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KATHLEEN E. METZ

Young Children Can Be Sophisticated Scientists

Elementary school science curriculum has been unnecessarily watered down out of an inaccurate belief that young children aren't ready for complex science.

Since the first international comparison of student achievement in mathematics and science, we've been worried about the disappointing showing by U.S. students. However, while the United States has tried to improve mathematics achievement in every grade from kindergarten to 12th, its efforts to improve science education have emphasized only middle school and high school. Elementary school science has been relatively neglected.

One cause is an outdated idea that elementary school children aren't developmentally ready to handle complex science. But my research and that of others shows that young children can be surprisingly capable scientists. Their abilities *far* exceed the notions of age-appropriate science in current curriculum policy documents. This means that today's science curricula are unnecessarily watered down.

What children know determines what they can learn next. If we update our thinking about what young children can do with science and give them more optimal learning opportunities, we may be able to significantly strengthen young children's scientific reasoning and position them to take on more rigorous curriculum in later grades.

What Science?

For many years, science educators have categorized what is appropriate for children according to Jean Piaget's developmental stages. We've thought about kids' capabilities and deficiencies in terms of different grade bands, and we've thought about the "science process skills" that are available to them in those grade bands. But this approach substantially underestimates children's capabilities.

One problem with Piaget's stages is that his investigations of children's scientific inquiry used tasks for which they had weak conceptual knowledge, thus handicapping their reasoning (Carey 1985). But how well children perform a science task depends on both how well they reason *and* how well they know important concepts. As Susan Carey noted, "If these concepts are not completely clear in the child's mind, due to incomplete scientific knowledge, then the child will, of course, be unable to separate them from each other in hypothesis testing and evaluation" (1985: 498). Later work on children's development by Piaget (1978, 1980) and others (see Duschl, Schweingruber, and Shouse 2007) reveals that young children have a wide range of intellectual resources. But many science educators have clung to the idea that young children have limited scientific reasoning capabilities.

The developmental literature may identify the intellectual resources that children *bring* to the classroom, but it is blind to the capacities that children can reveal under better learning conditions. Recent research suggests that children's capabilities are surprisingly plastic and sensitive to the opportunities they have to learn.

Stronger Science Instruction

In my research, I analyze how well children can think scientifically when they get instruction that uses their intellectual resources to the fullest. One line of my work investigates the power of scientific inquiry in the hands of children in the primary grades (Metz 2004, 2008). More recently (Metz et al. 2010), I've been investigating the extent to which young children can understand core scientific ideas.

From this work, I've developed five instructional design principles aimed at maximizing the power of children's scientific inquiry, and I've incorporated these principles into an elementary school curriculum. The design principles are:

1. **Scaffold relatively rich knowledge, emphasizing big ideas that transcend the topic being studied.**

A solid grasp of concepts leads to better scientific reasoning. Unfortunately, U.S. science curricula cover many topics superficially (Valverde and Schmidt 2000), undermining in-depth conceptual understanding. This instructional model sacrifices coverage of many top-

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ics to go deep into strategically selected ones. This principle gives rise to the next two.

2. **Engage children in purposeful scientific inquiry, with the goal of discovery and understanding.**

3. **Teach science processes and methods in the context of "doing" real science.**

The elementary science classroom seldom reflects a strong model of science as a way of knowing, particularly in primary grades. Curricula typically foreground the science "process skills" that have been deemed developmentally appropriate, like observation, measurement, and categorization. Breaking up scientific inquiry into discrete process skills may simplify teaching and let students practice the component pieces, but it obscures the very purpose of doing science — discovery and understanding. Furthermore, students can't learn how to use scientific processes and methods appropriately unless they use them for actual scientific inquiry. To be able to do this well, we need a strategy to encourage children's initial participation in scientific inquiry and to help them take up and eventually master new tools and ideas.

