Science for Young Learners: Foundation-Building Classroom Curriculum

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Introduction

The overall objective of the program discussed in this paper is to produce a high quality, standards-aligned, fully evaluated science curriculum designed specifically for the early elementary years (K and 1st grade).[2] Titled the *Science for Developing Minds Series*, this multi-unit curriculum is the result of a five-year collaboration among education and cognitive development researchers, science education and curriculum specialists, classroom teachers, and university scientists. This paper briefly presents the curriculum's approach to science education for young children and examines in greater detail one unit in the series, including the method and results from a formal evaluation of the unit's effectiveness.

Recent science standards initiatives such as the *National Science Education Standards* (NRC, 1996) and *Benchmarks for Science Literacy* (AAAS, 1993) have set an aggressive, ambitious agenda for comprehensive general science education for all students. To afford students a realistic opportunity to achieve the learning and understanding outlined in the new generation of standards for science education, it is imperative that we first identify and then provide a much richer, more productive learning foundation than is presently available to most students. Identifying and cultivating the best conceptual representations and organizations, skills, and explanatory frameworks for beginning science learners has not received anything approaching the kind of attention devoted to such matters for early mathematics and literacy. Current national standards for science include grade levels down to kindergarten, but standards and performance indicators are lumped (e.g., K-4th grade for NSES) in a way that makes them almost

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unusable for teachers of the youngest grades. Further, standards do not specify the learning sequences that would achieve them. The agenda set by these new standards makes it imperative to develop new early elementary science curricula that are informed by research in science learning and cognitive development and by studies of age-appropriate educational practice.

The collaborative, research-based development process for this curriculum is aimed at identifying, refining, and testing specific learning sequences that will support acquisition of the knowledge and understanding outlined in current national standards for science. The curriculum emphasizes conceptual content designed to build a foundation for future science learning, as well as thinking and inquiry skills important for science. Activities are designed to use relatively inexpensive, readily available materials, and to be easily adapted to a variety of classroom situations. Each of the six units in the series is extensively field-tested in a variety of urban classrooms and then formally evaluated in an assessment study. One of the units, on the senses and perception, is used here to exemplify the theoretical and pedagogical approach of the curriculum, and the method and results from evaluation studies. Assessment results for this unit indicate that experience with this unit—called *Science Makes Sense*—leads to significant gains in children's understanding that different sensory modalities enable us to take in different kinds of information and experiences.

Overview of *Science Makes Sense* Curriculum Unit

Perception may at first seem an unusual topic for early elementary science. In fact, it is often one of the very first science topics introduced to young children, in the form of "the five senses" (which, one might say, is a perennial in the American kindergarten). Later, students encounter principles and phenomena of perception when they study optics, the nervous system, and comparative biology. Typically, they also encounter significant learning problems in these areas (e.g., Driver et al., 1994; Johnson & Wellman, 1982). From a scientific viewpoint, the almost universal "five senses" introduction, with its emphasis on the peripheral anatomy and on precisely five independent sensory systems is seriously flawed as a foundation for understanding perception (Gibson, 1966). Yet teaching about "the five senses" has been virtually untouched by the modern study of perception.

Rather than emphasizing a simple pairing between a "sense" and its associated body parts (e.g., we see with our eyes, we feel with our hands), this curriculum focuses on how we experience and get information about the world through different modalities. The starting point is to help children become more aware of the different channels through which we get perceptual information. The strategy for achieving this is to create a sensory-rich environment in the classroom (e.g., fan blowing, radio playing, electric popcorn popper popping) and then ask the children to say *what* they notice and *how* they noticed it. The teacher uses small pictographs to help the class construct a chart showing the kinds of things noticed by the children and the parts of their bodies they used to notice them. In discussion, children discover that although people tend to rely very heavily on vision, our bodies provide a variety of ways to learn about and experience the world.

