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A Study of Common Beliefs and Misconceptions in Physical Science

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Abstract

The Science Belief Test is an online instrument comprised of 47 statements that require true or false responses and request written explanations to accompany these responses. It targets topics in chemistry, physics, biology, earth science, and astronomy and was initially designed to assess preservice elementary teachers' beliefs about general science content. A set of responses for six of the physical science items targeting force/gravity and physical/chemical change was selected for analysis from 305 respondents. Written explanations were coded into three general categories: (1) correct explanation, (2) incorrect explanation, (3) guess or uninterpretable. The correct response rates for the explanations were compared to the correct response rates that were based on the accompanying true or false answers. The explanations were further analyzed and coded into specific categories that included alternative and naïve conceptions. Correct response rates, when analyzed from the true/false or written explanations, were low (< 60%) for five of the six items. Naïve beliefs and/or misconceptions were prevalent for each of these five items, and understanding that students may hold these beliefs prior to instruction may provide teachers with useful information for the purpose of improving instruction.

Some scientific concepts are simply too difficult for individuals to understand. This can occur for a variety of reasons, but one of the primary reasons can be that everyday experiences can provide evidence that supports incorrect assumptions. While discussing the nature of science and how difficult it can be to help students believe abstract ideas, Margulis (2005) quoted Francis Bacon: "For what a man more likes to be true, he more readily believes." This quote helps to capture the heart of the confusion that can emerge. With experiences that shore up their beliefs, it is often difficult for science teachers to help students understand certain scientifically accepted ideas and concepts. Halloun and Hestenes (1985a) noted that "common sense misconceptions are not arbitrary or trivial mistakes" (p. 1056). They also remind us that many commonly held misconceptions were seriously advocated for by the likes of Aristotle and Galileo, adding some perspective to the challenges that lay before educators working to identify and change students' understandings of physical science concepts.

Theoretical Framework

Research on children's ideas, alternative beliefs, and science misconceptions has long been of interest to science educators in their pursuit of developing a scientifically literate citizenry. Fisher (1983) defined misconceptions as ideas that are at a variance with accepted views. Other terms have also been suggested such as alternative frameworks (Driver & Easley, 1978) and alternative conceptions (Hewson & Hewson, 1986). We use the term *misconception* to refer to students' ideas that are different from the ones generally accepted by scientists (Odom & Barrow, 1995). A significant amount of research has indicated that most people develop ideas about a variety of science topics before beginning formal science education and that these ideas tend to remain persistent despite efforts to teach scientifically accepted theories and concepts (Black & Lucas, 1993; Driver, Guesne, & Tiberghien, 1985; Driver, Leach, Millar, & Scott, 1996; Osborne & Freyberg, 1985). A number of studies have targeted common misconceptions in chemistry, physics, and physical science which are subject areas that include concepts that can be particularly abstract for learners to understand. This study investigates the extent to which specific physical science misconceptions are held by a sample of elementary preservice teachers.

Physical Science Beliefs

Compared to other areas of science, physical science concepts, such as force and motion, and physical and chemical changes, are often more abstract and are difficult for students to understand. In a study of student misconceptions in a university-level astronomy course, Zeilik, Schau, and Mattern (1998) studied both astronomy and physics concepts. The researchers found that although students generally had a lower score for understanding astronomy concepts, those concepts were easier to change through instruction than physics concepts were. Watts and Zylbersztajn (1981) studied children's ideas about force. In a series of questions that involved a multiple-choice with explanation format, students were asked to think about forces and motion through a variety of scenarios. They suggested that individuals tend to believe that force causes motion and a constant force must be required to maintain motion. Their results verified that students tended to have these same beliefs. Specifically, students had difficulty identifying the forces involved when an object is moving such as a thrown rock or a fired cannonball. They had difficulty understanding the force of gravity on the Moon, at different elevations on Earth, and when objects are at rest. Further, they had difficulty understanding and representing the forces involved during a tug of war game when one person is winning.

Lawrenz (1986) studied physical science misconceptions among elementary school teachers. The results indicated that misconceptions in physical science, across a range of concepts, were prevalent among the elementary teacher sample even though the teachers had strong educational backgrounds and a favorable disposition towards science. For a question about the change in mass of an iron nail after it had rusted or combined with oxygen, the responses revealed that only 36% of the teachers believed that the mass would be greater, and 46% believed that the mass would be less as a result of rusting.

