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

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AAAS Project 2061

NARST Annual Conference
Baltimore, MD

March 30 to April 2, 2008

Abstract:

The American Association for Advancement of Science Project 2061, with funding from the National Science Foundation, is developing student assessment items for middle school science that are precisely aligned with national content standards. These distractor-driven multiple choice items, in which common student misconceptions are used as distractors, will enable educators to probe student understanding of targeted concepts and gain a better understanding of student ideas about those concepts. Each item is developed and analyzed using a procedure designed to evaluate an item's alignment with important science ideas and its overall effectiveness as an accurate measure of what students do and do not know about those ideas. During the item development process, the items are pilot tested by middle school students at schools throughout the United States. This paper presents data collected from assessment items aligned to a middle school idea related to the dependence of organisms on other organisms for food and describes how we use information gathered from the students to gain valuable insight into their ideas and cognitive abilities as well as about the quality of the assessment items themselves.

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Introduction

As K-12 educators prepare for widespread testing in science mandated by the *No Child Left Behind Act*, concerns are growing about the quality of science assessments and their alignment to state and national content standards. In response to these concerns, the American Association for Advancement of Science / Project 2061 is developing distractor-driven, multiple-choice test items in which common student misconceptions are used as distractors (Sadler, 1998). This work is part of a multi-year, NSF-funded project to develop models of high quality assessment items aligned to middle school content standards in science, mathematics, and the nature of science from *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993) and the *National Science Education Standards* (National Research Council [NRC], 1996).

By rigorously applying a set of criteria to ensure the alignment of assessment items to specific learning goals and identifying features that may obscure what students really know, our goal is to accurately assess student knowledge of specific concepts and to diagnose gaps in their understanding. As part of the development process, items are piloted in urban, suburban, and rural middle schools serving a wide range of students throughout the United States.

In this paper we report the results of pilot testing of items used to probe students' thinking about middle school ideas regarding the dependence of organisms on other organisms for food. The items compare students' ability to answer questions involving direct versus indirect effects of changes to an ecosystem and questions that use the names of familiar organisms versus abstract symbols to represent populations of organisms in a food web diagram.

Procedure:

Pilot testing was conducted as described by DeBoer, Herrmann Abell, & Gogos, 2007. In addition to indicating whether an answer choice was correct or incorrect, students answered a series of questions about each test question (Table 1). They were asked to give written reasons for why each answer choice was correct or incorrect, to circle unfamiliar words, to describe anything that they found confusing about a question or a diagram (when appropriate), and whether or not they guessed. Students could also say if they were unsure if an answer choice was correct or incorrect.

Table 1. Questions students were asked about each piloted item

1.	Is there anything about this test question that was confusing? Explain.	
2.	Circle any words on the test question you don't understand or aren't familiar with.	
3.	Is answer choice A correct?	Yes No Not Sure
	Explain why or why not.	
4.	Is answer choice B correct?	Yes No Not Sure
	Explain why or why not.	
5.	Is answer choice C correct?	Yes No Not Sure
	Explain why or why not.	
6.	Is answer choice D correct?	Yes No Not Sure
	Explain why or why not.	
7.	Did you guess?	Yes No
8.	Should there be any other answer choices?	Yes No
	If you think so, what are they?	
9.	Was the picture or graph helpful? Why or why not?	Yes No
	If there was no picture or graph, would you like to see one?	Yes No
10.	Have you studied this topic in school?	Yes No Not Sure
11.	Have you learned about it somewhere else?	Yes No Not Sure
	Where? (TV, museum visit, etc)?	

For some items, students were asked an additional open-ended question. This allowed the researchers to ask broader questions about a topic or to get feedback on student understanding of particular terminology. For example, students might be asked "Have you heard the word 'organism' before? If so, what does it mean to you?"

The pilot testing involved a demographically diverse sampling of middle school students in grades 6 – 8 from 15 urban, suburban, and rural schools across the United States. Students were asked to indicate whether they were male or female, whether they were in sixth, seventh, or eighth grade, and if English was their primary language. Other demographic data was available at the school level but not at the individual student level. Approximately 100 – 150 students responded to each item.

All of the items described here used food web diagrams to help students understand the context of the question. A statement of the targeted key idea and an excerpt from the clarification statement detailing what we expected students to know about this idea are shown below.

Key Idea about the Interdependence of Life:

All organisms, both land-based and aquatic, are connected to other organisms by their need for food. This results in a global network of interconnections, which is referred to as a food web (AAAS, 2007).