Once children are more aware that they get different kinds of information through different modalities, the next step is to explore each of these modalities more carefully. To see which kinds of information and experiences each modality can bring us, children engage in a series of problem-solving activities designed to *isolate* a particular sensory system. In these activities, the targeted system is the only modality that can detect the information needed to solve the problem. For example, children are told that one of three apparently identical bags is not like the other two. They are not told, however, which one is different or how it is different. Using their senses as their tools, children realize that their eyes, noses, mouths, skin, and ears cannot detect any difference. Only by picking up the bags do they find out that one is heavier than the others. The only tool that could help them solve this problem was their "sense of heaviness" (proprioception). In another problem, children must find out which of three seemingly identical cups of tea is unlike the others. The do not know in advance that two are sweet and the other is unsweetened. By trying different approaches, children discover that looking, smelling, listening, touching with their skin, and picking up the cups do not provide any distinguishing information. When they taste each cup and detect the difference in sweetness, they realize that their tongue is the "only tool for the task." The metaphor of "the best tool for the task" helps children think about the unique nature of each of our sensory systems.

In the isolation activities, children are free to explore the stimuli in any way they wish, but the problems are constrained in such a way that the information relevant to solving the problem is confined to one modality (i.e., the items are the same in every way except for one feature). In the next series of activities, children become "sense specialists," in which they use just one designated sense to experience an object and to say what they can learn about it as that kind of specialist (e.g., an "ear specialist" can hear a clock tick but cannot tell its color). In these activities, the child has to actively ignore incoming information from other modalities and focus on the sense of his or her specialty. For example, even though the ear specialist can see, she must ignore all visual information and report only on information detected by listening.

The curriculum continues with activities designed to help children see that our sensory systems often work together to give us more complete information. Seeking out more sensory information can often inform or even change our beliefs about objects and events around us. In one activity, for example, the teacher sets up a situation in which some cooking ingredients that look very similar have gotten mixed up (sugar versus salt and water versus white vinegar). In the course of the activity, children discover that although two items *look* the same, examining them with another sense may reveal differences and thus change our beliefs about them.

Young children tend to equate immediate sensory experience with direct knowledge about the world, but the curriculum is designed to provide opportunities to help them become aware at a more conceptual level that sensory experience may be incomplete or misleading. Another classroom activity on this topic is actually an adaptation of a common task from the theory of mind research literature (Perner, Leekman, & Wimmer, 1987). For this activity, the teacher presents the children with a container with a familiar logo that has been filled with unusual contents (e.g., a Band-Aid™ box filled with crayons). After children say what they think is inside the container, the teacher questions them about how they formed that belief and what they could do to be sure. As the children lift, shake, listen, smell, and finally look inside, they change their beliefs and also examine what experiences led to the change. The next part of the activity highlights the point that differences in perceptual access between people may also lead to differences in beliefs. Now the teacher tells the children that another adult is going to be invited into the room and asked what he or she thinks is in the container. The children must predict what that person will say and why. After their visitor arrives and tells the class what he or she thinks, the teacher helps the children explicitly discuss the relationship between the opportunities someone has had to experience an object or event perceptually and, as a result, what that person may know or believe about it.

Like all of the units in this curriculum series, *Science Makes Sense* develops an extended series of step-by-step, carefully sequenced explorations which take about four to six weeks to complete. Activities introduce the primary conceptual points as clearly as possible, providing children with direct experience and opportunities to process that experience in group discussion and through reflection. There is a small number of core conceptual points for the whole unit, each of which is fully developed using several different approaches. Although the activities are highly interactive and engaging for children, they are not unstructured explorations.

Assessment Method

Subjects and Design. Four kindergarten classrooms in urban Philadelphia participated in the formal evaluation of this curriculum unit. All classrooms are from schools serving predominantly low income neighborhoods with high percentages of minority families. Two classrooms served as test classrooms, in which the teachers completed the entire curriculum unit with the children. Each of these classrooms was matched demographically to a control classroom that did not use the curriculum. Eight children were interviewed from each class but data from one instructed child were excluded because she did not give scoreable responses to a large number of questions. The final sample was 31 children, with 15 instructed children (7 girls and 8 boys; mean age 66 months) and 16 uninstructed children (7 girls and 9 boys, mean age 67 months). Each child was interviewed individually by a trained interviewer in two sessions of approximately 20 to 25 minutes each.

