

# Revisiting Science Misconceptions: Has Anything Changed?

***Rosemary A. Millham***

***Aaron D. Isabelle***

State University of New York at New Paltz

## ***Abstract***

This study describes how science misconceptions remain prevalent in middle school settings. Misconceptions were collected from primary and anecdotal sources (teachers) and posed to students using a survey. The students agreed or disagreed with specific statements and then explained why they agreed or disagreed. Findings demonstrate that students who incorrectly agreed or disagreed with a statement were less likely to explain their reasoning, and many students who correctly agreed or disagreed with a statement were not able to explain the science concepts. Analysis of students' explanations assisted middle school teachers in their thinking and scaffolding of understandings about science misconceptions.

## **Author Biographies**

Rosemary A. Millham, Ph.D., a geologist and educator, is an Assistant Professor of Education in the Secondary Education Department at the State University of New York at New Paltz. Her research interests include inquiry-based, engaging, evidenced-based teacher preparation programming, clinically rich pre-service experiences, misconceptions in science, and atmospheric mineral dust identification. Email: millhamr@newpaltz.edu

Aaron D. Isabelle, Ph.D., is Associate Professor in the Department of Elementary Education at the State University of New York at New Paltz. He teaches undergraduate and graduate courses in science education and is active in professional development and school-university partnerships. His research interests include history-of-science-inspired stories, science misconceptions, and inquiry-based methods for improving science teaching. Email:isabella@newpaltz.edu.

When the film, *A Private Universe*, was released by the Harvard-Smithsonian Center for Astrophysics (1987), the American education system received criticism as viewers from around the globe wondered how Harvard graduates could possibly know so little about basic concepts in science (e.g. how seasonal change happens or what is the cause of the phases of the

Moon). The film was produced following the 1983 report, “A Nation at Risk: The Imperative for Educational Reform,” written by members of President Ronald Reagan’s National Commission on Excellence in Education. Today, 30 years after the report, misunderstandings, misconceptions, and a lack of common core science concepts continue to elude the minds of many students in mainstream America. Despite efforts by educators, policy makers, and scientists to create the *National Standard Education Standards* (National Research Council/NRC, 1996) and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science/AAAS, 1993), which resulted in rethinking what students need to develop scientific literacy, students are still struggling with basic scientific conceptual understandings.

Students can carry misconceptions with them for long periods, even into adulthood. In fact, 45-47% of adults who took part in a national survey titled, “Survey of Public Attitudes Toward an Understanding of Science and Technology,” did not know how long the Earth took to orbit the Sun (National Science Foundation, 2008). Many misconceptions are developed through textbooks (King, 2010) where misconceptions can be found in almost every book reviewed for scientific inaccuracies (Hubisz, 2001). Hubisz (2001) lead a 2-year survey that found over 500 pages of scientific errors in 12 of the most used science textbooks in the United States. According to Hubisz, “These (books) are probably a strong component of why we (U.S. students) do so poorly in science.” Hubisz estimated about 85% of children in the United States use the textbooks his team examined during the study.

Research also shows that science misconceptions learned at an early age are not easily corrected as students mature (Rice, 2002). The process of bringing students’ misconceptions to scientific accuracy is a long and arduous process that requires breaking down old understandings and building new conceptual understandings through processes that include “uncovering student ideas” and building a conceptual bridge from where students are to where they need to be (Keeley, Eberle & Tugel, 2007; Keeley & Harrigan, 2010; Keeley & Sneider, 2012). Keeley (2010) suggests that this process requires formative assessment probes to move students forward in their understandings.

Academic language use is another concern in the development of misconceptions. Concerns about decisions to not use academic language in elementary grades does not prepare students for understanding concepts (Pechione & Chung, 2006) and educators cite the lack of science academic language use as a source for misperceptions, misconceptions, and naive conceptual understandings in students (Gee, 2005; Snow, 2010; Yin, Tomita & Shavelson, 2008). Understandably, the sciences are overwhelmed with academic language and causes problems even for adults. Practicing and using scientific academic language not only helps students understand what is being taught from grade to grade, but also can help transform misconceptions to complete and accurate conceptions as conceptual change develops (NRC, 2001).

Additionally, we need to consider the sociological aspects of misconception development. Students who have varied and extended experiences tend to develop fewer misconceptions than students who lack experiences outside of the home, school, neighborhood, and city/town in which they live. Dewey (1938) wrote about the benefits of an experiential education stating, “There is an intimate and necessary relation between the processes of actual experience and education” (Dewey, 1938, reprinted in 1998, p. 20). Dewey contends that there has to be an experiential component in teaching lessons in order for education to be progressive. He argues that if teachers focused only on content, they essentially eliminate the opportunity for students to develop their own understandings and opinions about concepts. Dewey also suggests that each student’s experience is individualized and based on an accumulation of experiences and understandings, and that not all students develop the same conceptual understanding of a particular concept. Additionally, when considering Dewey’s assertion that not all experiences “are genuinely or equally educative” (and suggests that in progressive education, the quality of the experience is essential), we have to recognize that not all experiences are fruitful or creative in nature, nor in concert with reality. In fact, modern society has become so complex that the disparity of experiences to which youth can be exposed has increased markedly and is primarily socioeconomic in nature (Abner, Grannis, Owen, & Sawhill, 2013; Dunlap, Scoggin, Green & Davi, 2007; Reardon, 2011). As educators, we do not have much power to change the socioeconomic structure around our students, but we can bring diverse experiences into the classroom to promote scientific understandings. Many resources exist in the public and private sectors that bring science to life in meaningful, experiential ways to develop the thinking and process skills students need to become scientifically literate.

