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College Students' Preinstructional Ideas About Stars and Star Formation

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Abstract

This study (Note 1) investigated the beliefs about stars that students hold when they enter an undergraduate introductory astronomy course for nonscience majors. Students' preinstructional ideas were investigated through the use of several student-supplied-response (SSR) surveys, which asked students to describe their ideas about topics such as what is a star, how is starlight created, how are stars formed, are all stars the same, and more. The results from more than 2,200 responses suggest that although students often have some initial knowledge about stars, their knowledge is often incomplete or incorrect in important ways that could negatively impact instructional objectives.

1. INTRODUCTION

As we look into the sky during the daytime, what we see is dominated by the incredibly bright Sun. In the Sun's absence, we see points of light—virtually all of which are stars. The Sun, our closest star, plays a tremendous role in the physical processes on Earth, which allow life to exist. Furthermore, the presence and patterns of stars have played important roles in human beliefs, primarily through religions, calendars, and mythologies. A tremendous number of stars populate the universe, and the study of their nature and evolution is a primary subdiscipline of astronomy. Given the importance of stars in our cultural and scientific history, it should come as no surprise that stars are considered a central topic in astronomy.

From a survey of U.S. college syllabi available on the Internet at that time, Slater *et al.* (2001) report that stellar evolution ranked in the top ten of the most frequent topics covered in an undergraduate introductory astronomy for nonscience majors (hereafter "ASTRO 101") curriculum. Other topics commonly taught include (but are not limited to) the nature of light, cosmology, our Sun, lunar phases, and characteristics of the Milky Way galaxy. For some of these topics (lunar phases and seasons, for example), substantial research on student understanding has been conducted; for many others, however, including those pertaining to stars, little research about the students' preinstructional ideas exists (Bailey and Slater 2003; Bailey and Slater 2005).

The topic of stars is also deemed important for middle and high school students. In the Earth science content standards of the *National Science Education Standards (NSES*, National Research Council [NRC] 1996), the history of Earth (grades 5–8) and formation of our Solar System (including our star, the Sun; grades 9–12) are both recommended for study. Adams and Slater (2000) list the 11 *NSES* content strands where astronomy is either explicitly or implicitly addressed, along with the research focusing on alternative conceptions to date. In addition to the content standards, “Evolution and Equilibrium” is a unifying concept and process highlighted in the *NSES*, for which the formation and evolution of stars and their contribution to the evolution of the entire universe can serve as a primary example. The evolution of systems is also a content goal for ASTRO 101 that was named by department chairs and astronomy education leaders in a series of workshops hosted by the American Astronomical Society (Partridge and Greenstein 2003).

Project 2061’s *Benchmarks for Science Literacy* [American Association for the Advancement of Science (AAAS 1993)] includes more detailed content benchmarks, some of which very specifically relate to stars. For example:

> By the end of the 12th grade, students should know that…the stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements that are found on the Earth and to behave according to the same physical principles (AAAS 1993, p. 65).

Slater (2000) lists 27 statements from the *Benchmarks* that contain astronomy content, organized by grade level; seven of these relate to stars or our Sun.

Given that these topics are recommended for study in high school, it is reasonable to expect that our ASTRO 101 students might already know something about stars at the start of their undergraduate coursework in astronomy. Understanding what ideas about stars students bring with them to our ASTRO 101 courses is an important first step to the design of effective instruction. This research study seeks to inform the science education and astronomy communities about these ideas.

2. CONCEPTUAL FRAMEWORK

The constructivist movement of the late 20th century suggests that knowing the ideas that students bring to the classroom can be important for guiding effective instruction (Bransford, Brown, and Cocking 1999). Research in science education over the past few decades has repeatedly demonstrated, in a variety of contexts, that students have a wide range of ideas, both scientifically accurate and inaccurate, about the world around them (e.g., Ausubel 1968; Driver and Easley 1978; Duit 2006; McDermott 1991). Students enter the classroom with tenacious, deep-seated ideas and fundamental reasoning processes that can serve to either help or hinder the incorporation of new concepts. As cognitive science rapidly expands our understanding of how people learn, educators have begun to place more importance on knowing what students understand about a topic when they enter a learning environment.

> Humans are viewed as goal-directed agents who actively seek information. They come to formal education with a range of prior knowledge, skills, beliefs, and concepts that significantly influence what they notice about the environment and how they organize and interpret it. This, in turn, affects their abilities to remember, reason, solve problems, and acquire new knowledge.… *If students’ initial ideas and beliefs are ignored, the understandings that they develop can be very different from what the teacher intends* [italics added] (Bransford, Brown, and Cocking 1999, p. 10).

The inclusion of stars in the K-12 curriculum, in combination with the interactions of students with nature, other people, and popular culture, means that undergraduate students may have a variety of ideas about this topic. However, unlike some other topics in astronomy, there exists almost no published research on students’ preinstructional beliefs about stars or their formation, evolution, or death (Bailey and Slater 2003; Bailey and Slater 2005). It should be noted here that we use “preinstructional” in this sense not to mean that students have had no instruction on stars; rather, we use it to indicate their level of understanding prior to starting an ASTRO 101 course.