Excerpt from June 2007 draft of clarification statement:

Students are expected to know that when organisms eat or are eaten by other organisms, there is not only an effect on the two organisms involved but also an effect on other organisms that are not eating or being eaten by those two organisms. They are expected to know that this is because once an individual organism is eaten, it is no longer available as food for other organisms and will no longer eat other organisms. Students are expected to know that changes in the size of a population may result from changes in the size of a predator population, changes in the availability of food, or both. Students are expected to know that interactions among selected organisms in food webs can be represented in the form of food web diagrams with arrows pointing from the population of organisms being eaten to the population of organisms doing the eating. They should know that if an arrow is not present, there is no food interaction between two populations of organisms.

Study I: Recognizing Direct vs. Indirect Effects of Changes to Populations of Organisms in Food Webs

In Study I, we were interested in finding out how well middle school students answer questions involving food web diagrams when the effect of a change in the ecosystem is one or more steps removed from the immediate change taking place. Previous studies have indicated that high school and even first year undergraduate students have a tendency to assume that changes in one population in a food web will not have any affect on another population that is not directly connected to it by a feeding relationship (Griffiths & Grant, 1985; Webb & Boltt, 1990). This was especially evident when populations of organisms were not on the same food chain on a food web diagram (Webb & Boltt, 1990).

In an effort to confirm these earlier results and further explore the implication that this misconception has for assessment, students in grade 6-8 from nine middle schools throughout the country were given a set of assessment items that included items in which the connection between populations of organisms was direct (i.e. predator/prey) or indirect (two, three, or more steps away) as well as items in which the populations in question were on different food chains within a food web diagram. Items were randomly assigned across the entire sample. In most cases, a student answered at least one direct effect question and one indirect effect question. An example of an item involving the direct effect of a change in a population of grasshoppers on a population of frogs is shown in Table 2.

Table 2. Sample piloted item for assessing students' ability to recognize direct effects of changes to populations of organisms in food webs.

If a disease kills most of the grasshoppers, which of the following describes what will happen to the grass and frogs? Use only the information in the diagram.

A. The amount of grass will increase and the number of frogs will decrease.*

B. The amount of grass will decrease and the number of frogs will increase.

C. The amount of grass will increase and the number of frogs will stay the same.

D. The amount of grass will stay the same and the number of frogs will decrease.

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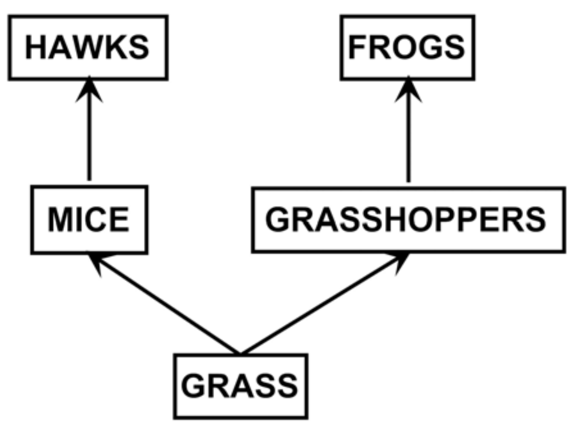
* Correct Answer

Items that targeted students' ability to recognize the indirect effects of changes to a population in a food web diagram on other populations in the diagram ranged from items involving only three populations of organisms, similar to the diagram used in the item shown in Table 2, to items involving five or more populations of organisms. They asked students about the relationships between populations of organisms two, three, or more steps apart, as well as items in which the populations in question were on different food chains within a food web diagram. An example of an item testing the students' ability to recognize indirect effects between different chains on a food web diagram is shown in Table 3.

Table 3. Sample piloted item for assessing students' ability to recognize indirect effects of changes to populations of organisms in food webs.

Populations of organisms are connected in a food web as described below.



Using only the information in the diagram, what will happen to the mice if a disease kills most of the frogs?

A. The number of mice will decrease because all of the organisms in this food web will decrease when the number of frogs decreases.

