Probing Middle School Students' Understanding of Ideas About Matter Transformations in Living Systems Through Content-Aligned Assessment

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Abstract: With funding from the National Science Foundation, we are developing a collection of student assessment items for middle school science topics that are precisely aligned with national content standards. By rigorously applying a set of criteria to ensure the alignment of assessment items to specific learning goals and to identify features of the items that may obscure what students really know, our goal is to accurately assess student knowledge of specific concepts and to enable educators to identify specific gaps in student understanding. In this paper, we focus on items specifically targeting ideas related to matter transformation in living systems. We were particularly interested in whether students see food as a source of molecules for growth and replacement of body structures or primarily as an energy source. The results indicate that, even though students may recognize that food is needed for organisms to grow, students usually think of food as providing energy for growth rather than being a source of matter for growth. This finding has important implications regarding students' ability to conceptualize the movement of matter in living systems.

Introduction

In the current climate of school accountability and standards-based education reform, reliance on assessment tools as measures of the extent to which educational objectives have been met has become increasingly important. Alignment of assessment instruments to educational objectives is central to their effectiveness as measures of student understanding of targeted ideas and concepts. For assessment to be most effective, student responses should not only provide a reliable measure of whether or not students understand a concept but should also reveal the alternative ideas that students who do not understand the concept may hold. In this way, assessment can inform teaching practices and curriculum development in addition to evaluating student understanding. Moreover, valid inference from assessment requires that performance reflect student understanding of the content addressed in the items, particularly if these inferences are the basis upon which decisions regarding educational practices are made (Gitomer & Duschl, 1998).

At its base, the validity of any inference drawn from assessment reflects the quality of the test items used. As a model for the development of high-quality assessment items aligned to content standards, Project 2061 has designed a procedure that involves three components: (1) clarifying the knowledge for which students will be held accountable for a given content

standard, (2) designing assessment tasks that are precisely aligned to the specific ideas in that content standard, and (3) using information obtained from student responses to revise items (DeBoer, 2007). This work is part of a multi-year, NSF-funded project to develop assessment items aligned to middle school content standards in science, mathematics and the nature of science from AAAS's *Benchmarks for Science Literacy* (AAAS, 1993) and the NRC's *National Science Education Standards* (NRC, 1996). By rigorously applying a set of criteria to ensure the alignment of assessment items to specific learning goals and to identify features of the items that may obscure what students really know, our goal is to accurately assess student knowledge of specific concepts and to enable educators to identify specific gaps in student understanding.

In this paper, we describe some of our findings from pilot testing assessment items in middle school science for the topic of Matter and Energy Transformations in Living Systems, which includes key ideas related to the use of food as a source of energy and building materials. Here, we focus on items specifically targeting ideas related to the use of food as a source of building material for growth and replacement of body structures. In these assessment items, we ask students to integrate a molecular understanding of matter transformations (chemical reactions in which carbon atoms are rearranged) with the more traditional substance-level approach generally taught in middle school science courses. We will highlight how we use information gathered from pilot testing to (1) provide insight on students' understanding of specific concepts and (2) inform revisions of the items under development.

Method

Pilot testing was conducted as described by DeBoer et al. (2007). The set of three test items discussed in this paper probed student knowledge about the nature of food and the incorporation of molecules from food into the body structures of living organisms. The test items were written to be aligned to two key ideas derived from national science standards. As shown below, these statements were expanded to specify exactly what students would be accountable for in assessment.

Key Idea: *All organisms need food as a source of molecules that provide chemical energy and building materials.*

Excerpt from clarification statement: Students are expected to know that food consists of carbon-containing molecules in which carbon atoms are linked to other carbon atoms. Students are expected to know that these carbon-containing molecules serve as the building material that organisms use for growth, repair, and replacement of body parts and provide the chemical energy needed to carry out various life functions. They are expected to know that materials that do not provide both chemical energy and building material are not food.

Key Idea: *Animals use molecules from food to make complex molecules that become part of their body structures*.

Excerpt from clarification statement: Students are expected to know that animals use some of the carbon-containing molecules from food to make complex molecules that are used in the growth and replacement of their body structures (such as muscle, bone, skin, and cells). Students are expected to know that during the process of making body structures, the atoms of carbon-containing molecules from food are used to make carbohydrates, fats, and

proteins that become part of their body structures. They should know that these processes involve chemical reactions in which some of the atoms of molecules from food are rearranged, not simply the addition of substances from food.

When responding to items, in addition to indicating whether an answer choice is correct or incorrect, students were asked to give written reasons for their choice, circle unfamiliar words, indicate whether anything was confusing about the question or a diagram (when appropriate), and whether or not they guessed. Students could also say if they were unsure whether an answer choice was correct or incorrect. Because students could select "Not Sure," the percentage of students answering correctly is most likely lower than if they had been forced to select an answer choice. In spring 2007, pilot tests were administered to students in grades 6-8 from twelve school districts in eleven states (all east of the Mississippi River). Each test item was administered to at least 100 students (although, in some cases, fewer students responded).