In the most comprehensive study to date, Agan (2004) investigated 17 students’ understanding of stars by using a clinical interview method. Eight of the students were high school freshmen enrolled in an Earth science course, five were undergraduate freshman who had never taken an astronomy course, and four were high school juniors or seniors enrolled in an astronomy course. Interview questions focused on the three following topic areas: the Sun as a star, the nature of stars, and the distances to stars. The Earth science students typically did not understand the Sun to be the same type of object as a star; they used physical characteristics to distinguish stars from other objects such as planets. They had no specific notions of distance or scale related to stars. More of the undergraduate students correctly responded that our Sun is a star. Some used more scientific language to describe the nature of stars, and they also had a better sense of scale than the Earth science students when asked about stellar distances. The high school astronomy students, however, gave responses more closely resembling scientific thought in all three topic areas. Agan (2004) did not address possible reasons for such differences in her discussion of the findings. These results provide a useful "first look" at students' ideas about stars, but further research is required before they can be validated and generalized.

Several published studies included a single or few questions about stars as part of a larger study of Earth science or astronomy. For example, Philips (1991) found that adults surveyed believed that the Sun and our planets formed during the Big Bang and that the universe is unchanging. Lightman and Sadler (1993) report that only 25% of the high school students in their study could acceptably interpret a H-R diagram (a graphical representation of stars' luminosities, or total power outputs, versus surface temperatures). Sadler (1992) found that 44% of respondents correctly said that if two stars appear to be the same brightness even though they have different luminosities, then the more luminous star must be farther from Earth. Schoon (1992) found that between 9% and 16% (depending upon the question) of more than 1200 people surveyed thought moonlight was created in the same way as sunlight, rather than the Moon being illuminated by the Sun. Through the collection of students' questions at the end of class periods over several semesters, Comins has created a list of common incorrect ideas in astronomy, several of which are related to stars or the Sun (Comins 2000; Comins 2001; Comins 2004).

In a larger study on astronomy topics included in the National Science Curriculum of the U.K., Sharp (1996) asked 42 10–11 year olds about their understanding of the Sun and the stars. The majority of students indicated that both the Sun and stars have a "round" shape (although whether or not round clearly meant "spherical" depended upon the question asked). The Sun was described by 67% of the students as "a big/huge ball of fire (gases, flames, and heat)"; it was correctly identified by 57% as a star (Sharp 1996, p. 694). Students were not clear on what a star is, although just over half said a star is "like the Sun" (Sharp 1996, p. 697). When asked about the size of stars compared to the Sun, Earth, and Moon, students' responses varied from being smaller than to being larger than these objects, or that stars can have a variety of sizes.

DeLaughter and colleagues investigated college nonscience majors' preinstructional beliefs about Earth science and related topics (DeLaughter *et al.* 1998a, DeLaughter *et al.* 1998b). Of the 18 open-response items, only one relates directly to this study. Question 7 asks, "How does the Sun generate its energy?" (DeLaughter *et al.* 1998b, p. 3). Only 9% of the 97 respondents correctly named nuclear fusion as the process; another 9% said nuclear processes. The most frequent responses were chemical reactions (32%) and "because it is a gas" (18%) (DeLaughter *et al.* 1998b, p. 3).

Schatz and Lawson (1976) provide two examples of common misconceptions about stars: the "truckin [sic] star problem" and "disappearing mass myth" (p. 6). The former is that students believe a star's changing position on the H-R diagram to be spatial motion (in other words, a change in physical position), when in reality it is only a change in one or both of the fundamental properties (temperature and luminosity) displayed by the graph. The latter, where students automatically assume larger diameter stars must also have greater mass, appears to be related to problems with understanding density. These examples were reported in materials related to an astronomy teaching workshop. No published investigations have been found relating to either of these reported misconceptions.

Although many studies in astronomy have touched on students' understanding of stars, few have addressed the ideas in depth or with large numbers of college nonscience majors. Such a study could have great value to the wider community of college and university science educators because of the enormous numbers of students who take ASTRO 101 each year—approximately 250 000 undergraduates (Fraknoi 2002). In response, the present research project using both quantitative and qualitative methods has been designed to investigate student understanding about star properties and formation.

Bailey (2006) designed a two phase, mixed-methods study on college students' preinstructional ideas about stars and star formation. Phase I was an exploratory study that used student-supplied-response (SSR, also known as open-ended) surveys to investigate the range and frequency of students' beliefs, prior to instruction, about stars and star formation. SSR surveys allow students to express their ideas in their own words, providing as much information as necessary to fully describe their beliefs. Phase II involved the creation and testing of a concept inventory that is intended to evaluate any change in students' beliefs after being exposed to different instructional strategies. The *Star Properties Concept Inventory* (SPCI) was validated locally as part of this larger study (Bailey 2006), and a national validation study is ongoing. The remainder of this paper will focus only on Phase I. The research questions addressed in this portion of the study are as follows.