Many researchers have studied students' beliefs about conservation during the changes in the state of water (Bar & Travis, 1991; Vassilia & Vasilis, 1997). Johnson (1998) found that 7th-grade students tended to believe the bubbles in boiling water were comprised of air, though students used the terms *air*, *oxygen*, and *gas* nearly interchangeably, as they did with *steam*. The general concept seemed to be that gas was something that went into the air and spread out or up. It was not until the end of three years of instruction and the introduction of the ideas of particles that most students were able to move to the idea that the bubbles were comprised of water as a gas. With respect to the bubbles in boiling water, students often perceive all bubbles to be comprised of air rather than different gases. These results were similar to those found by Novick and Nussbaum (1978) when they studied 7th-grade students' understanding of the particulate nature of matter through student interviews. The researchers found that the aspects of the particle model least assimilated by students were those most in dissonance with their sensory perceptions of matter.

Misconceptions about physical science concepts are not limited to children; they are also maintained throughout high school and into college, alerting researchers of the need to identify and challenge preservice teachers' understandings of physical science before they enter the classroom. The results of Halloun and Hestenes' (1985b) diagnostic study found that not only did college students enter their first course in physics lacking basic physics concepts, but their "alternative misconceptions . . . are firmly in place" (p. 1048). Their findings revealed that 47% of the students expressed a belief that under no net force, an object slows down; and 66% said that objects under a constant force move at a constant speed (Halloun & Hestenes, 1985a).

Method

The Instrument

In 2004-2005, the Science Beliefs Test (Larrabee, Stein, & Barman, 2006; Stein, Barman, & Larrabee, 2007) was developed to help identify common beliefs and alternative conceptions or "what a man likes to be true." Many of the items were developed from previous research on students' scientific misconceptions and alternative beliefs. Although other methodologies, such as interviewing, may be more likely to provide information on the underlying belief structures associated with scientific phenomena, this instrument sought to address the need for a methodology that can readily be used by classroom teachers in identifying misconceptions (e.g., see Peterson, Treagust, & Garnett, 1989). The Science Beliefs Test is an easily administered instrument that targets a wide range of science topics that was originally designed to assess preservice elementary teachers' science beliefs. While the items target secondary science content, many of the belief statements may be appropriate at the elementary school level as well. The Science Beliefs Test consists of an online administration format (Stein, 2008), with respondents receiving the correct answers and explanations upon completing their responses. The instrument consists of 47 declarative statements to which an individual responds with "true" or "false" and then has an opportunity, yet is not required, to provide a brief written explanation following each response. Nineteen of these items target physical science concepts related to physics and chemistry. The items include statements on forces, gravity, light, waves, energy, entropy, molecular motion, density, physical change, and chemical change. Two areas that tend to be persistently problematic for preservice teachers in our program are (1) understanding gravity as well as the forces associated with motion and (2) the difference between physical and chemical changes. For this study, a set of responses for six of the physical science items associated with these concepts were selected for an in-depth analysis.

The number of written explanations for each of the six items varied from 83 (item #18) to 171 (item #15). The written explanations were coded into three general categories: (1) correct explanation, (2) incorrect explanation, (3) guess or uninterpretable. The correct response rates for the explanations were compared to the correct response rates that were based on the true/false answers. The explanations were further analyzed and coded as alternative ideas and beliefs emerged.

The content validity of the instrument was previously established (Stein et al., 2007) by using a panel of content expert reviewers, analyzing the results of several iterations of the instrument to preservice and inservice teachers, and by using statements with established validity, for example statements found within the *National Science Education Standards* (*NSES*) (National Research Council [NRC], 1996) or within previously published instruments. Reliability was also investigated on a number of levels (Stein et al., 2007), including a measure of internal consistency (0.77), test-retest (0.776), and expert matching of explanations to true/false responses (91.7%).

Sample

From January 1 through June 1, 2005, data were collected from 305 respondents who accessed the Science Beliefs Test online. During this time period, students enrolled in teacher education programs at two different universities were told how to access the instrument and participate in the study. Although these students were not required to participate in the study, many of them chose to do so. During this time period, 305 respondents consented to have their data collected and analyzed. Of those respondents, 282 (92.5%) indicated that they were currently enrolled in elementary education programs. The remaining 23 respondents consisted of eight (2.6%) members of the general public, seven (2.3%) K-12 classroom teachers, five (1.6%) undergraduate non-education majors, two (0.7%) secondary education majors, and one (0.3%) elementary student. Of the 282 elementary education majors, 64 (22.7%) indicated that they had a major or a minor in science and the remaining 218 (77.3%) indicated that they had neither a major nor a minor in science. These elementary education majors have completed all of their content coursework and most are in their final semester prior to student teaching.

