.

> LA: Okay, so maybe the Sun would be out here and there'd be planets.
> ES7: Yeah.
> LA: Where do you think you'd have to go to find stars, on that same scale, if the Earth was this big and the Sun was like over here, a couple feet away?
> ES7: I don't know, I think of the stars in between. . .

All of the earth science students had a difficult time directly answering the question about distance scales, opting instead to speak in general terms about the large distances between stars. Six of these students described stars as being "far away." Three students indicated an awareness that the apparent brightness of stars can relate to a star's distance (presupposition 5). One student, however, acknowledged that the inherent brightness of stars could also vary, thereby dispelling presupposition 5.

> ES6: Probably, like some stars do seem farther away, but you can never tell--if they're really close to each other or if they're really far back, but they're next to each other right there. . . Yeah, like the farthest one away would probably be brighter but next to it, so it will seem as though they're next to each other.

3.3.2. Group 2: UN

One student in the undergraduate group described stars as objects within the realm of the Solar System (presupposition 4). Two of the undergraduate students relied on the scientific definition of distance, the light year, in describing the distances between stars, although their explanations didn't include a definite distance or any specifics on the definition of a light year.

> UN1: They're light years away, and the stars that we see now could be something that actually isn't there by the time we see it cause it's so far away.

The attempt to define distances between stars through a consideration of scale was successful with four of the undergraduate participants; they indicated a relatively appropriate scale for the large distances they had identified.

> LA: If we could shrink a star [sic] down to this size [indicates 1 inch], where do you think the next star over would be? Do you think it would be a foot away, do you think 10 feet. . .
> UN4: Yeah, um, I would say at least a couple of miles.

3.3.3. Group 3: AS

All of the astronomy students also responded to the question regarding the scale model with a sense of the large distances between stars, and one student referred to the scientific term "light years" in an explanation of distances, again without a clear definition of the term.

LA: So, if you were to shrink the Earth to this size, how far away do you feel like you'd have to go to find the Sun? Like, do you think that the Sun would be this far, a foot away or two feet away or 10 feet away or a mile away, like how far away do you think you'd have to go to find the Sun?
AS4: A mile away.
LA: Okay, if the Earth was that big, and then, on that same scale, where would you have to go to find the next star?
AS4: Like miles and miles and miles away.

3.3.4. Summary: The Distances Between Stars

Some earth science students considered stars to be small objects distributed throughout the Solar System (presupposition 4), while others spoke in general terms about the great distances between stars. These students did not translate this understanding into a description of relative scales, but some undergraduate students and all of the astronomy students were able to describe the large distances between stars in terms of a scale model.

3.4. Summary

The earth science students (Group 1: ES) did not generally identify the Sun as the nearest star to the Earth, and they differentiated the Sun from other stars through descriptive features, namely size. These students used descriptive qualities such as size and temperature as a primary means of identifying stars in general, with little attention to energy production. Their account of the distances between stars was vague, and some placed other stars within the realm of the Solar System.

The first-year undergraduate students (Group 2: UN) were more likely to identify the Sun as the nearest star than the earth science group, and the undergraduate students used both processes and descriptive features when identifying stars. The undergraduates were able to discuss the distances between stars through scale model questions and with indistinct references to the concept of a light year.

Students enrolled in the astronomy course (Group 3: AS) were most likely to identify the Sun as the nearest star to the Earth, and were more likely to identify a star by its energy production than by any descriptive features such as size or temperature. These students responded well to questions about the distances between stars by considering appropriate scale models.

4. ADDITIONAL RESULTS

4.1. Summary of Results

Detailed analyses of the interviews have led to a focus on responses characteristic of the three groups. Therefore, the identification of students' ideas about stars was viewed through an analysis of the participant groups. Table 3 summarizes the responses of all participants with regard to all of the interview questions posed. Some students answered questions in multiple ways, so the number of responses may exceed the distribution of questions.

