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Young Children's Thinking About Decomposition: Early Modeling Entrees to Complex Ideas in Science

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Abstract This study was part of a multi-year project on the development of elementary students' modeling approaches to understanding the life sciences. Twenty-three first grade students conducted a series of coordinated observations and investigations on decomposition, a topic that is rarely addressed in the early grades. The instruction included in-class observations of different types of soil and soil profiling, visits to the school's compost bin, structured observations of decaying organic matter of various kinds, study of organisms that live in the soil, and models of environmental conditions that affect rates of decomposition. Both before and after instruction, students completed a written performance assessment that asked them to reason about the process of decomposition. Additional information was gathered through one-on-one interviews with six focus students who represented variability of performance across the class. During instruction, researchers collected video of classroom activity, student science journal entries, and charts and illustrations produced by the teacher. After instruction, the first-grade students showed a more nuanced understanding of the composition and variability of soils, the role of visible organisms in decomposition, and environmental factors that influence rates of decomposition. Through a variety of representational devices, including drawings, narrative records, and physical models, students came to regard decomposition as a process, rather than simply as an end state that does not require explanation.

Keywords Decomposition · Decomposers · Modeling · Organisms · Investigation · Compost · Matter

Introduction

Although primary grades science instruction almost always includes the study of nature, the typical focus is on the growth of organisms and the conditions that support their life.

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Educational treatments of life cycles almost always conclude with the death of the organism, even though processes of decay are at least as consequential for the health and balance of our world. It is possible that educators skirt this issue because they are unwilling to discuss death with young children; moreover, because so much of the process of decomposition is not evident to the unassisted eye, educators may legitimately be unsure how best to proceed with youngsters whose knowledge seems so firmly anchored in things they can directly see. Perhaps for these reasons, there is little research on children's thinking about decomposition.

In the slim literature that can be found, the general focus is on what children do *not* know, rather than on resources that they bring to further learning. Reading these studies lends the impression that children from ages 5 to 16 have little to no understanding about what happens during the process of decomposition (Leach et al. 1996). Most studies found that more than half of the child participants believe that matter from dead animals and plants simply disappears (Hellden 1992; Sequeira and Freitas 1986). When children are asked explicitly about rotting or decay, they report that decay is a state that simply happens to materials and that does not require an explanation (Smith and Anderson 1986). Decay, therefore, is conceived as an index of the endpoint of life and not as a process (Driver et al. 1994). These teleological forms of reasoning are commonly observed even in older people (Hartley 2011). In the previous research, of the very few children between the ages of 14–16 years old who understood that microbes were involved in the process of decomposition (Hellden 1992), most believed that materials rot on their own and subsequently, microbes finish off the partially "self-rotted" matter (Cetin 2007; Smith and Anderson 1986). Because children generally do not have a well-developed theory of matter, it may not be surprising that they do not know that the material constituents of living organisms are neither created nor destroyed (Gayford 1986).

Here we describe the development of very young children's thinking about decomposition in the context of instruction specifically designed to bring this process into their first-hand experience via a modeling approach. The instruction and associated study were part of a multi-year project on the development of elementary students' concepts related to ecosystems, change, and variability, concepts that we considered foundational (especially in their interrelationships) to developing a strong understanding of evolution as students moved into high school (Lehrer and Schauble 2012a, b). A hallmark of the instructional approach was to support students in developing, adapting, and/or revising models of processes in the world as a way of developing a better understanding of them. Accordingly, the larger project follows students across elementary grades, tracking both the forms and processes of modeling that support the development of student conceptual knowledge in the life sciences. The research reported here focuses on first-graders, who had not previously participated in instruction related to this project.

The instruction about decomposition had two major goals. First, we aimed to help students build a more nuanced understanding of decomposition as a process. Identifying an appropriate level of understanding for very young students seemed important, given the role of decomposition in later taught, critical topics such as carbon cycling and climate change. Briefly, we sought to problematize students' views of soil (which they initially conceived as an inert substance, associated with contamination), of decomposers (although primarily, those visible to the unassisted eye), and of the process of decay (which, consistent with previous literature, they tended to think of as spoilage, particularly applicable to foods; as in previous research, they initially described decay as an inevitable conclusion to life that does not need further explanation). Our second goal was to explore young children's potential to work with (including developing) models of processes and objects in the natural world as tools for studying the world "out there." Modeling is a defining characteristic of science but is by no means an obvious epistemological gambit. People in general and children, in particular, do not necessarily find it self-evident why one would want to conduct investigations that involve representations of the natural world, rather than simply looking at the world itself (Bazerman 1988; Windschitl et al. 2008). Our ongoing research program (Lehrer and Schauble 2012a, b) focuses on learning about both the challenges and potential in modeling approaches with students, including young students, and this paper contributes to that line of investigation.