It is also unfortunate that many of our elementary teachers are not required to take a sufficient number of credits in the sciences (unless they are in a science concentration) yet are still expected to teach science. How can we expect our elementary teachers to prepare our youth in understanding basic scientific concepts for the rigors of science in the middle and high schools if they have not themselves been prepared to understand the concepts, nor how to teach science effectively? Although this topic is a discussion for another time, it needs to be considered as a source for misconceptions in student understandings in science. However, the lack of science background knowledge is not the only cause for lack of scientific understanding for teachers and students. We must also consider the impact that standardized testing has on what is taught in the elementary classroom. With the focus of testing centering on mathematics and literacy, elementary teachers are less likely to worry about teaching science and focus their endeavors on preparing their students for mathematics and literacy tests.

As a result of decades of research on students’ thinking in science,

the creation of conceptual map strands and Atlases of Science Literacy (AAAS), the advancement of methods of instruction to reveal and remediate misconceptions (Keeley, Eberle & Tugel, 2007; Keeley & Harrigan, 2010; Keeley & Sneider, 2012; Marshall, Horton, & Smart, 2009; Michael, 2006; Michaels, Shouse & Schweingruber, 2007), and the development of various misconception inventories (American Institute of Physics/AIP, 1997; AAAS, 2013; NRC, 1996) have been developed. In spite of these efforts, students continue to leave grade levels with conceptual misconceptions that pose a tremendous challenge for science educators. The bringing together of various conceptual elements, which results in the creation of scientific misconceptions, may be due to factors that have no significant connection with a particular scientific concept, nor to a particular method used to teach a concept. Finding the particular foundation for a misconception is a complex process that can be elusive since misconceptions often derive from students' lack of experiential knowledge, a conceptual or contextual misunderstanding, or a myriad of other factors defined or undefined. Whatever the source of the misunderstanding, science misconceptions remain pervasive and persistent in students' thinking and can be carried for decades until some perturbation of understanding occurs and new schemas develop. Our study begins a different journey - into the source of science misconceptions as a response to teacher frustration.

## **Background**

While visiting with former colleagues one evening (6<sup>th</sup>, 7<sup>th</sup>, and 8<sup>th</sup> grade teachers), we found ourselves discussing student perceptions and misconceptions in science, where these ideas formed, and how they were fostered over the years. The teachers' were quite excited about discussing the topic, but were definitely frustrated with their students' science misunderstandings over the years. Even at the university level misconceptions were apparent. One of us had recently experienced two simultaneous misconception events in science methods class that literally left two graduate students speechless. Considered bright and successful, both students found it difficult to wrap their minds around new understandings and rid themselves of their misconceptions. In addition to being science majors in the secondary education program, one of the students (alias Bill) was an interpretive science educator at a preserve, and the other (alias Sam) was a highly successful EMT and adjunct instructor for EMT training. Bill was enlightened during a class discussion when he found out that birds are not mammals. Sam was also enlightened during discussion when he discovered that the phases of the Moon are not caused by the shadow of the Earth!

At this point in the discussion with former colleagues, it was decided that middle school students would benefit from an analysis of their scientific

perceptions. Possibly a more important purpose is that an analysis of this type would provide the teachers with a constructive method for evaluating student understandings and inform their classroom instruction through effective evidenced-based practices.

## **Methodology**

This study is based on a beta survey (to be used in a future longitudinal research project) created for traditional middle school settings in our local districts to help our teacher-colleagues identify science misconceptions that exist among their 6<sup>th</sup>, 7<sup>th</sup>, and 8<sup>th</sup> grade students. Common science misconceptions were researched, especially those identified in earlier misconceptions research, and added to an inventory of misconceptions collected anecdotally in the teachers' classrooms. A list of twenty (20) statements was created for 6<sup>th</sup> grade, 7<sup>th</sup> and 8<sup>th</sup> grades, with all statements targeting specific scientific concepts (see Appendix A for a full listing of statements) (Note: the statements are a combination of scientifically accurate statements and misconceptions).

The survey instrument consisted of two parts: first, a student would choose to "agree" or "disagree" with a statement and second, the student would explain the reasoning behind his/her response. A comment box was provided for the survey explanations. This process provided two sets of data: 1) a set of simple responses and 2) a set of explanations for the responses. Our primary interest was not in the statement response of "agree" or "disagree", although these responses informed us about student understandings (or lack thereof). Our primary goal was to analyze the explanations for the student responses. We wanted to determine the depth of the students' conceptual understanding, the students' ability to find the language necessary to explain a concept, and whether or not the students understood what they thought they knew (and to what degree), either through a careful explanation and/or an accurate application of their understanding.

The study provides quantitative and qualitative data for analyses. Quantitative analysis of the data is derived from the number of agree or disagree responses for each statement. Qualitative data analysis is derived using a rubric created to determine if patterns or developing themes are evident in the language used by the students in their explanations. Specifically, we were interested in discovering: 1) if students had the language skills necessary to explain why they agreed or disagreed with a statement; 2) the degree to which the scientific concepts used by the students in their explanations demonstrated that the concept was understood by the students; and 3) if misunderstandings or prior knowledge interfered with correct explanations, especially relative to the use of the language used to explain responses.

The survey tool was administered in early winter and repeated in the late spring. The survey was not discussed in class and did not drive instructional content. (Note: access to the survey data was not shared until the last day of school). This pre-arranged decision not to have access to the statements or teach to the statements, or review the first survey results, ensured that the spring survey results were not influenced by teacher interventions in instruction.

After the completion of the late spring survey, it became evident that six (6) specific survey statements yielded the most intriguing student responses/explanations and were subsequently extracted for analysis. Additionally, the early winter and spring survey results were not significantly different ( $<0.1\%$  standard deviation); therefore, this study is focused on the compilation of data from only the late spring survey. Due to the quantity of data for all three grades (3,410 responses/explanations) for each survey event, only the sixth grade responses and explanations for the six statements were selected for this initial analysis (Note: total number of 6<sup>th</sup> grade explanations is 1,760 for the 20 statements. The six statements extracted for this study provided us with 528 explanations). The six extracted statements include:

1. Birds are mammals.
2. Whales and dolphins are fish.
3. The Sun is food for plants.
4. The phases of the Moon are caused by the shadow of the Earth on the Moon.
5. Batteries have electricity inside of them.
6. There is no gravity in space.