B. The number of mice will decrease because there will be more grasshoppers to eat the grass, so less grass will be available for the mice to eat.*

C. The number of mice will stay the same because there would be no effect on organisms below frogs in the food web.

D. The number of mice will stay the same because frogs and mice are not connected in the food web.

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* Correct Answer

Results for Study I:

For the two items used as examples above, 73.3% of the students chose the correct answer for the item assessing their understanding of direct effects and 41.4% of the students chose the correct answer for the item assessing their understanding of indirect effects. For the full set of items in which there was a direct connection between the organisms in question, an average of 76.4% of the students chose the correct answer. For the full set of items in which there was an indirect connection between the two organisms, an average of 46.8% answered correctly. This difference was found to be significant at the $p<0.001$ level ($\chi^2=87.1$, 1degree of freedom). Student comments revealed that many believed that populations of organisms that were not directly connected in a feeding relationship could not have any effect on one another. For example, in response to the item in Table 3 that assessed student understanding of indirect effects, some students said: “they are not connected so it won't effect the mice at all” and “Frogs and Mice don't have any thing to do with each other.”

In examining problems that students had with the question about indirect effects, one observation we made is that 11 of 103 students thought that answer choice B (*The number of foxes will decrease because if one population in a food web decreases, all of the other populations also decrease*) and C (*the correct answer*) were both correct. If that statement is viewed as a general rule, answer choice B is not correct; but in this particular situation, it is correct. In other words, if the worms decrease, both the robins and foxes (i.e., “all other populations”) will also decrease. Some students recognized that this was true in this particular case but not true as a general rule: When asked if this was a true statement, students said: “No, because the statement is not always true.” “This is only true with a few food webs.” “No, that doesn't always happen.” “No, that’s not always true.” “In another food chain that might not happen.” But other students, in response to whether B was the correct answer (incorrectly) said: “Yes, because if worms decrease, robins decrease then foxes decrease.” “Yes, worms are food to robins, but if they die out then the robins will die out as well so the foxes will die out.” “Yes, the less worms, the more robins die, the less robins, the more foxes die.” “Yes, In this case, that is true.” “Yes, this is some times true.” “Yes, because worms decrease the robins die from not enough food so the foxes start diying too.” “Yes, If the worms go down, evrything else goes down to.”

These are false negative responses. Even though the students selected the incorrect answer choice, their explanations suggest that they understood the idea being tested. To remove any confusion about whether we are asking about what is true in this particular case or what is true as a general rule, we revised this answer choice to say: "The number of foxes will stay the same because the worms are killed, not the foxes."

Study II: Interpreting Food Web Diagrams That Use Names of Organisms vs. Abstract Symbols

In Study II, we were interested in finding out how successful students would be with questions involving food web diagrams when the populations of organisms involved were described as abstract entities identified by symbols (i.e. A, B, and C) as opposed to familiar organisms (i.e. worms, robins, and foxes). Leach et al. (1996) showed that more than 80% of 14-16 year olds answered questions about relationships in food web diagram on the basis of what they knew about the organisms rather than based on their position in the given food web diagram. In addition, Schollum (1983) showed that many 14 year olds interpreted the arrows in a food web diagram or food chain as pointing from predator to prey. Therefore, when presented with an assessment item containing a diagram without the foothold of familiar populations of organisms, students may be unable to answer the question correctly, not because of a lack of understanding of the ideas being tested, but because of a lack of familiarity with conventions used in food web diagrams.

To probe this idea in middle school students and to further explore its implications for assessment, students in grades 6-8 from nine middle schools throughout the country were given sets of items in which two items were identical except for the substitution of symbols (i.e. A, B, and C) for the names of familiar organisms (i.e. worms, robins, and foxes) in the food web diagrams provided in the item. For each set, a randomly selected half of the students in each classroom received the version of the assessment item in which the names of familiar organisms were provided and half of the students received the version in which the populations of organisms were identified by symbols. An example of a set of items is shown in Table 4 below.

Table 4. Example of a set of items in which items are identical except for the substitution of symbols for the names of familiar populations of organisms

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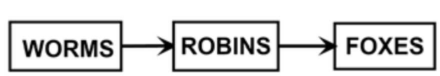
Version 1:

Populations of organisms are connected in a food web as described below.



If a disease kills most of the worms, which of the following statements describes what will happen to the robins? Use only the information in the diagram.

A. The number of robins will increase because there are fewer worms to eat them.

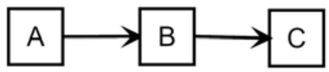
B. The number of robins will decrease because there are not enough worms to use for food.*

C. The number of robins will stay the same because the disease affects worms, not robins.

D. The number of robins will stay the same because a change in the number of worms will not affect any other organism.

Version 2:

Populations of organisms A, B, and C are connected in a food web as described below.