Data Collection and Analysis

Reviewers with expertise in science content and alternative conceptions analyzed the written explanations provided by the respondents to six physical science items that targeted force/gravity and chemical/physical change for a five-month period (January 1 through June 1, 2005). The number of written explanations for each of these six items varied since respondents were not required to provide explanations prior to advancing to the next question. Content analysis was used to examine the written responses. Coding categories were established, and analysis of the explanations followed an iterative process (Miles & Huberman, 1984). The process included reviewing the data to discover patterns and potential explanations. As each statement was analyzed, the reviewers determined whether the statement, apart from the corresponding true/false answer, reflected a correct or incorrect explanation. Some responders indicated that they had guessed or included statements that could not be interpreted by the reviewers; these responses are noted in the summary analysis. A comparison was made between the percentage correct when considering only the written responses to the percentage correct based on the true/false responses. In addition, each item was analyzed to determine the extent to which alternative ideas were expressed in the written explanation.

Each explanation was read independently by two reviewers who categorized the explanation as correct, incorrect, a guess, or uninterpretable. The reviewers then met to discuss any discrepancies in their analysis. There was a very high level of agreement (> 0.90 for each item) and a discussion of the interpretations that varied helped to create an even higher correlation between each reviewer's analysis of each item. The items were then analyzed for the purpose of coding the explanations into specific belief categories. The purpose of this analysis was to ascertain the extent to which (1) the true/false answers correspond with the written explanations; (2) specific alternative beliefs are revealed in the written explanations; and (3) specific topics in physical science demonstrate high levels of misunderstanding and, therefore, may be especially difficult to interpret.

Results

The physical science items selected for analysis and the overall correct true/false response rate for each item can be found in Table 1.

Table 1. Physical Science Items from Science Beliefs Test (N = 305)

Item Number	Item	Correct Answer	Percentage Correct Responses
14	When a book is at rest on a table (not moving), other than the force of gravity, there are no other forces acting on it.	False	56.7
15	An astronaut is standing on the moon with a baseball in her/his hand. When the baseball is released, it will fall to the moon's surface.	True	32.8
16	When two spheres that are the same size, have similar surfaces, but have unequal masses, for example, one made of wood and one made of lead (greater mass), are dropped from the same height above the ground, the more massive sphere (e.g., lead sphere) will hit the floor first.	False	53.8
18	A force is needed to change the motion of an object.	True	94.4
30	The bubbles in boiling water consist primarily of air.	False	34.8
32	When a chemical reaction occurs, the total mass of the resulting products can be less than or greater than the original mass of the reactants depending on the type of chemical reaction that took place.	False	34.1

The correct response rates ranged from 33 to 94%. Many of the 305 participants did not include written explanations for every item, causing there to be a different number of responses analyzed for each item. As a result of the number of written responses varying and being different than the number of true/false responses, it was necessary to adopt a single standard scale of measurement (z-scores) such that all distributions, despite their different origins and unit sizes, could be compared

(McCall, 1994). The comparison between the percentage correct when considering only the written responses to the percentage correct based on the true/false responses is summarized in Table 2. The analysis revealed a significant difference between correct written explanations and correct true/false responses for half of the six physical science items.

Table 2. Item Comparison of Written Explanations to True/False Responses

Item Number	Number of Written Explanations Analyzed	Percentage Correct for Written Explanations	Percentage Correct in True/False Responses	Z-Score
14	123	53.6	56.7	-0.54
15	171	22.8	32.8	-2.2*
16	128	57.1	53.8	0.77
18	83	74.7	94.4	-3.5*
30	94	25.5	34.8	-1.4
32	97	51.6	34.1	2.5*

*** Denotes significance at 0.05 level**

Ideas Targeting Beliefs Involving Force and Gravity (Items 14, 15, 16 & 18)

When explaining what forces are involved when a book is at rest on a table (Item 14), over 40% of respondents failed to recognize a normal force or reaction force that balances the force of gravity. The correct response rate for the written explanations was similar to the true/false correct response rate for this item. While some respondents indicated that other forces were acting on the book, such as air pressure (8.1%) or centripetal force from the Earth's rotation (2.4%), these were the only other forces suggested in their responses. Some respondents also indicated that if other forces were acting on the book, then this would be evidenced by movement or motion (5.7%). Some explanations also described heat, potential energy, and mass as forces that were acting on the book (13.0%).