Method

In the first-grade classroom where the research was conducted, the regular classroom teacher, with the first author's assistance, conducted science lessons on decomposition at least once a week during the course of a school semester (total number of sessions was about 18). The teacher had 13 years experience teaching at the time of the study, but had not previously taught decomposition in her class. Nor was she familiar with employing modeling approaches to science investigation. The instruction was designed in consultation with the second author, who had previously taught ideas about decomposition to students in middle school. However, in advance of this study, we did not know which ideas and modifications of previously developed instruction might be accessible to students as young as first-graders.

Participants

All the students in the class, who were 6 or 7 years old at the time of the study, participated in the classroom activities and discussions. The class included 10 boys and 13 girls and was situated in a school proximal to a public housing project; 22 of the students received parent permission to participate in the study. Most of the students had been raised in this thoroughly urban environment, and the school population included a large proportion of students eligible for free and reduced lunch.

Procedure

Pre- and post-instruction written assessments were conducted with the 22 participating students. In addition, to supplement the written work, we identified a focus group of six students, chosen by the teacher to represent a wide range of student performance, as assessed by regular class assignments and tests. More intensive information, in the form of daily notebook entries and repeated individuals interviews, was recorded from these six focus students throughout the study.

During the previous autumn, students in the class had gone outdoors with their teacher and collected a large sample of fallen leaves. The class spent time that autumn comparing and contrasting the leaves' color, shapes, and sizes. The current study was initiated early in the following February, when the teacher reminded students of their leaf collection, which remained indoors and was at the time sitting in a pile on the floor in a back corner of the classroom. She next asked a guiding question that set the context for the decomposition study and, in addition, served as a pre-instructional assessment of students' thinking about decomposition. Specifically, students were asked to consider what happens to autumn leaves after they fall from deciduous trees. The teacher reminded students that many leaves fall every year. Given this, she asked, why isn't the entire world simply covered with leaves?

Students talked with each other about this question in groups of four, and following these initial discussions, each student individually wrote an answer to the teacher's initiating question, illustrated by a drawing. We refer to this work as the initial assessment of student knowledge, and a parallel task (which we call the final assessment) was repeated at the end of instruction. In both cases, in addition to these written assessments, the first author conducted additional individual follow-up interviews with the six focus students, to further probe their answers. These interviews were conducted individually and were video recorded. The interviews contained additional questions about students' conceptions of "dirt" (the children's word for soils) and animals that live in "dirt."

Following the initial assessment, the teacher and first author implemented six phases of instruction, varying in duration from a single class period to several weeks. Figure 1 displays a timeline of this instructional sequence. As the figure shows, the phases are numbered sequentially, by order of their initiation, but as some of the phases were ongoing, there was considerable overlap among the phases. We next briefly overview these phases, but further details on each, along with information about student thinking, are featured in the "Results" section.

Phase 1. Each student brought a plastic bag filled with soil from a location of choice near his or her home. Students examined and described the samples, compared and contrasted their contents, and conducted individual soil profiles.

Phase 2. Students initiated ongoing observations, drawings, and textual notebook entries to describe changes over time in two examples of decay: a ripening and then rotting banana (one banana kept on each table group of four students), and three Halloween pumpkins that were set outside the classroom window to decay.

Phase 3. The children made a visit to an outdoor compost bin and investigated the contents. The school custodian explained how and why the bin was installed and the components included in the bin. He then turned the materials in the bin as students watched and extracted samples of material for students to hold and observe.

Phase 4. Students inspected and compared soils from their home samples (first investigated during phase 1) to samples taken from the compost bin.

Phase 5. Children developed and observed changes in classroom models intended to represent the process of leaf decay. These models included lettuce leaves to represent autumn leaves and other components considered necessary to represent

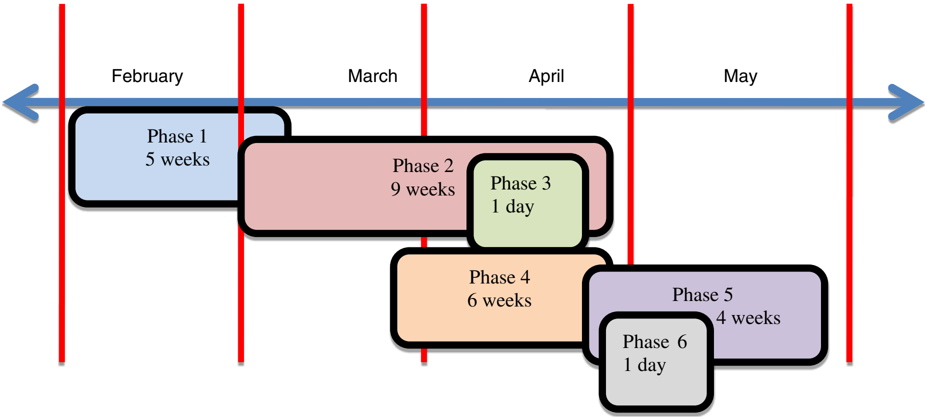

Fig. 1 Timeline of instructional phases

elements that might affect decay (different soil types, moisture levels, presence or absence of decomposing organisms, temperature, sunlight, etc.).