Results

Item 1: Recognizing that food is a source of energy and building materials

The first item asked students to identify food as a source of both energy and building materials (Figure 1). When asked this way, 50.3% of 143 students responding to the question correctly chose answer choice A, indicating that they recognized that food is both a source of chemical energy and a source of building materials. Of the 64 students that provided written explanations for why they thought that answer A was correct, 11 students focused on food as a source of energy in their explanation but made no reference to building materials. For example, one student supported his choice of answer choice A by stating, "If you don't have food then you don't have energy." Seven students made vague references to food as a necessary condition for growth, but their explanations did not demonstrate an understanding of food as the source of materials for growth. These students wrote, "Food gives them [plants and animals] energy and helps them grow" and "It turns into energy and helps the plant and animal grow." Similar ideas about food as an undefined but necessary condition for growth or as a source of energy for growth have previously been documented in studies of middle school students (Smith & Anderson, 1986).

The term "building materials" may have given some students problems with this item. Thirteen percent of students responding to the item indicated that they were unfamiliar with the term. A few of these students selected answer choice B, but most of them selected answer choice A (the correct answer) or "Not Sure" as their response.

Implications for item revision. Based on student responses to this item, we decided to revise the answer choices for future testing in order to clarify the terminology and provided examples of how food is used as a source of building materials.

A. Animals and plants need food as a source of energy and as a source of material for building body parts such as muscles in animals and leaves in plants.

Which of the following statements is TRUE about food for plants and animals?	%
A. Food is a source of both energy and building materials for plants and animals.*	50.3%
B. Food is a source of energy for plants and animals, but not a source of building materials for plants and animals.	8.4%
C. Food is a source of building materials for plants and animals, but not a source of energy for plants and animals.	2.1%
D. Food is needed to keep plants and animals alive, but is not a source of energy or building materials for plants and animals.	6.3%
Not Sure or Blank	30.1%
Multiple Selections	2.8%

*Correct answer

Figure 1. Pilot test results for Item 1. Percentage of students selecting each answer choice is indicated (*N* = 143).

Item 2: Connecting food with growth at the substance level

The second item (Figure 2) explicitly tests the link between food and growth and adds the possibility that unused food can be eliminated as waste. When presented with this item, only 15.1% of students selected the correct response (simpler substances from food become part of the animal's body). Out of the 55 students[1] that provided written explanations for why they thought answer A was correct, ten students focused on food being "broken down" and a few other students made reference to "digestion." For example, students explained that food "has to be broken down so that it can be used" and that "the digestive tract breaks down foods." Only five of the students providing written comments indicated that they selected the correct answer because they thought that substances from food became part of the body.

Of the 128 students who provided written comments explaining why answer choice A (the correct answer) was incorrect, their comments tended to justify their response in one of three ways. Many (40 students) stated that food could not become part of the body. Other students provided alternative outcomes to food, such as food being turned into energy or into energy and waste. Thirty-five students rejected the answer choice because "not all" food becomes part of the body or that some food is eliminated from the body as waste. It is not clear whether or not these students may still have understood that some food is used as a source of material for growth.

The students' focus on energy and especially the combination of energy and waste is confirmed in the large number of students (44.0%) who selected answer choice D as the correct response. As one student indicated, "Those are the two options [energy and waste]." Many of the students who provided written justifications for why they rejected answer choice C (energy only) said that they did so because not all food was changed into energy, often stating that it would also be turned into waste. Similar reasoning was seen in the responses of students who rejected answer choice B—not all food could leave the animal's body because "some has to be

[1] Written comments for students who selected multiple responses as correct are included in this total.

used for energy." Based on the results of this item, most students seem to have a mental model that says energy is extracted from food and what is left over is eliminated as waste, even when the focus of the question is on growth. Another way of saying this is that, in their minds, energy can produce growth, or matter is not needed for growth.

For an animal to grow, what must happen to the food that it eats?	%
A. The food must be broken down into simpler substances that become part of the animal's body.*	15.1%
B. The food must be broken down into simpler substances, all of which leave the animal's body.	7.0%
C. The food must be changed completely into energy in the animal's body.	6.4%
D. The food must be changed into energy or eliminated as waste.	44.0%
Not Sure or Blank	20.4%
Multiple Selections	7.0%

*Correct answer

Figure 2. Pilot test results for Item 2. Percentage of students selecting each answer choice is indicated (N = 357).

Implications for item revision. Based on student responses, some students appeared to use non-targeted knowledge (food being broken down/digested) to evaluate the correct answer choice. For future testing, we removed reference to food being "broken down" in answer choices A and B in order to improve alignment with the knowledge specified in the key idea. In addition, a number of students appeared to interpret answer choice A to mean that all food becomes part of the body. These students may have understood that some of the food is used as a source of material for growth even though they answered the item incorrectly. We revised the answer choice in order to address these two issues, as well as to specify that *new* substances (not the substances from food directly) become part of the animal's body.