Item 15 targeted respondents' understandings of gravity and specifically how a baseball would behave if released when an astronaut is standing on the Moon's surface. Of the six physical science items that were analyzed, this item had the lowest correct response rate on both written and true/false response rates. There was a significant difference between the correct response rates between the written explanations and the true/false responses. A number of alternative conceptions about this item emerged. Many respondents (41.5%) wrote that there is no gravity on the Moon. Some respondents also wrote that there is no gravity in space (5.8%) and indicated that the surface of the Moon and space are the same. Most often, these "no gravity" explanations also indicated that the ball would float. Some explanations simply stated that the ball would float (9.4%) but did not provide a reason why this would happen. A few respondents indicated that the gravity on the Moon is much less or "different" and, therefore, the ball would not fall (8.8%). Surprisingly, some respondents indicated that the ball would float because of gravity (8.8%).

The effects of Earth's gravity on falling spheres were targeted in Item 16. While a more sophisticated understanding of falling objects and terminal velocity creates the possibility of a correct true/false response—depending on the height at which the spheres are dropped—analysis of the written explanations provide an opportunity to observe the level of understandings about this concept. With a similar item, Zeilik et al. (1998) found that 67% of university astronomy students responded correctly. In our sample, 53.8% responded correctly to the true/false component. When the written correct response rate (57.1%) was compared with the true/false correct response rate, there was no significant difference. The majority of responses represented two belief categories: (1) mass does not affect the rate of fall (39.1%) and (2) the sphere that is "heavier" or "has more mass" is more affected by gravity. Within each of these categories, there was not one response that discussed higher-level concepts such as terminal velocity. A few respondents indicated that the density of the object is a factor (1.6%) or that the "lighter" sphere would fall faster (2.4%).

A majority of respondents correctly believed that a force is needed to change the motion of an object (Item 18) when analyzing the written explanations (74.7%) and true/false responses (94%). There was a significant difference between these two correct response rates. Newton's first law was provided as the belief that grounded this response for 48.2% of the respondents. Others included incorrect descriptions of other laws (4.8%), however, such as the belief that gravity is what causes a change in motion (3.6%) or other incorrect ideas regarding forces. For example, one respondent stated, "Humans can move their bodies without the help of force."

Ideas Targeting Beliefs Involving Physical and Chemical Changes (Items 30 & 32)

When responding to whether the bubbles in boiling water (Item 30) consist primarily of air, it was clear that many respondents do not understand the difference between chemical and physical changes. While there was no significant difference between the correct response rates for the written explanations (25.5%) and the true/false correct response rates (35%), both rates are quite low. The words "gas" and "water" were used vaguely in many responses and, thus, the number of responses that were guesses or uninterpretable for this item were quite high (24.4%). For example, some respondents would write explanations such as "they are gas" or "they are water," which are both true. When analyzing the entire set of explanations, however, it became clear that "gas" often referred to gases such as carbon dioxide, oxygen, and hydrogen. Similarly, "water" most often referred to liquid water rather than water vapor. Some beliefs that were expressed in the written explanations included the idea that the bubbles were comprised of other gases such as oxygen (7.4%), a mixture of hydrogen gas and oxygen gas (6.4%), and carbon dioxide (3.2.%). There were a number of explanations that referred to the bubbles as being comprised of "heat" (13.8%). A few explanations indicated that the bubbles were "condensation" (2.1%).

Item 32 targeted the concept of conservation of mass during a chemical reaction. The most unusual aspect of a comparison of correct response results for this item was that the correct response rate for the written explanations (51.6%) was significantly greater than that of the true/false responses (34%). Most often, the written explanations that were coded as correct even though the true/false response was incorrect referred to a correct explanation of the concept of conservation of mass. Thus, it was not possible to know whether the respondent had simply made an error in the true/false selection or, more probably, provided the conservation of mass explanation because it fit the item rather than reflecting an understanding of the concept. Respondents indicated that the mass of the products would be less than the reactants (5.2%) or less because a gas is given off when burning (5.2%). Other incorrect explanations included beliefs involving the effects of phase change or energy change on the mass of the products of the reaction (14.4%).