Phase 6. In the classroom, students initiated a study of earthworms and other (visible) decomposers that live in the soil. This work included magnified observations of the critters, enactments of the way they move, and reading of related trade books to learn about their structures.

As Fig. 1 shows, these phases overlapped and varied considerably in duration.

Results

Initial Assessments of Student Knowledge

Working in groups of four, students first discussed and subsequently wrote individual responses to the teacher's initial guiding question ("What happens to the autumn leaves after they fall onto the ground? Why don't we see more and more of them year by year until the entire world is covered with leaves?"). Most of these responses were accompanied by drawings. At this initial assessment, the majority of student responses ($N=11$) suggested that the leaves simply disappeared, with few attempts to explain where (although one child suggested they might have gone "to another planet"). Students said that the leaves "disappeared," "died," were "blown away," or were taken away by trash collectors, all reasonable replies, given the experiences of these urban children. One child simply responded that the leaves change color, which is certainly true, but irrelevant to the question posed. The remaining half of the students reported that the leaves decrease in volume over time and seemed to understand that somehow, this should be accounted for. However, not very surprisingly, these students proposed mechanical (rather than chemical) processes of change. They pointed out that people and animals step on leaves, which then break into smaller pieces. In these children's views, leaves get ground into ever-smaller pieces, and over time, the pieces become so small that they become difficult to see. Some of these students felt that rain plays a part in this process, perhaps softening leaves up so that they fall apart more easily. Otherwise, however, these accounts did not propose changes in the material make-up of leaves.

The interviews with the six focus children confirmed these ideas and also strengthened our initial conjecture that students conceive of soil as a homogeneous, lifeless substance that is generally to be avoided because of its contaminating qualities ("Dirt is ugly….and the dirt has things in it that are really dirty"). For example, one of the focus children pointed out that dirt "comes from different places, but all places got dirt." Another remarked simply, "Dirt is dirt." When asked whether all "dirt" is the same, two students proposed that dirt can sometimes be different colors, but this was attributed to moisture—that is, children had noticed that when it is moist, soil takes on a darker color. The other four insisted that all dirt is the same kind of stuff. Furthermore, students stated that soil provides home for critters (or at least, earthworms) and serves to hold up trees so that they do not fall down. Five of the six children felt that soil somehow helps plants grow, but they had no idea how. It was common for students to propose ideas about soil that seemed to be based on its perceived utility or importance for humans: "If we didn't have dirt, the earth would look like all water everywhere. We would have no grass or green or anywhere to live." Another protested that without soil, humans would have nowhere to walk. The initial phase of instruction was intended to help students develop a more nuanced idea of the variable properties of soil and of the inter-relationships of these qualities (such as texture, structure, and moisture) with the animals and plants that are found there.

Student Thinking During Instruction

After children completed the initial assessment, the first phase of instruction was launched. All phases of instruction featured both individual and small group work, whole class discussions, observations with microscopes and flexcams, and class read-alouds of nonfiction literature on related topics. During instruction students were regularly asked to record their observations and questions in their science notebooks, which served to further document student thinking. The teacher used a camera and easel paper to record student comments during class activities. She left these artifacts on the walls over the course of the semester so that students could refer to their earlier comments and discuss "changes in how we used to think and how we think now." Copies of these artifacts were collected during or at the end of instruction and served as further evidence of changes in student thinking. In addition, we collected classroom video, audio, and field notes to establish records of student thinking during classroom activity, whole group discussions, and occasional informal interviews. Each week the classroom teacher and first author met to discuss student progress and to plan for the upcoming week; these plans were usually preceded by discussions between the first two authors of the manuscript.

We next describe each of the phases of the instruction, providing examples that illustrate the forms of student thinking that we observed and (where appropriate), changes in thinking as the instruction progressed.

Phase 1. Observation and Analysis of Soil Samples The purpose of the first phase of instruction, which lasted about five weeks, was to encourage students to begin to think and talk about the properties of soil that vary, including its texture, structure, and permeability. All students brought a sample of soil from a location near their homes, and they spent several class sessions carefully combing through the soil on paper plates and describing its visible qualities and components, including small pebbles, roots, insects, and arthropods. Students were asked to describe how the soil felt, smelled, and looked under magnification of hand lenses. As students in the class proposed descriptive words, the teacher posted them on a word wall so that they could serve as a ready reference for ongoing journaling. Over time, the word wall came to include words that referred to texture (hard, soft, rough, stiff), color (dark, light, brown), moisture level (squishy, wet, dry), things found in soil (bugs, flowers, leaves, rocks, roots, grass), and words referring to quantity and other relevant ideas (shaped, high amount, low amount, labels, data). This kind of instructional adaptation makes it possible for students who are minimal readers to begin to record and subsequently refer to scientific observations.