Teachers who implemented the instruction were drawn from a pool of teachers who have served as resource people during the development of the curriculum series. These teachers have been regular participants in a colloquium series on early childhood science, and they have served on advisory teams for the various units in the curriculum. Project staff met with the two test teachers at their schools in several sessions before and during the implementation of the curriculum to review the learning objectives of the curriculum and to help plan and prepare materials for the activities. All instruction was carried out by the classroom teachers themselves. The teacher in one of the control classrooms was drawn from the same pool of teachers. The other control classroom was another kindergarten class in the same school as one of the test classes. Neither control classroom used any of the materials in this curriculum, though they were free to do whatever they typically do with the senses in kindergarten.

Materials and Procedure. The interview protocol for the assessment consisted of a series of tasks spread across two sessions. A three-part warm up always came first, in order to focus children on discovering information using various senses. A fairly extensive warm-up was included to ensure that instructed children did not perform better on the assessment simply because they had had more exposure to the general topic and vocabulary used in the interview. During the warm-up, children were shown a variety of items with multi-sensory properties and asked to explore and describe the items, to choose ones that had various properties, and to say whether they could learn something about them by using their eyes, ears, nose, tongue, skin and muscles. Both instructed and uninstructed children performed similarly on the warm-up tasks, suggesting that both groups were equally focused on and engaged with the interview and had similar levels of understanding of the basic vocabulary for human senses and associated experiences.

The primary focus of this paper will be on a series of items used to assess the effect of instruction on children's ability to differentiate the kinds of information available through different sensory modalities.[3] Following the warm-up, children were introduced to six miniature "robots," each of which was marked for a different function. The Eye Robot could only see; the Ear Robot could only hear; the Skin Robot could only touch (but could not pick

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[3] The interview included several additional tasks omitted here for reasons of length.

up or manipulate objects); the Tongue Robot could only taste; the Nose Robot could only smell; and the "Muscle" Robot could only lift things.[4] After a check to make sure they understood what each robot represented and which function it could perform, children were shown a series of items in which a discrimination had to be made between two objects. Children were asked to say whether each robot *by itself* could or could not make the discrimination. The six items were as follows:

(1) The child was shown two pieces of paper that were identical except one was red and the other green. The interviewer presented each robot, one at a time, and asked, "Can the [*nose, ear, skin,* etc.] robot find out which of these papers is green?" Choosing the Eye Robot and rejecting all of the others is the correct set of responses for this item.

(2) The child was shown two plastic bowling pins that were identical except that one had been filled on the inside (so as not to be visible) with a little playdough and the other had been filled with a lot of playdough and thus was substantially heavier. The interviewer presented each robot, one at a time, and asked, "Can the [*nose, ear, skin,* etc.] robot find out which one of these bowling pins is full?" From the outside, the two pins looked identical. They made no sound if shaken, and both sounded the same if tapped on the outside. The discrimination could only be made by picking them up (or pushing against them) and feeling the weight difference (indicated by the Muscle Robot).

(3) The child was shown two candies that were identical except that one was sweet and the other sour. The interviewer asked for each robot, "Can the [*nose, ear, skin,* etc.] robot find which one of these candies is sweet?" The candies did not smell different. The Tongue Robot is the only robot that should be accepted for this item.

(4) The child was shown two pictures, one depicting a pair of shoes and the other a pair of boots. The interviewer said, "This is a picture of shoes and this is a picture of boots," and then asked for each robot, "Can the [*nose, ear, skin,* etc.] robot find out which one of these is a picture of shoes?" The Eye Robot is the only robot that should be accepted for this item.

(5) The child was shown a piece of sandpaper and a piece of waxed paper. The interviewer asked for each robot "Can the [*nose, ear, skin,* etc.] robot find out which one of these papers is smooth?" Both the Eye Robot and the Skin Robot should be accepted for this item.