Each survey was analyzed quantitatively according to the following procedure: 1) the percentage of students who either agreed or disagreed with a statement was calculated; 2) we determined the percentage of students who negated their response by providing an explanation that proved to be a correct explanation for a scientifically sound response or whose explanation discounted their response (For example, if a student responded “agree” to the statement “birds are mammals” and subsequently explained that birds had feathers, but do not have mammary glands or feed their young with milk, then they essentially negated their “agree” response. Conversely, if a student responded “disagree” to the statement and then explained that birds had fur and produced live young, the statement response was negated); 3) the percentage of students who supported their response with a scientifically correct explanation was determined; and 4) and we conducted a comparative analysis of the qualitative assessment versus the quantitative assessment as a second level analysis of the degree to which students responded correctly or incorrectly.

Each survey was analyzed qualitatively using a rubric to measure the degree of understanding inherent in students' explanations to determine a level of conceptual accuracy (Table 1). The following questions guided the creation of the rubric: Did a student partially or fully negate the “agree” or “disagree” response for a survey statement in writing the explanation? Did the student provide a full explanation that showed that he/she understood the concept well enough to explain it properly? Did the student provide a valid concept to support the explanation?

Table 1. Science misconception rubric used in evaluating response explanations in the 2011 beta survey.

<b>Science Misconception Rubric – Table 1</b>			
<b>1 - Not Acceptable</b>	<b>2 - Progressing</b>	<b>3 - Proficient</b>	<b>4 – Target Exceptional</b>
Explanation has no connection to conceptual awareness; no support of response; negates response or no explanation evident	Explanation is somewhat correct; mostly supports the response but has no concept support	Explanation is mostly correct; includes conceptual error; partially supports response with 1 concept	Explanation is correct; includes relevant concept(s) and contains 1-2 concepts that support response

### Findings

Data from the “agree” or “disagree” *responses* for the 6<sup>th</sup> grade spring assessment event are displayed in Table 2.

Table 2. This table exhibits six of the original statements found in the survey (see appendix A for the complete list) and the results for the N=88 student responses to “agree” or “disagree” with the statement.

<b>Agree or Disagree Aggregated Data – Table 2</b>				
<b>Statement</b>	<b>Disagree Responses</b>	<b>Agree Responses</b>	<b>% Correct</b>	<b>% Incorrect</b>
Birds are mammals.	N=51	N=37	58	42
Whales and dolphins are fish.	N=71	N=17	80	20

continued on pg. 20

The Sun is food for plants.	N=28	N=60	32	68
The phases of the Moon are caused by the shadow of the Earth on the Moon.	N=53	N=35	60	40
Batteries have electricity inside of them.	N=22	N=66	34	76
There is no gravity in space.	N=34	N=54	39	61

As illustrated in the table, there exists a nearly equal split in understandings about birds as mammals (58% correct) and for the reason for the phases of the Moon (60% correct). These results are not promising. However, the data show that most students do not understand the complexities of the concepts surrounding how energy is created in batteries (34% correct), nor do they grasp the concept of gravity as a force that exists everywhere in the universe (39% correct). Interestingly, evaluating the *explanations* provided by the students resulted in significantly different, and more complex, results. In fact, the results for explanations do not mirror the results found in the “agree/disagree” response section of the survey for most of the six statements. When explaining why they chose an “agree” or “disagree” response for a particular statement, a significant number of the students either negated their response or could not conceptualize the concepts well enough to use the correct academic language or even identify the embedded concepts they needed for a correct explanation. For example, 77 out of 88 students (86%) did not provide an explanation for the statement, “Batteries have electricity inside of them.” In only a few cases were the explanations provided by students well developed and included the language and conceptual understanding needed to explain the concept accurately. Definitive inconsistencies were also found when comparing student responses with student explanations. These inconsistencies became evident after evaluating the explanations with the rubric (found in Table 1) to determine the value of an explanation.

According to the rubric, each statement’s explanation received a score from one (not acceptable) to four (target/exceptional) based on how close the explanation met the criteria for a particular value. When compared to the “agree/disagree” responses, it became evident that our knowledge about what students understood about what they were being asked was dependent upon the rubric. Table 3 provides a sample rubric assessment for each

statement and Table 4 provides a summary of the results of the qualitative analysis for all 88-student explanations. The sample explanations were chosen to illustrate how the rubric helped us to determine which statements belonged in a particular point category. The 1-point (not acceptable) and 2-point (progressing) statements represent significant errors in conceptual understandings. The 3-point (proficient) statements are not entirely valid but contain enough conceptual understanding and descriptive language to validate the score. The 4-point (target/exceptional) statements very closely match scientifically accurate understandings.

Table 3: Using the rubric point values described in Table 1, sample statements in this chart provide reasoning for value assignments for each statement.

<b>Sample Rubric Point Values – Table 3</b>				
<b>Statement</b>	<b>1 - Not Acceptable</b>	<b>2 - Progressing</b>	<b>3 - Proficient</b>	<b>4 – Target Exceptional</b>
Birds are mammals.	Agree because they have feathers and so do most mammals.	Disagree because birds do not have fur or warm blood. They are cold blooded.	Disagree because mammals have live birth and are warm blooded and birds lay eggs.	Disagree because mammals have hair and birds have feathers.
Whales and dolphins are fish.	Agree because they live in the water and have fins like fish.	Disagree because whales and dolphins are mammals. They breathe air.	Disagree because whales and dolphins are mammals because they have to breathe just like people.	Disagree because whales and dolphins don't have gills, they surface for air.
The Sun is food for plants.	Disagree because plants are not alive so they don't need to eat.	Agree because the sun helps the plants grow.	Agree because the things that plants need to survive are sunlight, water, and soil.	Disagree because plants make their own food.