Once they looked at it closely under magnification, students were surprised at the amount of variation that they observed within a single baggie-sized sample. In particular, they were surprised at the evidence of life sustained within the soil. As one wrote, "There are leaves and baby fragle (sic) sticks in it and a few roots in it." Another observed, "It feels rough and it has rocks in it, and grass. It smells like toast."

Next, the teacher drew children's attention to comparisons among soils from different locations. She asked them to contrast a grayish, dry clay, with a dark brown, moist soil taken from a garden, and a light-colored clumpy soil. Students examined these three samples at a center and wrote about their comparisons in their science notebooks, using the words from the word wall. This work, in turn, provoked the need to further expand their list of descriptors. Constraining the comparison to three choices that varied in extreme ways seemed to help the children focus more intently on variations in soil color, texture, and moisture.

Moving outdoors, the class used an auger to remove a core of soil about a foot deep from a location near the school. Students inserted their hands into the empty hole and discovered that the bottom was noticeably cooler than the soil near the top. Children wondered whether organisms that live in the soil (like earthworms) might prefer the cooler, moister environment below the ground. They described changes in the soil from the top to the bottom of its core, including temperature, moisture, and color.

Returning to their samples from home, students conducted soil profiles by placing half a cup of soil in a mason jar, adding water, shaking the jars, and then letting the soil settle. The teacher set a classroom timer so that students could observe and draw what they noticed every ten minutes for the next thirty minutes. Students noticed that the soil layers were differentiating ("The middle is getting lighter and lighter"), that different samples showed different numbers and widths of layers, and that some of the materials within the soil were becoming more visible as they were suspended in the water. Students compared soils in each others' baggies to the soil profiles in the jar, trying to account for the different layers and colors that they saw. The teacher introduced soil components such as clay, sand, and humus, and explained that although soil may look "all the same," in fact, it is made up of materials that look and feel different.

As this part of the instruction came to a close, students were now aware that soils are not all the same; that soils differ in color, smell, moisture, granularity, and texture; and that soils often contain evidence of organisms that live there (bits of roots, twigs, and leaf; intact insects and isopods, etc.). Moreover, soil taken from the same geographic location varies with depth. Children also began to think about soil and leaves, and some wondered whether soil might be "made of leaves."

Phase 2. Ongoing Observation of Decaying Banana and Pumpkins During the second phase of instruction, which lasted from the first of March through the third week of April, children intermittently observed decomposing fruits and vegetables within and outside the classroom. During this phase of instruction, we intended to introduce students to the understanding that decay is a process that occurs over time, that it is associated with changes in color; smell, size, and texture; and that its rate can be affected by environmental factors such as temperature.

First, the teacher put a single banana on each table where four students sat. The easy accessibility of the banana to sight (as well as smell and touch via occasional poking) encouraged students to notice gradual changes in its appearance from day to day, and the children drew and wrote descriptions of change in their notebooks. In addition, the students observed changes in three pumpkins that they had originally used during mathematics class the previous fall for investigations in measurement. Initially, the pumpkins were cut open indoors so that students could study the seeds. Afterward, however, they were set outdoors, but within sight from a window. Although the pumpkins could be seen, they were beyond students' immediate range of visibility (and touch), and therefore, students tended to look at them only when directed to by the teacher.

Students' notebooks include detailed descriptions of changes in their tabletop bananas, along with carefully labeled drawings. For example, beginning descriptions included: "The banana is bright and yellow and green and big. And the stem is littl." "It is pointy at the top. It is yellowish green at the top. It is a moon shape, and it has a little black line." Over time, the entries began to read: "The banana has little brown and yellow parts and it smells." "First the banana was yellow. Then the banana got brown and squishy. And made a hole were you can see." "The banana has bugs in it, and it has white on it, too." The descriptions noted changes in shape, smell, texture, color, and size (Fig. 2).

As the bananas were rotting, students occasionally looked out the window at the pumpkins, but when the teacher brought students outdoors for a closer look after several weeks, they were shocked at the transformation. As Fig. 3 shows, the pumpkins had entirely lost their original shape.

Students speculated that the inside of the pumpkin had disappeared or "gone into the ground." When the first author asked students what happened to the pumpkins, children replied, "…it went into the ground. Then it will turn into dirt because the bugs will eat it." Other students raised the possibility that changes in the pumpkin were due to the fact that "It got water on it." These initial proposals about environmental effects were explored later, during the fifth phase of instruction, when students constructed models of decomposition that included factors that might affect its rate.

Phase 3. Visit to the Compost Bin During a single day in mid-April, students visited the school's compost bin, located in the backyard beyond the school and maintained by the school custodian, an experienced gardener. Mr. B, the custodian opened the "earth machine," explained that this is where he brings uneaten fruit and vegetables from the cafeteria, leaves, and other yard waste to decompose and turn into humus. The bin was opened and the contents turned, and students inspected the contents. As in the previous work with their soil from home, students were asked to look carefully, to smell, and to feel—they noticed that the contents were moist and warm. The student who wrote the notebook entry in Fig. 4 summed up the question most on students' minds at this point: "I wonder what is the stuff in dirt?".