A. Prior to instruction, what ideas do undergraduate nonscience majors who are enrolled in an ASTRO 101 course have about stars and star formation?

B. What are the range and frequency of these ideas?

3. METHODS

3.1. Setting and Participants

This research project was conducted at a large research university in the southwestern United States. Undergraduate enrollments at this institution number more than 28 000 and are approximately 53% female and 47% male. Approximately 65% of the undergraduate students are Caucasian and 15% are Hispanic. Other ethnicities comprise about 14% of the population, with about 6% unknown. More than two-thirds of the undergraduates are aged 18–21, and the university has a 24% attrition rate after the first year.

The majority of the participants in this study were undergraduate nonscience majors enrolled in an ASTRO 101 course. Students in this course are typically in their first year of college and, as is true across the country, frequently are enrolled in the course to satisfy a general education distribution requirement in the natural sciences (Deming and Hufnagel 2001). At the university in this study, students are expected to take two introductory science courses during their tenure, as well as a third sophomore-level natural science course. There are nearly 70 different courses offered by multiple academic departments to address these requirements. The students in these courses are approximately reflective of the university's undergraduate population in terms of gender, age, and ethnicity. A predominantly lecture-based survey course typically serving 100–150 (and, in some cases, up to 300) students per section, ASTRO 101 introduces students to a wide range of foundational topics related to observational and theoretical astronomy, using both historical and contemporary contexts as appropriate. Lectures are held in large, auditorium-style classrooms. There is no separate laboratory component to the course at this institution; rather, some instructors incorporate hands-on, collaborative group activities that facilitate greater student engagement into the lecture.

3.2. Data Collection

Students in 15 sections of an ASTRO 101 course were invited to respond to one to three SSR survey questions relating to stars. Because the purpose of the study was to determine the ideas students hold when they enter ASTRO 101 courses, it was essential that the data were collected prior to any instruction on the topics of interest. Thus, SSR surveys were administered on the first or second day of class in the participating sections. Each student randomly received one of multiple survey forms in order to address as many questions as possible. The questions asked are listed in Table 1. A total of 2276 students completed surveys over four semesters, with the number of responses to individual questions ranging from approximately 200 to 1100. Students who declined to participate in the study did not respond to the surveys; however, the anonymous nature of the study prevents us from knowing exactly what percentage of students fell into this category. Our best estimate, taken from the number of students counted in the classroom during the survey and the number of blank responses returned, is that fewer than 10% of the students in the sections declined to participate.

Table 1. SSR Survey Questions

Semester	Form	Item(s)
Spring 2003	A	Describe what you think a star is.
	B	Describe where you think stars come from.
	C	Describe how you think a star is formed.
Fall 2003	D	Describe the process by which you think a star is formed. Support your answer with a sketch and labels, if possible.
	E	List all of the things that you think are present and/or will occur when a star forms.
	F	We see stars because they give off light (energy). Describe how you think this happens.

Table 1. (*Continued.*)

Semester	Form	Item(s)
Spring 2004	G	Describe what you think a star is. Support your answer with a sketch and labels, if possible.
		We see stars because they give off light (energy). Describe how you think the light (energy) is created inside and/or on the surface of the star. Support your answer with a sketch and labels, if possible.
	H	Describe the process by which a star is formed. Support your answer with a sketch and labels, if possible.
		Are all stars the same? Indicate 'yes' or 'no' below and answer the accompanying question. Support your answer with a sketch and labels, if possible.
		Yes_____ In what way(s) are all stars the same?
		No_____ In what way(s) are stars different?
	J	Is there a difference between a star and a planet? Indicate 'yes' or 'no' below and answer the accompanying question. Support your answer with a sketch and labels, if possible.
		Yes_____ Describe what you think the differences are.
		No_____ Describe why you think they are the same.
		We see stars because they give off light (energy). Describe how you think the light (energy) is created. Support your answer with a sketch and labels, if possible.
	K	Describe what you think a star is. Support your answer with a sketch and labels, if possible.
		Are all stars the same? Indicate 'yes' or 'no' below and answer the accompanying question. Support your answer with a sketch and labels, if possible.
		Yes_____In what way(s) are all stars the same?
		No_____In what way(s) are stars different?
		We see stars because they give off light (energy). Describe how you think the light (energy) is created inside and/or on the surface of the star. Support your answer with a sketch and labels, if possible.
Fall 2004	L	We see stars because they emit energy. Describe how you think this energy is created.
		Other than appearing to move quickly across the sky, how is a *shooting star* different from a *star*?
	M	Why do some stars appear brighter than others?
		Your friend tells you that a shooting star is the result of a star running out of fuel and "burning out." Do you agree or disagree with your friend? Explain why you think the statement is correct or incorrect.
	N	Why do some stars appear different colors?
		Your friend tells you that a shooting star is the result of a star running out of fuel and "burning out." Do you agree or disagree with your friend? Explain why you think the statement is correct or incorrect.