The phases of the Moon are caused by the shadow of the Earth on the Moon.	Agree because when the sunlight shines on the moon the earth rotates around it making full moons and half moons.	Disagree because the sun is a big part to the phases of the moon.	Disagree because the phases of the moon are caused by where the moon is and where the sun is. Because the sun puts a shadow on the moon.	Disagree because the phases of the moon are caused by the revolution around earth making it appear in different places every night.
Batteries have electricity inside of them.	Agree because when you use a battery the electricity is what makes the object work.	Disagree because the current in the battery and the other source is what creates electricity.	Disagree because they have a liquid that makes electricity inside it.	Disagree because batteries have acid inside of them and that makes electricity when you turn something on that has batteries inside of them.
There is no gravity in outer space.	Agree because in outer space there is no atmosphere. Everything would still be there that you have left behind. If there's no atmosphere, there can't be any gravity.	Disagree because there is gravity in outer space.	Disagree because if there [was] no gravity the planets would be all over the place.	Disagree because there is more gravity in space than anywhere else, that's how the planets orbit the sun - the orbit and the gravitational pull that keeps it in the same orbit.

It is difficult not to infer student meaning when reviewing the explanations and, as a result, errors occur on our part (in a limited number of cases) as to how well students understand the concept and can express their own thinking. For example, the explanation, "Disagree because there is gravity in outer space" (2-point example from Table 3), is difficult to accurately assess. It infers that the student believes that gravity exists in outer space,

but the student appears to be unable to explain why he/she believes this to be true. In the explanation, “Disagree because if there was no gravity the planets would be all over the place” (3-point example from Table 3), the student appears to know that objects in space need gravity to remain in place and, therefore, represents a more sophisticated explanation than the first example; however, the student is unable to fully explain why this is so. The portion of the student’s explanation that we used to assign a 3-point value is easily identifiable as “the planets would be all over the place.”

Table 4. This chart provides the scored rubric points and the total percentage of students these scores represent.

<b>Total Rubric Scores for All Students – Table 4</b>					
<b>Statement</b>	<b>1 - Not Acceptable</b>	<b>2 - Progressing</b>	<b>3 - Proficient</b>	<b>4 – Target Exceptional</b>	<b>Total Students</b>
Birds are mammals.	62 (70.5%)	4 (4.5%)	7 (7.9%)	15 (17.1%)	88
Whales and dolphins are fish.	24 (27.3%)	40 (45.5%)	5 (5.7%)	19 (21.5%)	88
The Sun is food for plants.	35 (39.8%)	43 (48.9%)	3 (3.4%)	7 (7.9%)	88
The phases of the Moon are caused by the shadow of the Earth on the Moon.	59 (67.1%)	20 (22.7%)	6 (6.8%)	3 (3.4%)	88
Batteries have electricity inside of them.	68 (77.2%)	10 (11.4%)	5 (5.7%)	5 (5.7%)	88
There is no gravity in outer space.	62 (70.5%)	10 (11.4%)	9 (10.2%)	7 (7.9%)	88
<b>Total % per score</b>	310 (58.7%)	127 (24.1%)	35 (6.6%)	56 (10.6%)	100%

The most startling findings exist in the comparative analyses of the two assessment measures – response versus explanation (Table 5). Evident in our study is the clear disparity that exists between students’ “agree” or “disagree” responses and students’ abilities to conceptualize understandings in writing their explanations. The data in the “% Explanation Correct”

column were subtracted from the data in the “% Response Correct” column (Note: The “% Explanation Correct” section includes explanations that received a value of 3 or 4 on the rubric and the “% Explanation Incorrect” section includes explanations that received a value of 1 or 2 on the rubric). The results of the percent difference are displayed in the last column titled, “% Correct Difference.” The negative percentages indicate an overall reduction in conceptual understanding for all six statements. Interestingly, the greatest disparity occurred for the statement, “Whales and Dolphins are fish,” where the difference in correct responses versus correct explanations is negative 52.8%. This, for us, was quite unexpected primarily because this science misconception is not very well documented in the research literature (American Institute of Physics/AIP, 1997; AAAS, 2013; NRC, 1996).

Table 5: The above table lists the percentage of correct and incorrect responses and the percentage of correct and incorrect explanations. Rubric scores of 3 or 4 are considered correct. The negative percentages in the “% Correct Difference” column indicate an overall reduction in conceptual understanding when explanations are compared to responses. These rubric scores fall in the 1-2 range.

<b>Comparative Analysis of Responses VS Explanations – Table 5</b>					
<b>Statement</b>	<b>% Response Correct</b>	<b>% Response Incorrect</b>	<b>% Explanation Correct</b>	<b>% Explanation Incorrect</b>	<b>% Correct Difference</b>
Birds are mammals.	58	42	25	75	-33%
Whales and dolphins are fish.	80	20	27.2	72.8	-52.8%
The Sun is food for plants.	32	68	11.3	88.7	-20.7%

continued on next page

The phases of the Moon are caused by the shadow of the Earth on the Moon.	60	40	10.2	89.8	-49.8%
Batteries have electricity inside of them.	34	76	11.4	88.6	-22.6%
There is no gravity in space.	39	61	18.1	81.9	-20.9%

It has long been known that students have difficulty with concepts that involve motions in space, reference points from Earth, and why objects appear to move as they do in the sky (Ashbrook, 2012; Hermann & Lewis, 2003; Lunar and Planetary Institute, 2012; NASA, 2012; Trundle & Troland, 2005; Trundle, Troland & Pritchard, 2008). Therefore, we expected the statement, “The phases of the Moon are caused by the shadow of the Earth on the Moon,” to be the statement with the greatest disparity. This statement came in second at a negative 49.8% correct difference. As one compares the “correctness” of responses to explanations, it is clear that most of the students surveyed who could succeed with an “agree” or “disagree” response could not succeed in explaining why. In other words, “agreeing” or “disagreeing” with a statement does not provide evidence that a student understands a concept. We believe these results provide solid evidence that teachers absolutely need to probe students’ thinking and ask them to explain their ideas to fully understand their conceptual understanding. This type of formative assessment is critical for teachers to accurately and effectively determine whether their students harbor science misconceptions or not.