Table 3. Summary of Student Responses Related to Individual Interview Questions

Questions and Responses	# of ES	% of ES	# of UN	% of UN	# of AS	% of AS	Total #	Total %
1. What is a star?								
Made of gas/fire	6	75%	5	100%	4	100%	15	88%
"Balls of gas/fire"	4	50%	2	40%	0	--	6	35%
Made of rock/dust	1	12.5%	0	--	0	--	1	6%
Made of lava/volcanoes	5	62.5%	1	20%	0	--	6	35%
Made from the Sun	1	12.5%	0	--	0	--	1	6%
Produce energy	0	--	0	--	3	75%	3	18%
2. How do stars shine?								
Shine by glowing	2	25%	0	--	0	--	2	12%
Shine by burning/heat	1	12.5%	4	80%	0	--	5	29%
Shine by reflection	2	25%	0	--	0	--	2	12%
Shine by radiation	0	--	0	--	1	25%	1	6%
Shine by chemical reactions	0	--	2	40%	0	--	2	12%
Shine by fission	0	--	0	--	1	25%	1	6%
Shine by fusion	1	12.5%	0	--	2	50%	3	18%
3. What is the difference between a star and a planet?								
Smaller than planets	4	50%	1	20%	0	--	5	29%
Bigger than planets	1	12.5%	1	20%	2	50%	4	24%

Bigger and smaller than planets	3	37.5%	0	--	1	25%	4	24%
Younger than planets	1	12.5%	0	--	0	--	1	6%
Less dense than planets	2	25%	0	--	0	--	2	12%
Stars don't move.	1	12.5%	0	--	1	25%	2	12%
Stars don't have gravity.	1	12.5%	0	--	0	--	1	6%
4. Where do stars come from/how are they formed?								
Form by collisions (like moon/comets collide)	2	25%	1	20%	0	--	3	18%
Form from parts of the Sun	1	12.5%	0	--	0	--	1	6%
Form from gravity	0	--	1	20%	1	25%	2	12%
Form in nebulas	0	--	0	--	2	50%	2	12%
5. Do stars change over time? **6. Is there anything left after a star stops shining?**								
Stellar evolution	0	--	0	--	4	100%	4	24%
Stars go through cycles	3	37.5%	0	--	0	--	3	18%
Stars burn out/fade away	3	37.5%	4	80%	0	--	7	41%
Leave material behind	2	25%	2	40%	4	100%	8	47%
Turn into shooting stars	1	12.5%	0	--	0	--	1	6%
Merge with other stars	1	12.5%	0	--	0	--	1	6%
7. How do stars differ from one another?								
Differ in size	3	37.5%	1	20%	4	100%	8	47%
Differ in temperature	1	12.5%	1	20%	3	75%	5	29%

Differ in distances	2	25%	1	20%	0	--	3	18%
Differ in brightness	2	25%	1	20%	0	--	3	18%
Differ in material	0	--	0	--	1	25%	1	6%
Differ in evolution	0	--	0	--	4	100%	4	24%
Don't differ	1	12.5%	0	--	0	--	1	6%
8. What is the difference between the Sun and stars?								
Sun is a star.	3	37.5%	2	40%	4	100%	9	53%
Sun is closer.	2	25%	1	20%	1	25%	4	24%
Sun is bigger (than Earth/than other stars).	8	100%	1	20%	3	75%	12	71%
9. What's the nearest star to the Earth?								
Sun is nearest star.	0	--	2	40%	2	50%	4	24%
North star is nearest star.	2	25%	1	20%	0	--	3	18%
Planet is nearest star.	1	12.5%	0	--	0	--	1	6%
Proxima Centauri is nearest star.	0	--	0	--	2	50%	2	12%
10. What are the distances to stars? If the Earth were 1 inch in diameter, how far away would the Sun/nearest star be?								
Light years away	1	12.5%	2	40%	1	25%	4	24%
Far away	6	75%	4	80%	4	100%	14	82%
Near planets	4	50%	1	20%	0	--	5	29%

4.2. The Use of Scientific Language

Another notable and interesting result from this study relates to the students' use of scientific language. The interview questions were designed to avoid the use of scientific terminology unless presented by the respondent, so student choices about language were self-generated and offer insight into their understanding and knowledge of how to talk about stars. It was hypothesized that the earth science students would have the most limited vocabulary with which to talk about astronomy, while the astronomy students would have the broadest vocabulary in this discipline. Alternatively, the undergraduate students might have the broadest general scientific vocabulary to aid them in the interview.