3.3. Data Analysis

The SSR surveys were inductively analyzed in an iterative, constant comparative process consistent with grounded theory in order to develop categories or themes (Creswell 1998; Glaser and Strauss 1967). First, all responses to a given question were read and common ideas were recorded. Because some of the ideas emerged late in the review process, the surveys were then analyzed a second time to determine whether the later-emerging themes also appeared in responses earlier in the review. This process was repeated until no new themes emerged. Each theme was then assigned a code. Matching codes were then written on each completed SSR survey response as appropriate. The frequency of each code was then calculated.

An individual response could be coded for multiple themes, and this was often the case, especially for lengthier responses. The themes were organized in such a way that a larger theme might have subcategories, although not all did. An example of this is a category called "burning," found in several different questions. Subthemes of burning include combustion, explosion/implosion, fire/flames, and unclear (i.e., the student used the word "burning" without any further explanation). Some of the themes were consistent across different questions; conversely, some themes were exclusive to a particular question. Whenever themes could be used for multiple questions, care was taken to use the codes consistently across all versions of the questions and their responses.

After coding the responses for content themes, a second level of analysis was performed for some of the questions. In this case, students' responses were compared to what would be expected as a correct answer at the end of the ASTRO 101 course. These "correct answers" (described below in conjunction with each question) are not necessarily the ideal response, but rather the *minimum* that instructors might expect their students to know. Element(s) of the expected correct answer were first identified by the first two authors, who have extensive experience teaching ASTRO 101 courses. Each response was then classified as one of four possible categories: Correct (C), where the response was complete and contained no wrong statements; Incomplete (I), where the response was missing one or more of the identified elements; Partial (P), where the response contained both incorrect and correct elements; and Wrong (W), where no element of the response matched the identified element(s) of a correct answer. For some questions, an additional category was used: True but insufficient (T), which included statements that were true but did not address the question in any meaningful way.

Questions on the SSR surveys evolved over the four semesters to reflect insights and new areas of interest after analysis of earlier data. For example, a question about prior astronomy courses was added to all surveys after one respondent in the first semester mentioned having learned the topic in an earlier course. In another case, a new topic of "shooting stars" (which are actually debris falling through Earth's atmosphere and are unrelated to stars) was added after repeated appearances in student responses.

4. RESULTS

4.1. Nature of Stars

Three survey questions asked students to describe their idea of a star (Forms A, G, and K; see Table 1 for exact wording of each question). A total of 391 students responded to this question over two different semesters. Nearly 80% of the students responded that a star is made of gas or a gas/dust combination. More than half of these responses included the phrase "ball of gas" to describe a star. The next largest category of responses was that stars are in some way burning (including those subthemes described above); 44% of the responses included something from this category. Energy release was indicated by 29% of the students—respondents might have said, for example, energy, heat, or light was released from stars. Almost a quarter of the respondents described some sort of physical characteristics about stars (e.g., their size, temperature, or color), while 16% indicated something about stars' large distances from Earth. The number and percentage of responses of these and additional selected themes are presented in Table 2.

Table 2. Themes Identified in Student Responses to "What is a star?" (*N*=391) (Note: Because responses could be coded for more than one theme, percentages may add to more than 100%; rows that are indented and in italics represent subthemes)

	Responses	
Theme	***N***	**%**
Gas/Dust	309	79.0
"Ball of gas"	168	43.0
Plasma	5	1.3

Theme	Responses	
	N	%
Burning	172	44.0
Energy is released	114	29.2
Characteristics described	90	23.0
Distance from Earth	61	15.6
Other/unclear, answered different question	48	12.3
Sun is a star	42	10.7
Hot/increasing temperature	31	7.9
Energy present	27	6.9
Light in sky	26	6.6
Nuclear reactions	21	5.4
Nuclear fusion	14	3.6
Gravitational force or pull	19	4.9
Chemical reactions	18	4.6
Undergoes evolution	18	4.6
Gravity as a substance	12	3.1
Nonscience or no response	12	3.1

Table 2. (*Continued.*)

For this question, the correct answer to which responses were compared included that the star is made of gas (or gas and dust) and that the star is undergoing fusion. As indicated in Table 2, only 14 students (4%) indicated anything about fusion, so it is not surprising that very few responses were classified as Correct—only 9 of 391. The majority of responses were classified as Partial. The complete data set for the classification of all student responses to this question is presented in Table 3.