## Discussion

This discussion takes a deeper look at student explanations for each of the six statements using the above rubric scores from 1 point (not acceptable) to 4 points (target/exceptional). We also offer insights and pose thought-provoking questions that may assist classroom teachers when teaching these topics.

## **Birds are Mammals.**

Out of the 88 students surveyed, 70.5% could not explain their responses or were incorrect in their explanation. The following are sample explanations for the statement, “Birds are mammals.”

- 1 point: I agree because there are two types of animals; reptiles, and mammals it can't be a reptile so it's a mammal.
- 2 points: Disagree because birds are animals.
- 3 points: Agree because they make their own food.
- 4 points: Disagree because birds have wings, beaks, and a different skeletal structure

Much of the current elementary science curricula in the United States are centered on concepts involving plants and animals, as well as the characteristics that set them apart from each other. Are these explanations an indication that student misconceptions about the animal kingdom are derived at the elementary level, or do they “learn” these misconceptions from a variety of experiences they bring with them into the classroom? Are elementary teacher candidates, who are specializing in science and teaching science to elementary students, required to take the science courses they need to teach science effectively? How well prepared are elementary teachers who do not specialize in science, but are expected to teach science to elementary students as part of the job? Teaching expectations differ from school to school, district to district, and state-to-state (and in some cases county-to-county), but the value of a substantive background in any field is essential if teachers are to be effective facilitators of learning in any field of study. So, it is important to look at some of the explanations to try and determine what conceptual misunderstandings exist and try to identify where conceptual understanding breaks down.

The student explanations for the statement, “Birds are mammals” provide an array of significant misconceptions and/or lack of scientific understandings. One might ask, how can a 6<sup>th</sup> grade student come to understand that mammals have feathers, birds are cold-blooded, or that there are only two kinds of animals – reptiles and mammals? How do students come to understand that animals make their own food? How does a student come to know that birds are animals and mammals are not? Viewed at the surface, the explanations are far from acceptable. However, some of the explanations are partially correct or minimally infer that some understanding is present, albeit not clear.

For example, consider the explanation, “Agree because they make their own food.” We know that mammals do produce milk for their young, but only until weaning. A cursory assessment of the explanation would place

this answer at level 1 on the rubric because birds do not make their own food. On the other hand, did the student mean that mammals make their own food? The source of these interpretations cannot be derived from the survey explanation and interviews were not part of our methodology. However, it is clear that this student cannot distinguish the characteristics that separate birds from mammals, but can infer that mammals make their own food, which we assumed meant the student was explaining that food production is milk for the young and that he did not mean that birds make their own food.

This explanation poses questions for educators that can influence evidence-based instructional practice when educators consider that the student is unsure about how long mammals nurse their young, that the student is confusing mammals with plants (making their own food), or that the student assumes that because birds do not produce milk to feed their young that birds must make their own food. There are a plethora of other possibilities for level 1 explanations including students' understanding of the academic language used in teaching and learning, prior experiences and knowledge, and prior conceptual misunderstandings.

Unfortunately, some explanations are problematic in a deeper sense relative to others. Take the explanation, "Disagree because birds are animals." This explanation infers that mammals are not animals, which is highly problematic and with "I agree because there are two types of animals, reptiles and mammals. It can't be a reptile so it's a mammal," the problem becomes larger in the scheme of elementary curricula. If a student has these beliefs about these concepts, redefining truths is very difficult. The effective scaffolding of conceptual understandings from a starting point applicable to all students is necessary if the goal is to rid a student of misconceptions. Clay & Cazden (1992) identify two strategies used in scaffolding: 1) working with new knowledge; and 2) accepting partially correct responses. Without knowing what students know and how they have come to know it, it is nearly impossible to change their thinking to accept new conceptual understandings (Hewson, 1992; Michaels, et al., 2007; Singer, Nielsen & Schweingruber, 2012).

### **Whales and Dolphins are Fish.**

Out of the 88 students surveyed, 23.7% could not explain their responses or were incorrect in their explanation. The following are sample explanations for the statement, "Whales and dolphins are fish."

- 1 point: I disagree. A whale is a mammal while a dolphin is a fish.
- 2 points: Disagree because they breathe air and they survive even though they live in the water.
- 3 points: I disagree because whales and dolphins are mammals. They do not lay eggs like fish do. Also, they breathe air.

- 4 points: I don't know if I agree or disagree because I have heard that dolphins and whales are mammals, but then again, I have heard that they both have evolved from fish from the time where dinosaurs lived.

Several problematic errors occur in the above explanations that clearly demonstrate students are confused about many issues in science. For example, how can a whale be a mammal and a dolphin be called a fish when the order Cetacea includes whales, dolphins, and porpoises? Also problematic is the phrase, "Disagree because they breathe air." Does this infer that fish do not breathe air? How does a student come to know this? And, if we suppose that a dolphin is a fish, does it breathe? These are interesting conceptual misunderstandings that have a thread of truth woven into the explanations. However, how does a student decide that all living things in the ocean are fish? To mitigate misconceptions such as these, educators must clearly delineate groups of living things involving students in the process of discovering particular characteristics that provide a basis for organizing living things in meaningful ways.

### **The Sun is Food for Plants.**

Out of the 88 students surveyed, 39.8% could not explain their responses or were incorrect in their explanation. The following are sample explanations for the statement, "The sun is food for plants."

- 1 point: I agree (I'm in the middle) because, their food is really the water but the sun is also their food.
- 2 points: Agree because without carbon dioxide, water, and sunlight they would die.
- 3 points: Disagree plants are not alive so they don't need to eat.
- 4 points: Disagree because sunlight provides energy for plants to make their own food.