Considerable interest was expressed about the organisms that students observed living in the compost: "In the earth machine, I saw some worms and beetles and roly polys, too….spider, bug, slug, plant, and dirt." Most likely because many of the materials in the bins were foods, students speculated that the animals were eating the food. Students noted that, in contrast to the decaying bananas on their tables, there was relatively little odor from the material in the bin ("It smells normal," as one child pointed out). From Mr. B, the students learned that putting all those components into the bin and turning them, perhaps assisted in some way by the animals, resulted in the generation of soil. Just how, they were unsure. One of the students speculated in her notebook: "When Mr. B showed us the earth machean, I saw worms, appels, oranges, rollipollies, beatels, and then when Mr. B mixed up

Fig. 2 Notebook series of descriptions of banana decay

Fig. 3 Classroom pumpkin after decaying outdoors for several weeks

the stuff it made me feel like if you mixed it with worms and appels, oranges, rollypollys, beatels, soil, grass, leafs, you can make dirt.” A second child wrote, “It looks brown and dark black. It has squished leaves in it. I wonder if the dirt grows by sun, water, soil?” By the end of the visit, most students had concluded that somehow, materials in the compost bin turned into soil. Some believed that animals within the bin were eating the contents and perhaps playing an (unspecified) role in their transformation. There was a good deal of conversation about how the animals might have gotten into the compost in the first place, a question resolved when Mr. B showed children that the bottom of the compost was in direct contact with the soil. Other students wondered why the material in the bin was so much darker in color, moister, and warmer than soil on the nearby ground. There were questions about the potential roles of sun and water, possibly provoked by noting the qualities of the composting material.

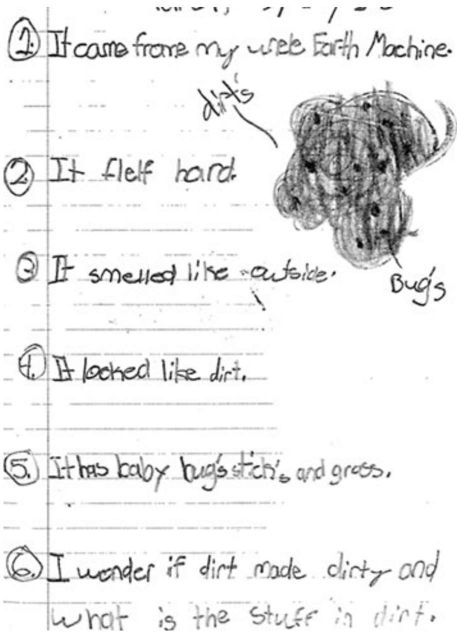

Fig. 4 First Grader’s notebook entry about the compost bin

Back in the classroom, the teacher read aloud to the class selected excerpts from *What's Going on in the Compost Pile*, by Chappelle 2008. The book introduced several key notions about compost, but it is unlikely that children understood them at much depth, and they probably assimilated most of this material to ideas they previously held. For example, the book stated that compost is decaying organic matter (defined as anything that comes from plants). However, it is unlikely that these first-graders necessarily equated fruits and vegetables with plants. The book further explained that insects, slugs, worms, air, and moisture all work together in compost to break down organic material, and that as organic matter decays, it becomes compost that fertilizes growing plants. We have no direct evidence of the interpretation children brought to the phrase "break down," especially as their initial ideas about decay emphasized simply breaking material into smaller and smaller pieces. The book contained a brief allusion to "microorganisms" and "bacteria," but the children probably had no idea what those terms referred to, so it makes sense that they focused more intently on organisms they could see in the compost. Although some children did suspect that moisture might play in role in creating compost, no one raised the possibility that air might play a role.

Phase 4: Comparison of Soils from Compost Bin and Home Next, students compared the qualities of material from the compost bin with those of their home soils. The students' notebook entries reveal that they noticed differences in texture, smell, moisture, color, and contents (Fig. 5). In a whole-class discussion that followed their initial comparison, the teacher posted students' ideas about the ways in which the samples were "same" and "different."

In the children's eyes, the most important differences were the darker color of Mr. B's compost, the fact that it was moist to the touch, and especially, the number of visible organisms that it contained. The teacher posed the question, "What are those organisms doing in Mr. B's compost?" Someone recalled that Mr. B had told the class that the organisms they observed in the compost eat the organic material and that their waste produces that "nice dark stuff."

Teacher: When we first looked inside, remember, it was lots of grass and fruit and leaves. Remember when Mr. B stirred it up and pulled it up, what did it look like?
Student: It becomes mud.
Teacher: Well, it becomes something that we use that Mr. B says is good for planting.