Table 3. Classification of Student Responses to "What is a star?" (*N*=391)

Classification	Responses	
	N	%
Correct	9	2.3
Incomplete	105	26.9
Partial	235	60.1
True but insufficient	17	4.3
Wrong	25	6.4

4.2. Creation of Light in Stars

The understanding that fusion is the source of energy in stars is a fundamental concept in astronomy. It is also addressed in the *NSES* (NRC 1996). This process creates the light that we see on Earth and, at least in the case of the Sun, provides needed energy to support the environment that has allowed life to evolve. Several variations of the question "How is the light that we see from stars created?" were asked to more than 1000 students (see again Table 1). Major themes identified in the responses to these questions are presented in Table 4. Fusion was identified in only 7% of the responses. The burning theme, identified in 32% of the responses, is particularly problematic in this question. Astronomers often call the process of fusion "hydrogen burning," despite the process being unlike any kind of burning we experience on Earth.

Table 4. Themes Identified in Student Responses to "How is the light that we see from stars created?" (*N* = 1071) (Note: Because responses could be coded for more than one theme, percentages may add to more than 100%; rows that are indented and in italics represent subthemes)

	Responses	
Theme	***N***	**%**
Gas/dust	393	36.7
Ball of gas	61	5.7
Burning	346	32.3
Chemical reactions	296	27.6
Internal energy	166	15.5
Characteristics described	126	11.8
Nuclear reactions	118	11.0
Nuclear fusion	78	7.3
Motion	109	10.2
Rotation, spin, or angular momentum	6	0.6
Other/unclear, answered different question	104	9.7
Properties of light	94	8.8
Reflection, refraction, or absorption of light	85	7.9
Nonscience or no response	67	6.2
Same as sun	32	3.0

For this question, the only element needed for a correct response was fusion, either the term itself or an accurate description of the process. No incorrect processes could also be included for the response to be classified as Correct. The complete data set for the classification of all student responses to these questions is presented in Table 5.

Table 5. Classification of Student Responses to "How is the light that we see from stars created?" (*N* = 1071)

	Responses	
Classification	***N***	**%**
Correct	33	3.1
Incomplete	17	1.6
Partial	469	6.4
Wrong	952	88.9

4.3. Star Formation

Another set of questions were used (each with slightly different wording; see Forms B, C, D, and H in Table 1) to ask how students believe stars are formed. As in the previous section involving students understanding of the *Nature of Stars*, a large number of students (61%) indicated that the star is made of gas or gas and dust. Nearly half of the students (48%) said that the material from which a star is made is brought together through some mechanism. Only in a small number of cases was this mechanism specified; for example, about 16% of the students said that gravity caused the material to be pulled together. Selected themes and the percentage of responses classified in each are presented in Table 6.

Table 6. Themes Identified in Student Responses to "How is a star formed?" (*N* = 904) (Note: Because responses could be coded for more than one theme, percentages may add to more than 100%; rows that are indented and in italics represent subthemes)

	Responses	
Theme	***N***	**%**
Gas/dust	551	61.0
Ball of gas	57	6.3

Table 6. (*Continued.*)		
	Responses	
Theme	***N***	**%**
Material comes together	429	47.5
Gravitational collapse	142	15.7
Burning	388	31.9
Energy present	145	16.0
Energy is released	130	14.4
Motion	108	11.9
Rotation, spin, or angular momentum	49	5.4
Other sources	99	11.0
Nonscience or no response	93	10.3
Chemical reactions	78	8.6
Nuclear reactions	68	7.5
Nuclear fusion	47	5.2
Increasing temperature	58	6.4
Other/unclear, answered different question	45	5.0
Nebula	37	4.1
Gravity as a substance	26	2.9
Big Bang	18	2.0

As before, elements of a correct response were identified for this question. Four elements were needed for a complete and correct response: the star will be made of gas (or gas and dust); this material is pulled together by gravity; the temperature will increase during this process; and finally, fusion begins. Of the 904 students who answered this question, only three were classified as Correct. Of these students, one indicated that he or she had taken an astronomy course prior to the one in which he/she was responding to the survey; the other two were not asked about prior astronomy coursework. The complete data set for the classification of all student responses to these questions is presented in Table 7.

Table 7. Classification of Student Responses to "How is a star formed?" (*N*=904)

	Responses	
Classification	***N***	**%**
Correct	3	0.3
Incomplete	211	23.3
Partial	406	44.9
Wrong	283	31.3

4.4. Comparing Stars to Other Objects

To further investigate students' understanding of stars, participants were asked in several different questions to consider how stars compare to each other and to three different astronomical objects. On Forms H and K, students were asked:

> Are all stars the same? Indicate "yes" or "no" below and answer the accompanying question. Support your answer with a sketch and labels, if possible.
> Yes_____ In what way(s) are all stars the same?
> No_____ In what way(s) are stars different? (see Note 2)

A total of 381 participants responded to this question. Responses were first coded for yes or no responses. Themes were then identified within each yes or no category. One difficulty here is that some students indicated both responses or gave reasons in both categories. The percentage of responses stating yes or no is given in Table 8. Most participants (86%) indicated that stars are different from one another. However many students who stated that stars are different also recognized that stars are all the same type of object. For example, one student said, "No—They have different sizes, gases, heat, age. They're like snowflakes, the same basic things but completely individual at the same time" (Form K, student #041–1029–141).