The confusing conceptual misunderstandings in these explanations are tied to whether or not the Sun is food for plants, that other things are necessary as a source of food for plants, or whether or not plants are living things. Why would a 6<sup>th</sup> grade student be unaware that plants are living organisms? How does a student who can create a list of essential ingredients needed by plants to make their own food actually come to 'know' the sun is the food for the plant? It is true that without water, nutrients, the Sun's energy, and carbon dioxide, a plant would not live? How might a student not know that plants make their own food, or that chlorophyll in green plants is necessary for plants to make their own food in a process

called photosynthesis? Out of 88 students, only one student mentioned photosynthesis (incorrectly and without the use of the word chlorophyll) and only one student mentioned chlorophyll (and did not mention photosynthesis). Is this a matter of the lack of use of academic language (Gee, 2004; Snow, 2010), lack of complete knowledge by the teacher, the method of teaching, student preconceptions, or the lack of experience or active involvement in the process of growing plants? What better way to understand plants and plant growth than a clearly defined investigation or experiment that provides students with evidence to support their understandings? Teachers need to create a more scientifically-based activity that truly meets the objectives of the activity – that plants make their own food through a process called photosynthesis – and include all of the elements of photosynthesis so students can “see” what is happening, why it is happening, and be able to explain the process accurately and clearly.

### **The Phases of the Moon are caused by the Shadow of the Earth on the Moon.**

Out of the 88 students surveyed, 67.1% could not explain their responses or were incorrect in their explanation. The following are sample explanations for the statement, “The phases of the Moon are caused by the shadow of the Earth on the Moon.”

- 1 point: I agree because when the sunlight shines on the moon the earth rotates around it making full moons and half moons.
- 2 points: Agree, because sometimes the earth is between the moon and the sun.
- 3 points: Disagree because it is caused by the shadow of the sun on the moon.
- 4 points: Disagree because the phases of the moon are caused by the revolution around earth making it appear in different places every night

As stated previously, misconceptions about objects in motion in space, and our view of these objects from Earth, are extremely difficult concepts for students to develop. In evaluating these explanations, it is possible to see that, in some ways, many of the explanations hold a bit of true scientific understanding. For example, it is evident that over 80% of the student explanations used the Sun as an indicator for the concept of the phases of the Moon, but they were unclear about how that mechanism works. Many of the students who used the Sun as part of their explanation stated that, “The Sun casts a shadow on the Moon.” This leads us to ask: How is it possible that students think that the Sun could cast a shadow? And, what is it that

they really mean when they say this? It appears that some students do not know how to interpret or explain the concepts of object motion relative to each other or how sunlight is involved in the process of the phases of the Moon. There are many hands-on, minds-on, inquiry-based, and evidence-based methods for teaching and learning addressing these concepts, and two of the teachers whose students took this survey have used these methods to teach the phases of the Moon. So, what is missing in the instructional practice that prevents students from clearly understanding that it is a combination of the Moon's place in space as it orbits Earth, and the sunlit portion of the Moon visible from Earth that creates the "phases" as seen from Earth? One suggestion is to remind students to put themselves on Earth, as a reference point, to look out toward space, and use beginning statements such as, "Knowing you are standing on the surface of the Earth, look out at the Moon." This helps students to learn how to view objects in space from a reference point that is easy for them to identify. Feet on the ground and looking outward toward space!

### **Batteries have Electricity Inside of Them.**

Out of the 88 students surveyed, 77.2% could not explain their responses or were incorrect in their explanation. The following are sample explanations for the statement, "Batteries have electricity inside of them."

- 1 point: I disagree because it is the object that's using the batteries itself that has the electricity in it. Batteries just help power it without electricity.
- 2 points: I disagree because when the power goes out you usually use a flashlight that has batteries in them and if batteries contained electricity then we would not be able to use them.
- 3 points: Disagree because the battery itself connects to the object that has electricity.
- 4 points: Disagree because batteries have acid inside of them and that makes electricity when you turn something on that has batteries inside of them.

First, we would like to point out that one of our spouses is an electrician. When approached with this statement, the spouse responded, "Of course batteries have stored electricity in them. How would you expect them to work otherwise?" This spouse was challenged and subsequently provided several pieces of verbal evidence to support his belief in the statement, and not one piece of evidence was valid or researched. It was not until the spouse was urged to research batteries and energy that the issue was resolved. The spouse will never forget that the statement is false. So that brings us to why

students do not understand electricity and batteries – if a licensed electrician maintains this misconception, it is no wonder that many middle school students have the same difficulty.

Regardless of the complexity of the concept for students, it is problematic to see responses that either: 1) place the electricity inside the battery or 2) inside the object into which the batteries are placed. Most elementary students conduct electromagnetic activities using nails, copper wire, and batteries to make electromagnets, or use batteries and switches and light boards in series and parallel circuit projects. We have not been able to locate an elementary or middle school lesson or text that clearly discusses how energy is produced inside a battery in such a way as to allow for a student's conceptual understanding to occur. Without understanding where the energy in a battery originates, they may assume (probably due to experiences with electricity) that electricity is stored in a battery. Interestingly, one student explained: "I disagree because when the power goes out you usually use a flashlight that has batteries in it and if batteries contained electricity then we would not be able to use them." That explanation is a demonstration of higher order thinking because the student related the energy in the batteries to experiences that occurred when electricity was not available. Although the student may not know how a battery really works, the explanation tells us that the student is aware that electricity is not stored in batteries. Essentially, the student is stating that if the electricity goes out and there is no electricity to operate the flashlight then the flashlight works from some other source of energy. The odd part of this explanation is, "if batteries contained electricity then we would not be able to use them (if the power went out)" connecting a flashlight to losing electrical power. The student appears to associate the concept of electrical forces to objects that are not even connected to an electrical outlet. This student clearly indicates that if the flashlight operated by electricity, then it would not work if the power went out. How does someone associate the intricate electrical connections required to operate lights, appliances, and machines (plugged in to an electrical system) with an object that is not remotely connected to that system?