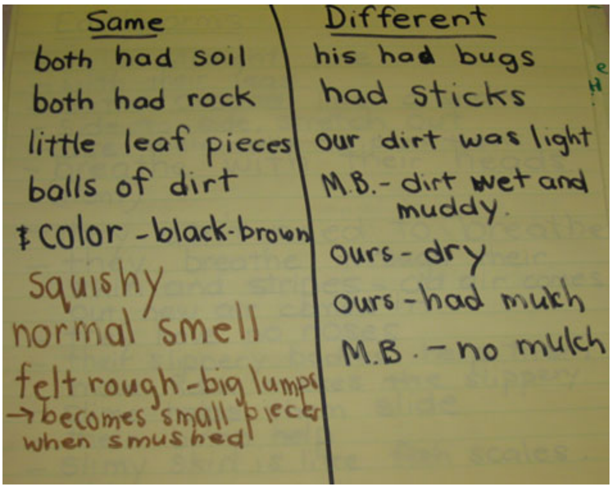

Fig. 5 Similarities and differences between compost and home soil samples

What does it become?
Student: Dirt.
Teacher: Another name for dirt?
Student: Soil.
Teacher: …becomes the soil. So you guys think the bugs and the worms eat the fruit and the leaves and poop it out and it turns into soil.

By this point in the instruction, most students held an idea about the process of composting that was overly simplified in many ways, yet more nuanced than their original thinking about decay. Their model of the process equated insect waste with compost and compost with soil. On the other hand, the mental model held by most of the children did now regard decay as a process and included the ideas that plant material gets transformed, that organisms play a role in that transformation, and that soils vary in their color, moisture, content, and their capability to support the growth of living plant life.

Phase 5: Design and Observation of Models of Leaf Decomposition Late in April the teacher posed a new question: "What do worms and bugs eat if we don't give them apples and oranges?" A student proposed, "They can eat the leaves?....Maybe they eat the leaves that fall?" This reply provided an opportunity for the teacher to remind the children of her original question, "What happens to the leaves that fall each year?" Students suggested looking up the answer to this question on the Internet. The teacher proposed instead that they observe change themselves, and further suggested that students could "pretend" that lettuce leaves take the place of "leaves that fall outside." (We proposed lettuce so that change would be accelerated and more visible to the children.) Suspecting that students might not necessarily accept lettuce leaves as stand-ins for autumn leaves, the teacher asked, "Are lettuce leaves like leaves from trees?" The children concurred that they were, "…because they come from plants." As the teacher prompted students to explain what happens when leaves fall from trees, students replied that they fall onto the ground. At this point, the teacher suggested that to model this situation, the class place some leaves in jars that contained the soil children brought from home. Other leaves were placed in jars that contained material from Mr. B's compost machine. The teacher and students agreed that they would observe carefully over time to see what happened to the lettuce leaves resting on these two kinds of substrates. "We will put dirt from different tables in the jars. We want to know what happens to the leaves over time. We will see whose dirt will cause change in the leaves, because we are not sure." Before proceeding, however, the teacher asked a further question: "What happens outside, though? We want to make sure this is like outside, going through the same thing that the dirt outside is going through. What happens when dirt is outside?" The children replied that in the outdoors, "dirt" is exposed to "sunlight and water." Asked how it might be possible to simulate those conditions with their jar models, the children volunteered that they could arrange for sunlight by placing the jars near a windowsill and to simulate rain, "…you can get some water from the sink and just put a little bit in to see what happens." The teacher asked, "Are we going to give one table (that is, the jar placed on one table) more water than the other table?" The students protested that this would be "unfair" and eventually agreed that each jar should receive two teaspoons of water.

An extended discussion followed about whether the jars should be lidded. Some students were concerned that if lids were put on, the critters inside the soil might be unable to breathe. Others worried that if the jars were left open, "But then the bugs will come out!" Eventually students agreed that even if the jars remained closed, there might still be sufficient air inside, so the procedure agreed upon was: "When you put the water in there, then you shut it back up. Then you just wait."

Eventually, the class negotiated two further conditions, a leaf that did not rest on soil and a leaf that did not rest on soil but was exposed to moisture by resting on a damp paper towel. At the conclusion of this discussion, the class had agreed on a comparison among four kinds of models: a jar model that included soil from home, a jar model with material from the compost bin, a Ziploc bag containing no soil, and a Ziploc bag with moist paper towels but no soil. In earlier work, we have described these kinds of representations as remnants, that is, fragments of the phenomena under study that are brought into classrooms in forms that make them amenable to closer investigation by students (often because they omit features that are not theoretically important). In this case, the jars contained attributes (soil, leaves, critters, moisture, sunlight) that are the same as or similar to those in the external world (with the exception of lettuce leaves to represent leaves on trees). However, the jars also omitted attributes (rocks and pebbles, twigs, gum wrappers) that children also saw outside. These models were placed on the tables where children sat (four children to a table), and students observed the leaves closely over the next four weeks. Periodically, leaves were removed from their jars and magnified with hand lenses or projected with a flex cam. Students recorded the changes that they observed, including changes in leaf shape, color, moisture, texture ("slimy"), and size. Children claimed after a few days that the leaf in the compost jar was "getting smaller faster" than the leaves in jars with their home soil. Ridges were observed on the edge of the compost leaf, and someone proposed, "The bugs are eating the leaves." One of the notebook entries stated, "I think the bugs caused a hole (in the leaf) because on it, I saw some teeth marks on it and also for the shape. The shape been, at first, the shape wasn't that crooked. It's turning crooked." Students also noticed that the leaves on the paper towel and in the jar without soil were not rotting as quickly as those that included soil. This led them to suspect that soil somehow was playing a role in decay. Recalling their previous observations at the compost pile and noting that the leaf in the compost model was decaying so much more quickly than the leaf in the jars that contained what they called "regular dirt," students suspected that the critical factor was "bugs." As one recorded in his journal, "Table blue don't have much bite, and then Mr. B has more bite than us. Mr. B has more bugs than us, and Mr. B has dirt, and he has more bugs than us. The bugs poop is dirt and they eat the leaves."