4.2.1. Group 1: ES

Two students from the earth science group offered examples as part of their explanations about stars. These examples took the form of stories, so the students were able to explain their understanding of stars by referring to other astronomical objects and events.

> ES1: They come from like, material that's probably like, swept away by like, moons and stuff that probably a meteor hit and then all the debris that came out probably like, floats away, then that all gets together. Like what happened to the moon, a big big meteor hit that earth and then it floated away and a big huge meteor got caught in the earth's gravitational pull. That's how we got the moon.

Although these students used stories to explain certain concepts, the remaining students from the earth science class avoided scientific terminology and stumbled over the inclusion of scientific language in their explanations.

> ES6: I think a sss--I don't know, it's kind of like, it's hard to explain, cause it's just like, I think it's like scientifically just like chemicals out there and you know all that stuff, but I don't know, yeah, that's what I think it is the leftovers of, I don't know, just like dust and rock.

4.2.2. Group 2: UN

Though undergraduate students' use of scientific language was mixed, two students applied related scientific knowledge to their use of astronomical terms that they introduced into the interview.

> LA: What is the galaxy? You said the Sun's going to affect the galaxy.
> UN 3: Right. I don't know specifically, but I would imagine that the galaxy is like a division of what we know as the universe, like cells are a division of an organism.

This example shows one end of the spectrum of student use of scientific language. It was just as common for a student in the undergraduate group to struggle with the use of scientific language and astronomical terms. This was especially true for the two students in the undergraduate group who had not yet taken a college-level science course.

> UN5: I was also told in my [high school] physics class that, like, the light that we see is, those stars are already gone. Like, how do I explain. . . Yeah, like, done--it's already like we're be--how do I explain--um, we're--the star that we can see now is already been passed, we're just light years or something like that, I don't know [laughs].

4.2.3. Group 3: AS

All of the students in the astronomy class were most closely "speaking the language" by using astronomical terminology in their conversations about stars, but these students did not have a firm grasp of scientific language generally.

> LA: Um, where--do you have a sense of where stars come from or how they are formed originally?
> AS2: Like by the, um, like I know one example, like the Orion, Orion’s belt, the nebula. I know that’s a birthplace for stars, but I don’t--like all the protostars and I know that, but, once you get down into the very beginnings of it, it’s--it’s--I’m sure it’s all like very theoretical and all that stuff. I don’t--Well, they probably can figure it out using equations and everything, but. . .

This response shows the student’s insecurity with the use of scientific language, even though the student was able to use the appropriate astronomical terminology.

Although some of the earth science students used scientific stories as part of their explanations, their use of scientific language and formal terminology was minimal. The undergraduate students’ use of scientific language was mixed; they struggled with specific astronomical terminology but also related their astronomical knowledge to other scientific concepts. The astronomy students’ use of scientific terminology was inconsistent; they generally possessed the appropriate astronomical knowledge but sometimes lacked a broader base of scientific language.

5. CONCLUSIONS

The research reported in this article provides a comparison between participant groups with regard to their understanding of stars. The first-year high school students enrolled in the earth science course relied most heavily on observable presuppositions in their understanding of stars, while the third- and fourth-year high school students enrolled in the astronomy course provided responses that were most similar to current scientific knowledge about stars. The first-year undergraduate students’ responses were generally more accurate than the earth science students’ responses, but they lacked the specific content knowledge demonstrated by the astronomy students. These results indicate that astronomy courses at the high school level can be very effective at improving students’ astronomical content knowledge in a short period of time.