Methods that should be integrated into activities for batteries should include comparative investigations into various sources of energy used to power objects. They include appliances, flashlights, solar lights, hydropower, and wind energy so students are able to determine the differences that exist among the various sources of power, and can explain how each source of power exists. In isolation, batteries are difficult to understand because a student's experience with batteries can be limited to objects they can use to operate electronics.

## **There is No Gravity in Outer Space.**

Out of the 88 students surveyed, 70.5% could not explain their responses or were incorrect in their explanation. The following are sample explanations for the statement, “There is no gravity in outer space.”

- 1 point: I agree because if you were in outer space you float. The thing is that if you are in a space suit you go down and don't float,
- 2 points: I agree because there is no atmosphere in space.
- 3 points: Agree because there is no oxygen in outer space.
- 4 points: I disagree there is more gravity in space (than) anywhere else (that's) how the planets orbit the sun - the orbit and the gravitational pull that keeps it in the same orbit.

With the plethora of space movies, television shows, books, and video games that illustrate the lack of gravity in space, the explanations for this statement are not surprising. Even astronauts talk about zero gravity when they talk to the public about living and working in space! In reality, space is a “microgravity” environment as long as objects are in motion, stay in motion at a specific distance from other objects, and are not impacted by some outside gravitational force (e.g., a large asteroid, galaxy, or star gets too close to a smaller object or vice versa). If gravity did not exist in space, how would everything stay where it is? As one student stated in his/her explanation, “I disagree there is more gravity in space (than) anywhere else (that's) how the planets orbit the sun - the orbit and the gravitational pull that keeps it in the same orbit.” That explanation tells us that this student has at least a clear understanding that gravity exists everywhere and keeps things moving in space where they need to be for gravitational equilibrium. However, how does a student explain that the lack of gravity has anything to do with the lack of oxygen in space, or the lack of an atmosphere? Where did they obtain this information? Why do students believe that floating in space in a spacesuit proves that there is no gravity? One student was fairly close to a correct explanation by stating, “Disagree because if there was no gravity the planets would be all over the place.” Unfortunately, the student could not explain why she/he knew this either because it was an unknown, or the student did not have the language to explain the concept well.

As we know, there is no such thing as zero gravity. Classroom activities need to demonstrate the connections that exist between and among objects, their masses, and their distance from each other. Students need to actively experience gravity to develop understandings. The connections to gravity in space is difficult for students to understand and impossible for them to experience. We suggest that, after teaching about the laws of motion and gravitational forces, you begin discussions with your students about how these concepts impact objects in space.

## Conclusion

The survey assessment instrument and overall results of this study, along with the various questions we posed, greatly assisted our teacher friends in their thinking, interactive dialogue, and scaffolding of understandings about science misconceptions with their students. As we prepare to analyze our most recent set of data, participating teachers who conducted the fall 2012 misconceptions survey will conduct an intervention (suggested methodologies were shared by us) prior to the spring survey. We expect the teachers to go deeper into student understandings, choose varied and intellectually stimulating methods to engage their students in actively adjusting their misconceptions into reality, and demonstrate significant progress in the late spring survey. We hope that our study will be of assistance to you in your classrooms as well.

## References

- Abner, L. J., Grannis, K. L., Owen, S., & Sawhill, I. (2013). Middle childhood success and economic mobility. Center on Children and Families at the Brookings Institute, The Social Genome Project. Retrieved from <http://www.brookings.edu/~media/Research/Files/Papers/2013/02/15%20education%20success%20economic%20mobility%20aber%20grannis%20owen%20sawhill/15%20education%20success%20economic%20mobility%20aber%20grannis%20owen%20sawhill.pdf><http://www.brookings.edu/~media/Research/Files/Papers/2013/>.
- American Association for the Advancement of Science. (1993). *Benchmarks for science literacy: Project 2061*. New York, NY: Oxford University Press.
- American Association for the Advancement of Science (2013). AAAS science assessment. Retrieved from <http://assessment.aaas.org/topics>.
- American Institute of Physics. (1997). Children's misconceptions about science. Retrieved from <http://amasci.com/miscon/opphys.html>.
- Ashbrook, J. (1984). *The astronomical scrapbook: Skywatchers, pioneers, and seekers in astronomy*. New York, NY: Cambridge University Press.
- Clay, M., & Cazden, C. (1992). "A Vygotskian interpretation of reading recovery." In L.C. Moll (Ed.), *Vygotsky and education: Instructional implications and applications of sociohistorical psychology*. New York, NY: Cambridge University Press.
- Dewey, J. (1938, reprinted in 1998). *Experience and education*. New York, N.Y.: Free Press.
- Dunlap, M., Scoggin, J., Green, P. & Davi, A. (2007). White students' experiences of privilege and socioeconomic disparities: Toward a theoretical model. *Michigan Journal of Community Service Learning*. Retrieved from <http://quod.lib.umich.edu/cgi/p/pod/dod-idx/white-students-experiences-of-privilege-and-socioeconomic.pdf?c=mjcs;idno=3239521.0013.202>.
- Gee, James P. (2004). Language in the science classroom: Academic social languages as the heart of school-based literacy. In R. Yerrick & W-M, Roth (Eds.), *Establishing scientific discourse communities: Multiple voices of teaching and learning research*. Mahwah, NJ: Erlbaum.
- Harvard-Smithsonian Center for Astrophysics. (1987). *A Private Universe*. Distributed by the Annenberg/CPB Project, Washington, DC, and by Anker Publishing Co., Bolton, MA.
- Hermann, R. & Lewis, B.F. (2003). Moon misconceptions: Bringing pedagogical research of lunar phases into the classroom. *The Science Teacher*, 70(8), 51-55.
- Hewson, P. W. (1992). Conceptual change in science teaching and teacher education. University of Wisconsin-Madison, Madison, Wisconsin. National Center for Educational Research, Documentation, and Assessment. Paper presented at a meeting on "Research and Curriculum Development in Science Teaching," under the auspices of the National Center for Educational Research, Documentation, and Assessment, Ministry for Education and Science, Madrid, Spain.