(6) The child was shown two identical open jars, one of which was filled with white glue and the other with a scented white lotion of the same color and consistency. The interviewer asked for each robot,

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[4] In keeping with the view that "the five senses" model is an inadequate catalog of human sensory capacities, instructed children were introduced to a variety of "touch" experiences, including the temperature and pressure information obtained through the skin receptors and proprioceptive and relative heaviness information obtained through receptors in the joints and muscles. For this reason, six robots were used in the assessment.

"Can the [*nose, ear, skin,* etc.] robot find out which one of these jars has hand lotion?" The Skin and Nose Robots should be accepted for this item. We scored both "yes" and "no" responses as correct for the Tongue Robot, since adult judges disagreed about whether tasting (without smelling) would make the discrimination (and no one was willing to try it!).

The six discrimination items were presented in counter-balanced order across children. The robots were presented in the same order on each trial, but the interviewer systematically varied which one she started with across items for each child.

Assessment Results

Assessment results revealed clear differences between the instructed and uninstructed groups in their ability to relate different kinds of sensory information to the senses that process them. An unpaired t-test comparing the two groups' overall scores on the discrimination items described above yielded a significant difference ($t(29) = 2.596$; $p = .0146$). Instructed children had a mean score of 30.7 correct (out of 36) compared to 25.3 for uninstructed children.

Further analyses explored patterns across the modalities tested. A repeated measures ANOVA with Condition (instructed vs. uninstructed) as the Between factor and Modality (i.e., the modalities represented by the six robots) as the Within factor yielded a significant effect of both Condition ($F = 6.931$, $p = .0134$) and Modality ($F = 15.823$, $p = .0001$), but no interaction between them. Instructed children's scores were significantly higher than those of uninstructed children. The mean number of correct responses for each of the modalities also varied, with the following order from highest to lowest mean scores: Tongue, Ear, Muscle, Nose, Eye, and Skin.

Understanding the kinds of information that come to us via vision and skin touch (which we distinguished from proprioception in both the curriculum and the assessment) turned out to be the most difficult for the children. Both groups tended to overestimate the kinds of information that could be picked up by vision, but uninstructed children did this more often. Thirty-five percent of all children tested showed a pattern of saying that the Eye Robot could make all or almost all (5 or 6 out of 6) of the discriminations tested. (In fact, the eye was correct for only three of the items.) As one child expressed this view, "You can tell anything if you have eyes." This pattern of overestimating the discriminations that can be made visually was more common among the uninstructed children (50% of whom showed the pattern) than the instructed children (20% of whom showed the pattern).

With respect to the information that can be detected through skin touch, children made both over- and underestimation errors. For the discrimination between glue and hand lotion, 71% of the entire sample of children did not think touching them would reveal the difference. Thirty-nine percent of the children judged that one could not tell the difference between sandpaper and waxed paper by touching them. On the other hand, 29% of the children thought that touching the red and green papers would reveal which one was green, and 26% thought that touching the two candies would distinguish the sweet one from the sour one.

Uninstructed children were more likely to make other errors across the various modalities. Examples of other kinds of errors that were more common among uninstructed children were believing that touching or listening to a picture would reveal what was depicted in it and that smelling two bowling pins would reveal which was heavier.

Since children were asked for brief explanations on each trial, responses were rescored to take into account any extenuating justifications a child might offer for an incorrect answer. For example a child might say that the Nose Robot could tell rough from smooth by rubbing its nose against an item to feel it. This would technically be incorrect, since the introduction to the robots emphasized that each robot had one and only one function, but we were interested in whether instructed and uninstructed children might have differed in their ability to assimilate these directions. Analysis of the rescored data yielded the same pattern and magnitude of results as before, indicating that uninstructed children's poorer performance was not merely an artifact of construing the task differently. (Both groups also performed very similarly on warm-up tasks, including one to check that they understood what each robot represented.)