Table 8. Responses to "Are all stars the same?" (*N*=381)

Category	Responses *N*	Responses %
Yes only	16	4.2
No only	386	85.6
Both yes and no	31	8.1
Nonscience or no response	8	2.1

Within the reasons accompanying the yes or no responses, themes were identified. Approximately ten themes emerged as reasons that stars are all the same, while nearly three times as many differences between stars were described. In responding that all stars are the same, the two most frequent responses given were that stars are made of the same materials or elements (6% of the total responses) or that they all give off light (3% of the total responses). All identified themes for yes are given in Table 9.

Table 9. Themes Identified in Student Responses to "In what way(s) are all stars the same?" (*N*=381) (Note: Because responses could be coded for more than one theme, percentages may add to more than 100%)

Theme	Responses *N*	Responses %
Same composition	23	6.0
All emit light	13	3.4
Other reason	11	2.9
Same formation process	9	2.4
All in Universe	3	0.8
Nonscience or no response	3	0.8
Go through same stages	2	0.5
All have gravity	2	0.5

Of all the responses to explain the differences between stars (see Table 10), the most common response was that stars may have different sizes (68%), followed by different compositions (27%). In most cases, characteristics which might differ between stars were simply listed (e.g., "size and composition" might constitute an explanation under "no"). As indicated earlier, some participants provided responses describing how stars are essentially the same basic objects while also listing characteristics that might vary among stars. This question was used to help identify the ways in which students define and describe stars; as such, responses to this question were not classified as Correct, etc., as had been done for previous questions.

Table 10. Themes Identified in Student Responses to "In what way(s) are stars different?" (*N*=381) (Note: Because responses could be coded for more than one theme, percentages may add to more than 100%)

Theme	Responses *N*	Responses %
Radius or size	257	67.5
Composition	102	26.8
Luminosity, brightness, amount of light released	95	24.9
Color	71	18.6
Other difference	67	17.6
Age or total lifetime	66	17.3

Table 10. (*Continued.*)

Theme	Responses *N*	%
Stages of evolution	64	16.8
Distance or location	57	15.0
Temperature	52	13.6
Shape	50	13.1
Amount of energy, heat released	25	6.6
Mass	21	5.5
Density	15	3.9
Gravity or gravitational pull	11	2.9
Nonscience or no response	9	2.3
Binary or multiple star system	7	1.8
Names	6	1.6
Formation	4	1.0

Form J asked participants to compare stars to planets. Like the previous question, this asked for a yes/no response with an explanation.

> Is there a difference between a star and a planet? Indicate yes or no below and answer the accompanying question. Support your answer with a sketch and labels, if possible.
> Yes_____ Describe what you think the differences are.
> No_____ Describe why you think they are the same (Note 2).

Most participants (89%) indicated that stars and planets are different objects (see Table 11). Like in the previous questions, the analysis of this question was based on the identification of themes within the yes or no responses. Themes for each category are described below. The identification of an ideal correct response, like in the previous question, was difficult and depended on the reason provided. In order to focus on the exploration of students' ideas, and for consistency of analysis with the previous question ("Are all stars the same?"), Correct, Incorrect, Partial, or Wrong classifications were not assigned to these responses.

Table 11. Responses to "Is there a difference between a star and a planet?" (*N*=208)

Category	Responses *N*	%
Yes only	184	88.5
No only	13	6.3
Both yes and no	10	4.8
Nonscience or no Response	1	0.5

As in the previous question, themes were identified for both yes and no responses. The most frequent explanations given for why stars are different than planets is that they are different states of matter (typically, though not exclusively, that stars are gas and planets are solid; 31%) and that stars "burn" while planets do not (25%). The range of themes is described in Table 12.

Table 12. Themes Identified in Student Responses to "Describe what you think the differences [between stars and planets] are." (*N*=208) (Note: Because responses could be coded for more than one theme, percentages may add to more than 100%. Rows that are indented and in italics represent subthemes to the larger themes)

Theme	Responses *N*	%
Different states of matter	64	30.8
Stars "burn"	51	24.5
Other difference	39	18.8
Stars emit light	36	17.3

Table 12. (*Continued.*)		
	Responses	
Theme	***N***	**%**
Planets orbit stars or the sun	28	13.5
Radius or size	27	13.0
Stars are larger	14	6.7
Planets are larger	13	6.3
Planets have atmospheres	18	8.7
Planets are habitable	17	8.2
Different composition	14	6.7
Nonscience or no reason	14	6.7
Stars are hotter	11	5.3
Sun is a star	10	4.8
Stars undergo fusion	9	4.3
Different mass	6	3.0
Different gravity or gravitational pull	5	2.4
Stars farther than planets	4	1.9
More stars than planets	3	1.4

Fewer than 5% of the participants gave reasons for citing why planets and stars are the same kinds of objects, and most of the reasons provided were offered by single participants (and so are lumped together in "other," 4%). Other reasons cited by more than one participant include that planets and stars look the same in the sky (2%), both emit light (1%), and are made of the same materials (1%). Details are provided in Table 13.