- Hubbard, L. (2008). Bringing moon phases down to earth. *Science and Children*, 46(1), 40-41.
- Hubisz, J. (2001). Report on a study of middle school physical science texts. *The Physics Teacher*, 5(39), 304-309.
- Lunar and Planetary Institute. (2012) Moon phases: Misconceptions and educational research. Retrieved from [http://www.lpi.usra.edu/education/pre\\_service\\_edu/PhasesMisconceptions.shtml](http://www.lpi.usra.edu/education/pre_service_edu/PhasesMisconceptions.shtml).
- Keeley, P. Eberle, F. & Tugel, J. (2007). *Uncovering student ideas in life science. Vol. 2: 25 More formative assessment probes*. Arlington, VA: NSTA Press.
- Keeley, P. & Harrigan, R. (2010). *Uncovering student ideas in physical science, Vol. 1-45 NEW force and motion assessment probes*. Arlington, VA: NSTA Press.
- Keeley, P. & Sneider, C. (2012). *Uncovering student ideas in astronomy: 45 NEW formative assessment probes*. Arlington, VA: NSTA Press.
- King, C. (2010). An analysis of misconceptions in science textbooks: Earth science in England and Wales. *International Journal of Science Education*, 32(15), 565-601.
- Marshall, J. C., Horton, B. & Smart, J. (2009). "4E x 2 instructional model: Uniting three learning constructs to improve praxis in science and mathematics classrooms." *Journal of Science Teacher Education*, 20(6), 501-516.
- Michael, J. (2006). Where's the evidence that active learning works? *Advances in Physiology Education*, 30(4), 159-167.
- Michaels, S., Shouse, A. W. & Schweingruber, H. A., (2007). *Ready, set, science!: Putting research to work in K-8 science classrooms*. Washington, DC: National Academies Press.
- National Aeronautics and Space Administration (NASA) (2012). Earth's moon: Common moon misconceptions. Retrieved from <http://moon.nasa.gov/moonmisconceptions.cfm>.
- National Research Council. (1996). *National science education standards*. Washington, DC: National Academies Press.
- National Research Council. (2001). *Knowing what students know: The science and design of educational assessment*. Washington, DC: National Academies Press.
- National Science Foundation. (2008). Survey of public attitudes toward an understanding of science and technology. Retrieved from <http://www.nsf.gov/statistics/srvyattitude/>.
- Pecheone, R.L. & Chung, R.R. (2006). Evidence in teacher education: The performance assessment for California teachers (PACT). *Journal of Teacher Education*, 57(1), 22-36.
- Plait, P. C. (2002). *Bad astronomy: Misconceptions and misuses revealed, from astrology to the moon landing "hoax."* New York, NY: John Wiley & Sons.
- Reardon, S. F. (2011). The widening academic achievement gap between the rich and the poor: New evidence and possible explanations. In R. Murnane & G. Duncan (Eds.), *Whither opportunity? Rising inequality, schools, and children's life chances*. New York, NY: Russell Sage Foundation.

- Rice, D. C. (2002). Using trade books in teaching elementary science: Facts and fallacies: Trade books can be a valuable addition to the science curriculum, if teachers know how to select good ones.” *The Reading Teacher*, 55(6), 552-565.
- Singer, S. R., Nielsen, N.R. & Schweingruber, H.A. (2012). *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. Washington, DC: National Academies Press.
- Snow, Catherine E. (2010). Academic language and the challenge of reading for learning about science. *Science*, 328(5977), 450-452.
- Trundle, K. C. & Troland, T. H. (2005). The moon in children’s literature: How to avoid the pitfalls of introducing misconceptions when reading about the moon. *Science and Children*, 43(2), 40-43.
- Trundle, K. C., Troland, T. H. & Pritchard, T. G. (2008). Representations of the moon in children’s literature: An analysis of written and visual text. *Journal of Elementary Science Education*, 20(1), 17-28.
- U.S. Department of Education, National Commission on Excellence in Education. (1983). *A nation at risk: The imperative for educational reform: A report to the nation and the secretary of education*. Washington, DC: The Commission.
- Yin, Y., Tomita, M. & Shavelson, R. (2008). Diagnosing and dealing with student misconceptions: Floating and sinking. *Science Scope*, 31(8), 34-39.

## **Appendix A.** The complete list of the twenty (20) survey statements.

1. Dinosaurs and cavemen lived at the same time. (*life/Earth*)
2. Batteries have electricity inside of them. (*physical*)
3. Large objects sink. (*physical*)
4. All metals are attracted to a magnet. (*physical*)
5. The Sun orbits the Earth. (*Earth/space*)
6. The Moon and the Sun are about the same size. (*Earth/space*)
7. It is hot in the summer because we are closer to the Sun. (*Earth/space*)
8. Sunlight is yellow. (*physical*)
9. Whales and dolphins are fish. (*life*)
10. There is no gravity in space. (*Earth/space*)
11. Water “disappears” when it evaporates. (*physical*)
12. Trees are not plants. (*life*)
13. The Sun disappears at night. (*Earth/space*)
14. Meteors are falling stars. (*Earth/space*)
15. The Sun is food for plants. (*life*)
16. Heat only travels upwards - it rises. (*physical*)
17. The phases of the Moon are caused by the shadow of the Earth on the Moon. (*Earth/space*)
18. Birds are mammals. (*life*)
19. Gases do not have mass. (*physical*)
20. The bubbles in boiling water contain air. (*physical*)