Discussion and Conclusions

Many young children do not spontaneously make clear differentiations among the kinds of information that correspond to different sensory modalities (see also O'Neill, Astington, & Flavell, 1992). However, experience with the *Science Makes Sense* curriculum allows children as young as 5 years to progress toward a more scientifically accurate understanding of perception. The experiences provided in the curriculum offer a variety of opportunities for young children to develop a more explicit, accessible understanding of the relationship between perceptual experience and beliefs about how things are in the world. In this respect, it bears on recent research on children's developing "theory of mind"(e.g., Wellman, 1990). A theory of perception is analytically a necessary component of a complete theory of mind, but the development of children's understanding of perception has been relatively understudied, with most studies focusing only on vision (Winer, 1991). Results from our evaluation study indicate that acquiring a more sophisticated understanding of how information is gained from perceptual experience is not a purely maturational development for the five-year-olds in our sample: experience of the kind provided in the curriculum led to demonstrable gains in children's ability to differentiate among the kinds of information and experiences available through different sensory modalities.

It is perhaps worth pointing out that the understanding aimed at in this curriculum and assessed in the evaluation study is at a conceptual level: we are interested in children's explicit awareness of modality/information type correspondences and in children's ability to analyze relations between perceptual access and information detected in a concrete setting. The curriculum activities are not meant to teach children *how* to use their senses—we generally believe this to be an unnecessary exercise under ordinary circumstances, though we have seen examples of early childhood curricula that seem to take this as the objective.

Indeed, we are impressed with children's *implicit* ability to explore the environment using different sensory modalities. Much like adults, children automatically orient their eyes to get better focal vision, turn their heads to locate the source of a sound more accurately, lean close and take a deep whiff to smell something better, manipulate objects in their hands to get proprioceptive, temperature, and pressure information, and so forth. We speculate that it may be this efficient, automatic ability to obtain perceptual input that may underlie some of the confusions children have about the information available through vision and skin touch. When we examine something closely in everyday circumstances, we are often seeing its visual properties, feeling its weight, experiencing its surface texture and temperature, hearing any noise it makes, and so forth *all at the same time.* A child who knows to "pick it up and look at it" may require no more sophisticated understanding of perception than that to achieve good conditions for perceptual input for an object of interest. An explicit, accessible conceptual understanding, however, requires more differentiated knowledge of our perceptual modalities and experiences. That is, the implicit knowledge we have as everyday users of our senses must be represented in a more accessible conceptual format (Karmiloff-Smith, 1992). It is this level of understanding that we believe is a necessary foundation for ongoing learning about perception from a scientific point of view.

The typical early elementary introduction to "the five senses" focuses on a pairing between an anatomical part and a perceptual activity (e.g., we see with our eyes, we hear with our ears). Systematic examination of what *kinds* of information we obtain by looking (as opposed to touching or listening or engaging in some other form of perception) or the conditions under which our modalities operate (e.g., vision requires light) are usually not explicitly discussed or explored. Children's next encounter with science instruction about perception in subsequent years often jumps directly to detailed descriptions of anatomy (e.g., the pupil, lens, cornea, and retina of the eye) and/or a discussion of energy transformations (e.g., transduction involving sound waves in the air causing mechanical events in the ear). We found no differences among instructed and uninstructed kindergartners in their ability to associate a body part with a named activity (e.g., hearing with ears or tasting with tongue), but we found significant differences in their ability to say *what information* is obtained when one looks or tastes or listens and so forth. Given that the typical "five senses" model is somewhat inaccurate and lacking in depth and given that early elementary children are demonstrably capable of richer explorations of perception, we suggest that there is no compelling reason to continue to present the simple "five senses" catalog as the ubiquitous introduction to perception.

More generally, carefully engineered and sustained sequences of experience-based explorations and accompanying discussions are an effective way to introduce science to young learners and to achieve demonstrable conceptual gains. Developing science curriculum for young children that (1) takes into account developmental and educational research, and (2) analyzes and addresses the conceptual and knowledge requirements of the curriculum to be encountered in subsequent years holds promise for providing a more rational, coherent, and effective foundation for science learning with young children.

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