Table 13. Themes Identified in Student Responses to "Describe why you think [stars and planets] are the same." (*N*=208) (Note: Because responses could be coded for more than one theme, percentages may add to more than 100%)

	Responses	
Theme	***N***	**%**
Other response	9	4.4
Look same in the sky	4	1.9
Both emit light	3	1.4
Same composition	3	1.4
Both in solar system	2	1.0
Same formation process	2	1.0
Nonscience or no response	2	1.0

Forms L, M, and N asked two different questions to again investigate students' understanding of the nature of stars by comparing them to yet another type of object: shooting stars. On Form L, students were asked, "Other than appearing to move quickly across the sky, how is a *shooting star* different form a *star*?" Forms M and N used a different format question that required students to consider a hypothetical student statement about the relationship between a star and a shooting star:

> Your friend tells you that a shooting star is the result of a star running out of fuel and "burning out." Do you agree or disagree with your friend? Explain why you think the statement is correct or incorrect.

A total of 236 students responded to one of these two questions.

More than a third (36%) of the participants recognized that shooting stars are completely different objects than stars, and 29% correctly identified what a shooting star is (15% said meteor while 14% said something like "space debris"). Nearly 16% either said or agreed with the idea that a shooting star is a *dying* star or one which has lost or used up its energy. A quarter of the respondents indicated that a shooting star is some kind of object moving or falling through Earth's atmosphere. The complete set of themes identified for these questions is provided in Table 14.

Table 14. Themes Identified in Student Responses to "How is a shooting star different from a star?" (*N* = 236) (Note: Because responses could be coded for more than one theme, percentages may add to more than 100%; rows that are indented and in italics represent subthemes to the larger themes) (SS denotes shooting stars)

Theme	Responses *N*	Responses %
Different types of objects	85	36.0
Meteor	36	15.3
Space debris, rocks, etc.	33	14.0
Asteroid	16	6.8
Comet	14	5.9
Different but unspecified	11	4.7
Other	67	26.7
SS moves or falls through Earth's atmosphere	60	25.4
SS is a "dying star"	37	15.7
Nonscience or no response	23	9.7
SS Moves, stars are stationary	12	5.1
Energy—SS has more	10	4.2
SS leaves a tail or trail behind	8	3.4
Distance—SS is closer	6	2.5
See a streak of light	5	2.1
No nuclear fusion in SS	3	1.3
Energy—SS has less	2	0.8

5. DISCUSSION

SSR surveys were used to determine the range and frequency of students' ideas about the questions listed in Table 1. Through an inductive, iterative analysis of the responses, themes were identified for each of the SSR survey questions posed. Overall, results showed that students have appreciable prior knowledge about stars, however, that knowledge is inconsistent (or incomplete) when compared to current scientific understanding. For example, in responding to the "what is a star" question, more than 80% correctly identified that a star is made of gas and 43% specifically used the phrase "ball of gas." Few students provided any description beyond this basic idea of composition. Therefore, student mental representations of stars are, at best, incomplete, which may result in an individual synthetic conceptual model about stars that contains both correct and incorrect mechanisms after instruction (Vosniadou, Vamvakoussi, and Skopeliti 2008). Such a synthetic model of stars would be consistent with studies involving student understanding of other astronomical phenomena (Vosniadou and Brewer 1992; Vosniadou and Brewer 1994).

The primary defining characteristic of a star—that it undergoes nuclear fusion in its core—was stated by fewer than 4% of the participants prior to instruction. Instead, students who made any attempt to describe the energy production process used "burning" as the explanation. This was stated by nearly half (44%) of the participants. From some extensive responses, it was clear that students do not always think of burning as a standard combustion reaction consistent with their familiar conception of fire. Some students do seem to recognize that the combustion processes we are most familiar with typically involve oxygen, and that the lack of oxygen in space, then, would prevent stars from creating light through this process. However, it was rare that students could further clarify their ideas or explain what they meant by burning given this knowledge. It is also possible that the idea that gases are often flammable (as reported in Driver *et al.* 1994) might support the idea of a star as a "burning ball of gas." On the SSR surveys, where space and time were significantly more limited than would be the case in interviews, this kind of distinction between combustion and some other, typically unknown process was rarely explained.