Unlike many of the models pursued by scientists (which may be expressed computationally or via mathematical expressions or models of chance), remnants like the ones featured here have a rather low representational overhead, because they preserve similarity between the model and the target phenomena. Because they have this characteristic of similarity, remnants are often appropriate entrees to modeling for young students. Yet, their cognitive challenge is far from trivial. Even though they do not make rigorous representational demands, they still require children to construct and cognitively maintain the relationships between objects and relations in the model and those in the modeled world; to identify relevant attributes to include (such as moisture) and exclude (gum wrappers); and to agree on standard ways to observe and measure (how do we *know* that a leaf is smaller today than it was yesterday?). Although the first-graders were scaffolded in these decisions by the teacher, they debated energetically about qualities of the model (2 teaspoons of water), appropriate comparisons ("regular" versus compost soil, moist conditions versus dry, soil versus no soil), and interpretation of the outcomes.

Phase 6: Classroom Study of Decomposers One day early in May, while students were still engaged in recording changes in the jar models, the teacher brought in some earthworms for closer study. Students examined the worms' behavior, structure, and environment, smelling, touching, and drawing them, and then simulating their movement by attempting to enact "earthworm crawling." Students discussed decomposing material as food for the earthworms and proposed a relationship: The more food in the soil, the more organisms in the soil. The teacher read brief selections from *Earthworms*, by Holmes 1998, a children's trade book that described the lifecycle, structures, and behaviors of earthworms, including their preferences for moisture and cool temperatures and for eating "rotting vegetables, plants, leaves, and grass." These earthworm studies served to help connect children's observations of decay in the jar studies with their studies of soil by confirming students' suspicions that organisms in the soil are largely responsible for decay. At one point the teacher suggested that there could also be "very small organisms in the soil, even if we cannot see them," but this idea was not pursued further.

Post-Instruction Assessment As the academic year came to a close, we asked the children once again to consider the teacher's initial question about autumn leaves and again to write an answer. Figure 6 summarizes the changes in children's responses from pre- to post-assessment. As the figure illustrates, at the close of instruction, there were no more suggestions that leaves die, disappear, or somehow travel to another planet. Many children continue to focus on mechanical change, that is, that leaves break up into smaller pieces. In addition, however, it was clear that students were now strongly influenced by the potential role of insects. Students suggested that the leaves are eaten by "bugs," that bugs then "poop them out," and that in some way, "poop turns into dirt."

The individual interviews with the six focus students confirmed these shifts and added some further insights about their thinking about the role of soil and organisms. Before instruction, students described dirt simply as "mud and water." In contrast, after instruction, students said dirt was made up of flowers, leaves, grass, oranges and juice (memories of the compost bin!), water, and soil. When asked where dirt comes from, students initially said

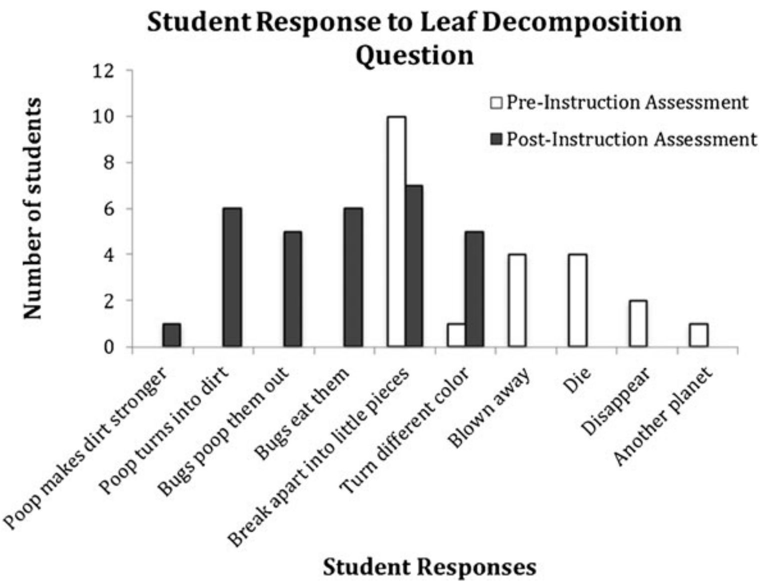

Fig. 6 The number of responses of each type both pre- and post-instruction to the question, "What happens to leaves that fall each year?"

