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Hints of a Fundamental Misconception in Cosmology

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Abstract

To explore the frequency and range of student ideas regarding the Big Bang, nearly 1,000 students from middle school, secondary school, and college were surveyed and asked if they had heard of the Big Bang and, if so, to describe it. In analyzing their responses, we uncovered an unexpected result that more than half of the students who stated that they had heard of the Big Bang also provided responses that suggest they believe that the Big Bang was a phenomenon that organized pre-existing matter. To further examine this result, a second group of college students was asked specifically to describe what existed or occurred before, during, and after the Big Bang. Nearly 70% gave responses clearly stating that matter existed prior to the Big Bang. These results are interpreted as strongly suggesting that most students are answering these questions by employing an internally consistent element of knowledge or reasoning (often referred to as a phenomenological primitive, or p-prim), consistent with the idea that "you can't make something from nothing." These results inform the debate about the extent to which college students have pre-existing notions that are poised to interfere with instructional efforts about contemporary physics and astronomy topics.

Hints of a Fundamental Misconception in Cosmology

Teachers are continually amazed and frustrated by the long list of conceptual difficulties students have when learning concepts of physics and astronomy. In fact, Neil Comins has just released the results of a decade-long study revealing more than 1,600 inaccurate ideas that non-science major undergraduate students bring to the introductory astronomy course (Comins 2001). Comins's list presents a worthy challenge to astronomy teachers at all levels. Few of us would be surprised to see that students' alternative

conceptions surrounding seasons, moon phases, and gravity sit atop this exhaustive list, as they have been repeatedly documented and confirmed elsewhere (Adams & Slater 2000). Unfortunately, the degree to which teachers should allocate precious class time to helping students overcome their reasoning difficulties about these topics is the subject of some debate (Pasachoff 2001; Pasachoff 2002). One side of the debate suggests that students should be exposed to more contemporary topics in astronomy rather than devoting the time required to fully teach basic concepts. In contrast, the other side suggests that it is more important for students and teachers to expend the time and mental effort needed to fully understand the most basic of topics. What is clear from both perspectives is that significant instructional time and targeted instructional strategies are required for students to develop a meaningful and deep understanding of complex ideas. We do not attempt to join this important debate here; rather, this article reports on some preliminary findings showing that, just as with basic topics such as moon phases and seasons, students also have alternative and pre-existing conceptions regarding the modern topic of cosmology.

A constructivist approach to instruction requires that teachers be aware of and design instruction around the pre-existing ideas their students bring into the classroom (Prather & Harrington 2001; Slater, Carpenter, & Safko 1996). In an effort to develop curriculum supplements from this perspective, we administered a survey to 177 introductory astronomy, non-science major university students prior to collegiate instruction on cosmology. Our survey directly asked students if they had heard of the Big Bang and, if so, to please describe it. These surveys were then analyzed inductively by organizing responses into themes, often called phenomenological categories, and looking for patterns in student responses. These results are summarized in Table 1.

Table 1. If you have heard of the Big Bang Theory in Astronomy, what is it?

	College (n = 167)	**High School (n = 153)**	**Middle School (n = 340)**
Theory Describing Creation of the Universe	**54 %**	**48%**	**27%**
Explosion of pre-existing matter	*80 %*	*70 %*	*62 %*
Explosion from nothing	*1 %*	*0 %*	*4 %*
No explanation provided	*18 %*	*27 %*	*28 %*
Other	*1 %*	*3 %*	*6 %*
Theory Describing Creation of Planetary Systems	**25 %**	**28 %**	**37 %**
Solar system/planets	46 %	65 %	83 %
Earth	*54 %*	*35 %*	*17 %*
Other Answers (including "I've heard of it but I have no explanation")	**21 %**	**24 %**	**36%**

NOTE: Students were asked if they had heard of the Big Bang and if so, to please describe what it is. The data in the table above represent only students who responded that they had heard of the Big Bang. The percentages of students who answered no were: $n_{college}$ 10/177 (6%); $n_{high\ school}$ 24/177 (14%); $n_{middle\ school}$ 267/607 (44%). High school data is for males only. Additionally, the subcategory percentages listed in italics represent the percentage of the total number of students responding in that particular category.

We found that an overwhelming 94% of the initial 177 college students surveyed reported that they had heard of the Big Bang. Of these 167 students who reported having heard of the Big Bang, one-quarter gave responses suggesting that it was a theory describing the creation of stars, planetary systems, solar systems, or Earth, whereas more than half stated that it was a theory describing the creation of the universe. A full 80% of those students stating that the Big Bang is a theory describing the creation of the universe gave statements clearly indicating that the Big Bang was an explosion of some form of pre-existing matter. Much to our surprise, only two college students (1%) stated that the Big Bang was an explosion from nothing. Even if one makes an unfounded assumption that the remaining 18% of these students who did not provide any further description also believe that the Big Bang was an explosion from nothing, these results suggest that the majority of students in this population do not think of the Big Bang in a manner consistent with the contemporary cosmology model of the origin of the universe. These results are consistent with a smaller-scale pilot study conducted by Crowder and his colleagues (2001).