Consider the following description of energy production in stars, taken from a popular ASTRO 101 textbook:

> This process of **nuclear fusion**, by which hydrogen is converted into helium at the Sun's center, is called **hydrogen burning**, even though nothing is actually burned in the conventional sense. (The chemical reactions involved in ordinary burning act to rearrange the outer electrons of atoms but have no effect on their nuclei.) Because it can occur only at high temperatures, hydrogen burning is called a **thermonuclear reaction** or **thermonuclear fusion** (Kaufmann and Freedman 1999, p. 438).

The process of nuclear fusion is described here using four different bold-faced vocabulary words, including one which uses burning to describe the process, potentially leading to confusion for students who are unable to understand that the terms are intended to mean basically the same thing. Despite the acknowledgment that burning is not used in the way students might at first think, such apparent conflict between our everyday language and more precise scientific definitions, or variability of scientific definitions between situations or disciplines, can be a significant challenge for students trying to understand new materials (Williams 1999). A variety of research demonstrates the difficulties students have with the scientific meaning of terms such as the Big Bang (Prather, Slater, and Offerdahl 2002), half-life (Prather 2005), or energy (Jewett 2008), for example.

The burning misconception was dominant in both the "what is a star" and "how is the light we see from stars created" questions. The second most common idea for this second question was that chemical reactions were the source of energy production in stars (28%). Although it is not known what percentage of these participants took a high school chemistry class, it is reasonable to conclude that this idea may have come from such prior instruction. One of the basic characteristics used to identify whether or not a chemical reaction has taken place is that it can emit heat or light (see, for example, Wilbraham, Staley, and Matta 1997). It is not surprising then that students might take this piece of information and misapply it to stars. This may also suggest the development of synthetic models about stars (Vosniadou, Vamvakoussi, and Skopeliti 2008).

In describing how a star forms, nearly half of the more than 900 respondents indicated that material is brought together in some fashion. Again, the details are lacking, with only 16% identifying gravitational force as the cause of this process. This is not surprising when we consider that gravity is not typically discussed as a central force until high school physics at the earliest and, further, that fewer than one-third of all students in public high schools take physics (American Institute of Physics Statistical Research Center 2006). Many of the students provided little in the way of a description of a process of formation, but rather simply provided information about specific characteristics that the process might have (e.g., composed of gas and dust, energy is released, etc.)

Many students were able to identify characteristics which might differ from one star to another or between stars and planets, such as radius, composition, distance, energy emission, and so forth. Students had more difficulty, however, distinguishing a star from a shooting star. A shooting star was sometimes mistaken for a dying star (16%). This is another area where a conflict between everyday and scientific language may interfere with learning (Williams 1999).

The SSR surveys provided rich data on surveyed students' preinstructional ideas about stars. Although the level of detail varied among the responses, students seemed willing to make a reasonable attempt at an answer (as indicated by the fact that fewer than 10% of the participants on any given question provided a nonscience or no response).

6. CONCLUSION

The identification of the range and frequency of students' beliefs about the properties and formation of stars is an important first step in improving instruction on this topic in our ASTRO 101 courses. The data from this first phase of a larger study have provided a great deal of insight into what students think about the topic of stars prior to instruction. The most common ideas identified through the SSR surveys were used to develop the *Star Properties Concept Inventory* (SPCI) in the second phase of the larger study (Bailey 2006). This will allow instructors to use a valid, reliable instrument to determine how much their students have learned about the topic over an instructional period. It is also anticipated that the SPCI could be used to compare different instructional strategies.

Future areas of research in this area are rich. Results from the SSR surveys suggest that students may develop synthetic models (Vosniadou, Vamvakoussi, and Skopeliti 2008) about stars, in which scientifically correct and incorrect elements are combined. The data from this study indicate two major areas that may be fruitful for further research on possible synthetic models: the processes of energy production within stars and the formation of stars. In both areas, student responses to the SSR surveys indicate the presence of basic but incomplete (and sometimes scientifically incorrect) ideas. Additional work that builds on this study and the work of Agan (2004) is needed to understand the origin of common misconceptions and the specific mental models students might create during K-12 education. The use of alternate data collection strategies, such as interviews, may be better suited to the identification of specific mental models (Brewer 2008).

The current study focused only on the properties and formation of stars, but purposefully did not address the idea of stellar evolution. What difficulties do students have in understanding the lifecycles of stars? Does the anthropomorphic nature of the language in this area create additional problems? Furthermore, the current work focuses only on college nonscience majors. Finally, investigations into how these ideas change with instruction are needed in order to understand to what extent the design of our ASTRO 101 courses is effective in engendering learning in the area of stars.

7. NOTES

Note 1: This study was completed as part of the first author's doctoral dissertation while all authors were at the University of Arizona. An early version of this manuscript was presented at the National Association for Research in Science Teaching International Conference 2005, Dallas, TX.
Note 2: As an anonymous reviewer noted, it is possible that the disagreement in number between the main 'yes/no' portion of this question and the required explanation could have been confusing for students. No unusual trends were noted in the analysis of responses, but further research would be required to ensure that this was not a problem. The question should be reframed for use in future research.

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