they did not know or said it comes from the ground. After instruction, students said that "organisms poop it out" or that it comes from leaves. Constituents of dirt were initially considered to be mud and water, seeds, and rock, and most students said dirt is homogeneous (the same kind of stuff). After instruction, students mentioned insects, insect waste, plants, rocks, water, and mud, and were adamant that there are many kinds of "dirt" with different constituents. The number of kinds of organisms one can find in soil increased from 3 at pre-instruction (roaches, ants, worms) to 7 at post-instruction (worms, rolly pollies, roaches, beetles, ants, spiders, lady bugs). Instead of describing organisms as being at "home" in soil, students now focused instead on function: earthworms were described as "making more dirt" or "eating and finding food" (Fig. 6).

Discussion

Over several weeks of instruction, the first-grade children in this study made some modest progress in better understanding the decomposition of familiar organic materials (such as leaves and food). They became increasingly aware of decomposition as a process, rather than simply an end-state, and were able to identify changes that signaled decay, such as color, texture, shape, and smell, or the presence of mold. They discovered that different kinds of matter decay at different rates, and that environmental factors also seem to be associated with different rates of decomposition. With their lettuce leaf models, they concluded that temperature, moisture, and especially, the organisms living in soil, may be responsible for differences in the speed of decay. Their conceptions of soil shifted from a view of homogeneous, inert dirt to a view in which soils are highly variable in their make-up and loaded with life. Students were particularly interested in organisms, such as earthworms and isopods that fall into the soil and assist in the early stages of decomposition of organisms. In this instruction, we did not focus on the role of invisible decomposers, nor did we devote time to the mysteries of chemical change. It is possible that with additional instructional time, we might have found ways to open some of these thorny instructional issues with youngsters. Our purpose here, however, was restricted to setting the stage for learning more challenging biological ideas and modeling practices in subsequent education.

The relationship between the original target of query (autumn leaves) and the investigations undertaken by the children was representationally layered and required these young students to maintain several levels of systems intended to stand in for other systems. For example, although to some students it remained literally a compost bin, the compost bin was also intended as a model of the process of decay, and over time, students did import elements from the bin (such as fruit, insects) into other contexts of decay. The simple lettuce leaf models that students worked with capitalized on resemblance between the items and relations in the models (i.e., lettuce, moisture, compost) and the objects being modeled in the world (i.e., tree leaves, rain, soil). As we have found in our earlier research (Lehrer et al. 2000), physical models like these, composed of remnants (actual materials taken from the target phenomena being studied), seem to be easiest for young or inexperienced children to access, and therefore provide an appropriate entrée to modeling. Children's drawings and narrative descriptions entailed a further increase in their growing representational capacity, and their notebook records of phases of decomposition, coordinated with time (days of decomposition) were yet an additional shift away from the phenomenon of interest and into the representational world itself. The teacher supported the descriptive qualities of these notebook entries, which at first were often embellished with hearts, flowers, and other decorative devices. Over time, as she encouraged students to compare and evaluate their illustrations, these embellishments began to drop away and the drawings began to show increasing realism and detail. In addition to the life sciences goals, therefore, a second important objective of this instruction was to assist students in developing a more sophisticated representational repertoire and applying these tools for understanding the world. These alternative ways of representing and depicting the world were critical tools for studying and communicating about complex phenomena. They were important for the first-graders' growing understanding of decomposition and, moreover, are also central to the professional practice of science.

Our study exemplifies the importance of beginning from resemblance and remnants of the target phenomenon because this is a great route to follow in most modeling studies with young students. Educators should begin by asking students to generate representations that do not require a lot of experience with specialized forms of inscription—remnants and drawings and other representations that look like the phenomena being represented are good places to start. Educators may find that they need to help children overcome their propensity to use drawings expressively, rather than depictively. Students learn to draw what they see when the features of drawings are compared and contrasted, to consider together how they "tell us" what we are looking at. Over time it is possible for educators to stretch these early forms of representation into those that are syntactically more complex, such as T-charts, tables, and simple graphs.

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Appendix: Classroom Pre- and Post-written Assessment

Every year, in the autumn, all the leaves fall off of the trees to the ground below. You may have enjoyed raking the leaves into huge piles and jumping in them. Although you have only been around for 6 or 7 years, the leaves have been falling each of those years and many more. That's a lot of leaves!! Why aren't there mountains of leaves covering everything after all this time? In the space below, carefully explain what you think is happening so that a student in Mrs. Smith's class would understand. Draw and label a picture to help you explain what is happening to the leaves.

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