This research provided material with which to consider possible presuppositions that may guide students’ understanding of the relationship between the Sun and stars, the nature of stars, and the distances to stars. Table 4 lists the presuppositions that have been identified as a result of this study.

Table 4. Presuppositions Related to the Nature of Stars

Presupposition 1: The Sun is bigger than other stars.
Presupposition 2: A star is made of fire or lava.
Presupposition 3: Stars and planets differ primarily because of their composition or size.
Presupposition 4: Stars are small, nearby objects.
Presupposition 5: A star’s distance relates to its apparent brightness in the sky.

It seems obvious that students who have taken a semester-long astronomy course are more likely to correctly answer questions about the nature of stars than students who have not taken astronomy. However, the responses of the astronomy students who participated in this study were especially striking. These students used functional qualities for the differentiation of astronomical objects (energy production in stars) and regularly expressed a deep appreciation for distance scales. An emphasis on energy production in stars and an appreciation of scale are two aspects of astronomy that are central to the expert scientist’s understanding of the subject matter. Notably, the topic of energy production is specifically recommended for instruction in the current *National Science Education Standards* (National Research Council 1996). Furthermore, the general enthusiasm shared by the students enrolled in the high school astronomy class was heartening.

The interpretations of results presented in this article require further exploration and validation by researchers. Specifically, how consistent are the ideas that students hold about stars? How resistant to change are the presuppositions reported here? What are effective means for helping people abandon incorrect presuppositions? Answers to these questions may indicate that students have mental models, as defined by Vosniadou and Brewer, related to stars. The present study allows for speculation that students’ ideas about stars are related to mental models. Neil Comins (2001) reported that some students hold the belief that the Sun is not a star. Students may therefore hold initial models based on this presupposition. Students may progress through synthetic models that include the idea that the Sun is related to stars (one student in the present study responded that stars are "little pieces of the Sun" and populate the entire Solar System). Finally, students abandon this synthetic idea and hold the scientific model that the Sun is the nearest star to the Earth. If mental models related to stars are identified, researchers may consider how the progression of mental models correlates with age.

The methodology of the present study was limited insofar as there were no means by which students could represent their responses in three dimensions. Following the reasoning used by Novak & Nussbaum (1976) in their seminal study on children’s ideas about the shape of the Earth, the choice to not use physical representations allows the responses of students to be more creative: "It was observed that visual props were apt to provide the child with some cues that would interfere with the spontaneity and authenticity of his [sic] natural thinking (thereby risking the validity of the interview interpretation)." In the present study, the lack of physical models limited the students’ ability to consider and communicate distance and size scales in their understanding of stars.

Although the interview questions used in this study were carefully reviewed in advance, they still limited the students' responses and the researcher's interpretations of those responses because the questions suggest the type of answer that is expected. For example, the phrasing of question 3 (What is the difference between a star and a planet?) encourages the student to answer that there is indeed a difference and to identify only one fundamental difference between these two types of celestial bodies when there are, of course, a multitude of secondary features that differ. The semistructured nature of the present inquiry attempted to minimize any such shortcomings because the researcher and participants engaged in a dialogue. However, eliminating such biases from the research design is a major challenge for any future studies of this kind.

Again following Novak & Nussbaum (1976), the results reported in the present study "should be taken as a first description of inferred constructs in the subject area requiring further validation and refinement through research." The analysis of results reported here offers an initial description of students' ideas and a focus on common constructs that require further exploration.

The *National Science Education Standards* recommends instruction about stars and stellar evolution at the high school level (National Research Council 1996). Students in this age group offer a wealth of ideas about astronomy that warrant exploration by educational researchers. By considering astronomy concepts that are part of the high school students' curriculum, researchers can impact instruction in this area.

Rather than offering definitive conclusions, the results of this study invite continued research into students' understanding of stars, galaxies, and the cosmos, and encourage teachers and educational researchers to consider topics beyond the realm of the Solar System.

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