If a disease kills most of the "A"s, which of the following statements describes what will happen to population B? Use only the information in the diagram.

A. The number of organisms in population B will increase because there are fewer "A"s to eat them.

B. The number of organisms in population B will decrease because there are not enough "A"s to use for food.*

C. The number of organisms in population B will stay the same because the disease affects population A, not population B.

D. The number of organisms in population B will stay the same because a change in population A will not affect any other organism.

* Correct Answer

Results for Study II:

For the two examples provided above, 81.5% of students chose the correct answer when the names of the organisms were used in the item, and 18.1% of students chose the correct answer when symbols were used in place of the organisms. Results for the entire set of items show that an average of 66.4% of students answered correctly when the names of organisms were used in food web diagrams and that an average of 28.5% of students answered correctly when letters were used (χ^2=143.6, $p<0.001$, 1 degree of freedom). In addition, when symbols were used in place of the names of familiar organisms, 55.3% of students selected answer choice A, the distractor aligned to the misconception that arrows point from predator to prey, and only 4.6% selected this answer choice when the names of familiar organisms were provided. For all of the items in which this distractor was used (4 of 5 item pairs), an average of 41.6% of the students surveyed selected this distractor when given the items with symbols, and only an average of 6.0% of the students selected this answer choice when given the names of familiar organisms. This suggests that a significant number of the students relied on their knowledge of the feeding habits of particular organisms to help determine the meaning of the arrows. This was confirmed in the students' written comments. For example, when giving reasons as to why answer choice A was incorrect in the example above in which the names of the organisms were provided (Table 4), many students made comments such as "Worms DON'T eat Robbins!" or "Worms don't eat birds." This knowledge enabled them to reject the answer choice that implied that worms eat robins. However, that kind of knowledge could not be applied to a question that refers to the eating of organism B by organism A.

Summary and Conclusions

In Study I we learned that middle school students are much more successful at recognizing the consequences of changes to populations of organisms that are directly connected to each other in a feeding relationship (predator/prey) than when those connections are indirect (when the effect is mediated by one or more populations or organisms). They seem to be unfamiliar with the idea that even when one population of organisms is not directly interacting with another population in a food web they are still connected and dependent upon each other. However, these data are difficult to interpret because the indirect effects items produced a much wider range of student success (from 25.0% to 76.7% of students chose the correct answer) than did the direct effects items (from 72.5% to 83.3% correct), suggesting that other factors besides the indirect vs. direct factor are operating. Specifically, these items differ in the number of populations of organisms described in the food web diagram, how far removed the effect was from the originating cause, and whether or not the answer choices included explanations of the effects. Although there is evidence that students have more difficulty with items that address indirect effects, the issue is highly complex and requires further careful research to understand the nature of student thinking on items that ask them to recognize indirect effects in ecosystems. The data do suggest, however, that questions that focus on indirect effects are testing a different idea or cognitive ability than questions that focus on direct effects and should be tested independently.

In Study II we learned that a significant proportion of middle school students have difficulty with questions involving food web diagrams when symbols are used to represent populations of organisms instead of the names of familiar organisms. The data suggest that a significant number of students are not familiar with the convention that the arrows in food web diagrams point from prey to predator. So, when given a food web diagram,, many middle school students rely on their knowledge of the feeding habits of the particular organisms involved to determine the meaning of the arrows. Without the aid of familiar organisms, a significant number of the students interpreted the arrows in the diagram as pointing from predator to prey, the opposite of what is convention in these diagrams.

Whether the use of symbols also placed an added cognitive burden on students (besides not giving them information about a particular food-web-diagram convention), is not clear from this study. This is an area that requires additional investigation, drawing from work in a variety of other contexts including the life and physical sciences and mathematics. For example, we need to find out more about how students think about the symbols used in chemistry, as well as those used in algebra, and especially at what age or developmental stage such symbols begin to have meaning for students.

Student involvement in assessment item design through pilot testing is an invaluable tool that provides insight into students' content knowledge, their cognitive abilities, and the comprehensibility of assessment items. In this study, pilot testing allowed us to gain information regarding student understanding of the simple and more complex interdependencies of organisms within ecosystems. We were able to probe for student misconceptions, the use students make of informational cues in food web diagrams, and for concepts that students find particularly difficult, such as the indirect effects of population dynamics in a food web.

For more information on this work or on AAAS Project 2061, please visit our web site: www.project2061.org.

This work is funded by the National Science Foundation National (Grant # ESI-0352473).

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