A. Some of the food is changed into new substances that become part of the animal's body.

We revised answer choice B to use the term "waste" since a number of students used the word in their written responses. In addition, we incorporated similar sentence structure in the other answer choices. For example,

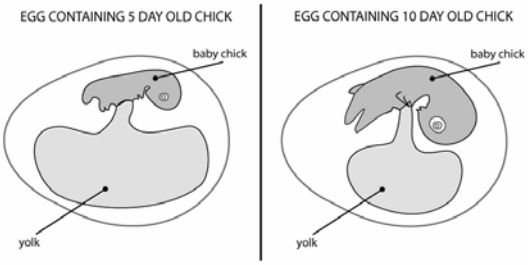
C. All of the food is changed into energy…
D. Some of the food is changed into energy, and the rest…

Finally, we modified the wording in the stem to focus attention on what happens to food *as* growth occurs (i.e., the addition of matter) not *for* growth to occur.

Item 3: Connecting food with growth at the molecular level

The third item (Figure 3) tests a number of common misconceptions and also focuses on the matter-for-growth question. Many students (43.8%) thought that the food (yolk) was used by the chick to live and grow (answer choice C), but they rejected the idea that the molecules from the yolk were incorporated into the chick's body. In their written explanations for why answer choice D was incorrect, eight of the 27 students providing written comments explicitly confirmed this. One student wrote, "The yolk does not become part of the chick's body in any form or way, it's just used for food for the chick." Other students wrote that they rejected the answer choice because they thought that molecules could not be broken down or reassembled. Even among students selecting the correct answer, no student explicitly confirmed an understanding of the yolk as a source of molecules that are reassembled into new molecules. For example, students wrote, "The yolk became part of the chick's body," and, "The chick uses the yolk to create its body," without mentioning molecules. From these responses, it is not clear that the students understand that the yolk is a source of molecules for growth. Instead, students may think that food is simply something *needed* for growth or something that *helps* the chick to grow.

The yolk inside an egg is a source of food for a growing chick. As the chick grows, the yolk becomes smaller. Why does the yolk become smaller?



	%
A. The yolk gets smaller to make room for the growing chick.	15.4%
B. The yolk gets smaller because some of the molecules from the yolk become part of the chick's body unchanged.	4.7%
C. The yolk gets smaller because the molecules from the yolk are used by the chick to live and grow even though none of the molecules from the yolk become part of the chick's body.	43.8%
D. The yolk gets smaller because some of the molecules from the yolk are broken down and reassembled into molecules that become part of the chick's body.*	18.8%
Not Sure or Blank	9.4%
Multiple Selections	7.8%

*Correct answer

Figure 3. Pilot test results for Item 3. Percentage of students selecting each answer choice is indicated (N = 64).

Implications for item revision. As in Item 2, we removed terminology referring to food being "broken down" from the item in order to reduce the possibility that students would use non-targeted knowledge to evaluate the correct answer choice.

D. …some of the molecules from the yolk are reassembled into new molecules…

In addition, answer choice C was clarified so that students with a correct understanding of the idea that molecules from food must be chemically changed before becoming part of the body could not select the answer choice because they interpreted it to mean that none of the molecules from the yolk become part of the body without being chemically changed.

C. …none of the atoms of the molecules form the yolk becomes part…

Finally, answer choice B was revised to clarify what *unchanged* referred to because some students were unsure whether the chick's body or the molecules were unchanged.

Discussion

From the students' written comments, we were able to determine particular language, terminology, and structure that may be confusing to students. In addition, their written justifications for why each answer choice was correct or incorrect provided valuable insight into revisions that might allow us to further refine our assessment probes. For example, in Item 2, some students with a correct understanding of the idea may have rejected the correct answer choice because they interpreted the answer choice to mean that *all* food is used as material for growth, leaving nothing for energy or waste. In Item 3, it appears that some students did not know what the term "unchanged" meant in the context of answer choice B. This confusion may have reduced the effectiveness of the item to discriminate between students who correctly understand that molecules from food must be reassembled into new molecules that become part of an organism's body structures and those that believe food becomes part of body structures without first being changed.

The key ideas targeted by this set of items specify that students should understand food as a source of matter for growth and that the addition of matter (i.e., growth) involves chemical reactions in which some of the atoms of molecules from food are rearranged into new molecules. Our results confirm that this is an unfamiliar idea to middle school students. Even when asked about growth, students tended to focus on food as a source of energy and had little knowledge of food as a source of building materials for growth. To many of them, growth just happens. Most students appeared to have a mental model that once energy is "extracted" from food, whatever is left over is eliminated as waste. Clearly, without an understanding of food as a source of matter for growth, these students will have difficulty with the more advanced idea that atoms of molecules from food are rearranged during chemical reactions before they become part of an organism's body structures. The larger problem for students is that they do not think that food (either at the substance or molecular level) becomes incorporated into the body structures of an organism. This finding has important implications regarding students' ability to conceptualize the movement of matter in living systems and suggests that middle school students'

understanding of these concepts has not progressed much in the last twenty years (cf. Smith & Anderson, 1986).

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