Discussion

The prevalence of misconceptions related to physical science has been well documented by the consistency of findings over the last 20 years. The results from this study help to confirm that little progress has been made toward helping learners understand specific science concepts in ways that are aligned with the views held by scientists. Except for Item 18, the statement that force is needed to change the motion of an object, the correct response rates for these items were quite low when considering the true/false format of the instrument. In general, the written explanations revealed that the respondents do not have a clear understanding of what gravity is and how objects behave as a result of gravitational forces. The written responses also revealed that there are many misconceptions regarding what is happening at a molecular level when physical and chemical changes occur.

Many would agree that K-12 classroom teachers can have direct and important influences on their students' conceptualizations of scientific phenomena. This study helps to confirm that, in the elementary grades, students are likely to have teachers who have an abundance of misconceptions related to concepts involving force, gravity, and changes in matter. Providing preservice teachers with opportunities to explore their scientific beliefs in a nonthreatening way, such as through the online Science Beliefs Test, may help them develop improved understandings. Moreover, many of the current research methods used to solicit students' beliefs are not feasible to implement in K-12 classrooms. The format of the Science Beliefs Test can be adapted and used in K-12 classrooms to help teachers acquire a sense of the misconceptions that might be prevalent and some of the underlying beliefs that support these misconceptions. Many of the items are comprised of statements directly found in the *NSES* (NRC, 1996) or from topics that are found in K-12 science programs. Administering items from the instrument and analyzing the results at the elementary, middle, and high school levels will need to occur to appropriately adapt the instrument for classroom use.

Children and adults develop misconceptions as they attempt to make sense of the world they observe. Their common sense understandings of physical phenomena, developed over their lifetime and influenced by news items, popular science journals, and misleading science texts, are very difficult to challenge (Viennot, 1979). Halloun and Hestenes (1985a) found that when physics students were presented with experiences that challenged their beliefs, students were more likely to argue that outside laws or principles were interfering with the results rather than change their conceptions.

While the task of guiding students to consider adopting more generally accepted physical science concepts is challenging, no change can be effected if instruction is undertaken without knowing students' currently held beliefs. More importantly, nothing can be changed if the teachers have misconceptions and are not aware of them. Varelas, Pappas, and Rife (2006) investigated young students' beliefs about evaporation, boiling, and condensation and found that children theorize about the same phenomena in different ways and suggested that we "need to enter the students' world if we are to fathom what they know and how we might reach them" (p. 657).

In order to effect change in the misconceptions held by children, a change must first be effected in their teachers. Vital members in the larger cadre of science educators are the instructors in preservice teacher education programs. Those who provide content coursework to preservice teachers could benefit by exploring their students' existing beliefs before proceeding with instruction. Some higher education faculty who teach various science courses may not be aware of the important role that prior beliefs has on the ability of the learner to understand counterintuitive ideas. Thus, the instructors may not take the time to discern pre-existing beliefs. The results from administering these items to science students in higher education settings may help instructors to understand the array of surprising beliefs held by their students. Building on the work of Dana, Campbell, and Lunetta (1997) and Rice (2005), the importance of constructivism in teacher education as instruction based in this theoretical construct provides opportunities for students to develop more helpful conceptions from the origins of their prior knowledge.

The Science Beliefs Test, in total or in subsets, will give science educators a tool to assess students' prior knowledge of basic science concepts. With this knowledge, instructors will be able to identify students with greater or less general science knowledge as well as the most commonly held misconceptions. In this study, the participants had already completed their science content coursework and, thus, the opportunities for these preservice teachers to engage in instruction that might influence their beliefs was limited. If these or similar items were administered by instructors earlier in a university program, however, there would be greater opportunities for these science educators to then guide the preservice teachers' instruction accordingly by attending to those students with the greatest need and by designing experiences that challenge those students' most widely held misconceptions. Clement (1982) cautions that due to students' reluctance to disavow their current beliefs, simple recitation of principles and laws will allow students to continue to misunderstand and/or distort what they hear in order to maintain their present constructs. With this in mind, science educators need to develop experiences that will specifically challenge commonly held misconceptions and require students to critically reflect upon their current constructs to begin to consider the ideas generally held by scientists.

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