To explore the extent to which pre-college students might also harbor these inaccurate ideas, we also surveyed 603 twelve- and thirteen-year-old eighth-grade students and 177 male high school physics students. The results, also shown in Table 1, are overall quite similar to the collegiate data. The vast majority of these middle and high school students also have pre-existing and inaccurate beliefs about the Big Bang. It seems that many students of all ages, and likely the general public, carry with them the mistaken idea that the Big Bang was an event that organized pre-existing matter. These inaccurate ideas are well positioned to interfere with instruction designed to help students adopt a scientifically accurate view of the Big Bang.

To better inform instruction, we felt it was necessary to look deeper into what students believe was occurring during the Big Bang. We administered a second survey to a different group of 133 college non-science majors who had not yet received instruction on the Big Bang. Using the results from our initial survey that suggested that most students had heard of the Big Bang, this survey more closely targeted students' beliefs by stating and asking, "The Big Bang is a scientific description of the origin and evolution of the universe. Provide a detailed, written description of what you think existed or was occurring (i) just before, (ii) during, and (iii) just after the Big Bang." The results from the analysis of students' written responses to the first question of this second survey are summarized in Table 2.

Table 2. Describe What Existed or Occurred Just Before the Big Bang.

	College Astronomy Non-science Majors (n = 133)
Nothing (of matter) existed before the Big Bang	**28%**
Nothing without additional comments	*49%*
There existed region of space and/or energy but not matter	*35%*
A point or singularity (possibly containing energy) but not an object or location of mass	*16%*
Some configuration of matter existed before the big bang	**69%**
A distribution of gasses, particles, atoms, or molecules floating around an otherwise empty space	*47%*
Single large massive object, or star or planet	*18 %*
Single compressed, very small, point-like and massive object	15%
A different or somehow altered version of our universe	*3%*
A collection of large massive objects, or planets, or Stars or Meteors	*9%*
An earlier state or configuration of Earth	*8%*
Other	**3%**

As with the initial survey, we found that the majority of these students (nearly 70%) provided a written response clearly indicating that matter existed in some form prior to the Big Bang. Their ideas most often include atoms, molecules, and gas particles existing within an otherwise empty space, or the existence of a massive object such as a star or planet. A less common response given by only 11% of these students suggested that a single, compressed, very small, point-like massive object existed prior to the Big Bang. This response could be considered to have at least an element of consistency with current scientific thinking. The belief that matter existed before the Big Bang is further illustrated by students in their written responses to the second question of the survey, in which students were asked to describe what they thought happened during the Big Bang. A description involving an explosion that either distributed matter throughout the universe or formed planets, stars, or galaxies was given by 49% of students. In addition, 17% of the students described a scenario in which matter combined or came together; and another 10% listed changes on Earth, such as separation of Earth's continental plates or the occurrence of mass

extinctions. Overall, the results from the second survey further illustrate that students hold scientifically inaccurate ideas about the modern topic of the Big Bang when they enter the classroom.

One approach to interpret students' scientifically inaccurate ideas that has proved fruitful in the context of physics education research is to consider the framework of knowledge as discrete pieces--called phenomenological primitives, or p-prims--that students develop throughout their lives to make sense of their physical world (di Sessa 1993). For example, the p-prim often referred to as "closer means more" is useful in helping us understand that car headlights appear brighter when cars are closer than when they are farther away. However, students all too often misapply this p-prim when asked to reason about seasons and the corresponding changes in Earth's temperature. In this context, students will often state that Earth is hotter in the summertime because Earth is closer to the Sun than in the wintertime. Much to the disappointment of faculty, students will often continue to misapply this p-prim to the concept of seasons despite targeted instruction intended to help them understand otherwise.

The results of this survey suggest that a p-prim might well explain the difficulties that students have when reasoning about the Big Bang. In particular, if students have spent years verifying the context-independent idea that "you can't make something from nothing," then ideas presented by lecture in an introductory astronomy class that contradict such a p-prim will likely require a more thoughtful approach to instruction. The existence of a "you can't make something from nothing" p-prim might also account for the origin of the perpetually asked question from students about "what is the universe expanding into?" suggesting a mental picture of the Big Bang as a primordial grenade exploding into a pre-existing empty room. Furthermore, students invoking this particular p-prim might also account for the persistent (both pre-course and post-course) student difficulty concerning locations for the center of the universe. This difficulty is illustrated by student responses to a question from the Astronomy Diagnostic Test (ADT). In this question, students are asked to identify what can be said about the location of the center of the universe by selecting from the choices: (a) Earth; (b) Sun; (c) Milky Way Galaxy; (d) an unknown, distant galaxy; or (e) the universe doesn't have a center (Hufnagel et al. 2000; Hufnagel 2001; Deming 2002).

Regardless of whether a "you can't make something from nothing" p-prim does exist, an instructor who follows the tenets of constructivism will need to alter the conventional textbook-based lecture approach to instruction if he or she wishes to help students who appear to think about the topic of the Big Bang in a manner consistent with this particular p-prim. Furthermore, this work suggests that instructors who would advocate teaching more contemporary astronomy topics in an effort to circumvent the tenaciously difficult basic topics of seasons, moon phases, and gravity because of the time required to "teach it right" might still encounter a considerable challenge in helping students make significant learning gains on contemporary topics. It appears that students do harbor pre-existing and often scientifically inaccurate ideas, or alternatively they may inappropriately activate phenomenological primitives on the spot to makes sense of contemporary astronomy topics. In either case, these recurrent patterns in student thinking need to be explicitly addressed for meaningful learning to take place.

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