4. **Manipulate both the size of the student groups working on scientific inquiry and the extent to which the curriculum presents the inquiry in "well-structured" form instead of asking students to undertake the design themselves.**

5. **Build knowledge and responsibility to the point where pairs of students who are at the same level academically assume primary responsibility for their own investigations.**

Engaging children in scientific inquiry means teaching them to use scientific processes in context. Thus, we need a strategy to smoothly introduce children to scientific inquiry and to increase the cognitive demand as they take up and eventually master new tools and ideas. At one end of the continuum, the whole class takes on well-structured investigations; at the other end, pairs of students design their own investigations. By increasing their responsibility for scientific inquiry, we cultivate children's interest in science, their capacity to undertake scientific inquiry on their own, and their understanding of science as a way of knowing.

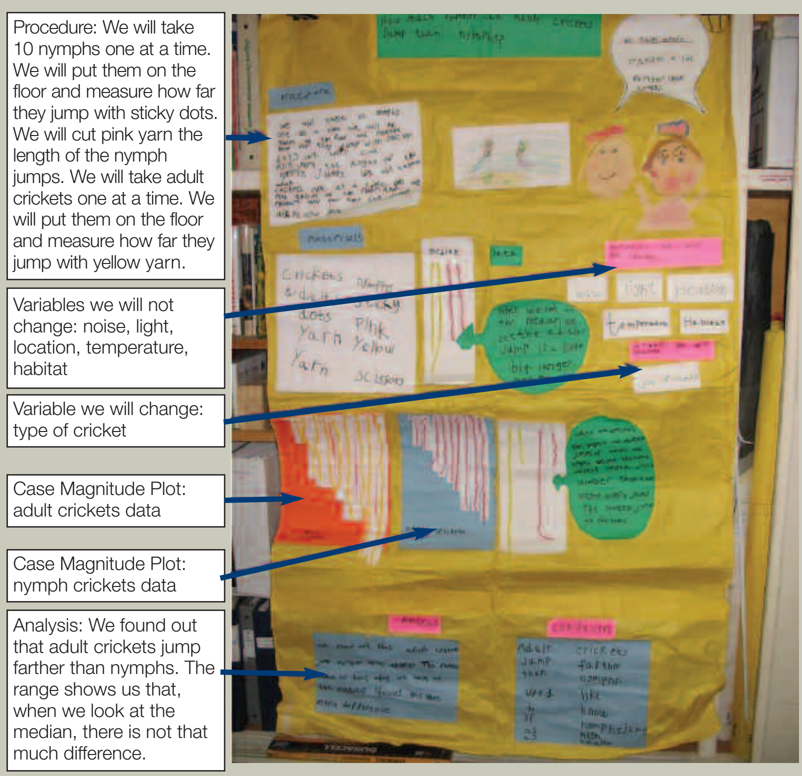
Children's Scientific Thinking

I investigated how 1st graders reasoned scientifically after receiving instruction based on my five design principles (Metz 2008, 2011), and I found that they could successfully participate in scientific inquiry that is much more demanding than what prevailing curricula assume to be "developmentally appropriate." They could assume increasing responsibility for planning and carrying out scientific inquiry. They were able to draw on the knowledge, science processes, and methods they had learned in whole-class investigations to design a study of their own in areas they had studied in depth (animal behavior and botany).

Each pair of students developed a research poster that illustrated the nature and form of their scientific inquiry. At this point, the children assumed considerable responsibility for their own research projects, supported by whole-class exploration of how to generate questions, a model of the components of a research poster, and a menu of methods constructed in class as students learned ways to collect data. For children with limited spelling or

Reform of elementary school science is a fundamental part of the solution to addressing underachievement in science among U.S. students.

How much farther can adult crickets jump than nymphs?



Courtesy the author

writing abilities, an adult was available to transcribe what they said onto the poster.

Even pairs of students who were relatively weak academically were able to come up with their own study, incorporate analytic tools used in a prior study by the whole class, and develop reasonable claims based on their data. The structured interview I conducted with each pair afterward let me closely examine their reasoning, including their confidence in their findings, the strategies they suggested for becoming more certain, and, more generally, their ideas for improving their study.

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To evaluate the 1st graders' thinking, I followed a rubric developed by Rosalind Driver and her colleagues (1997) that defines three levels of reasoning about scientific inquiry:

- *Phenomenon-based reasoning*, the most naive level, consists of simply "making observations about the world, either looking carefully at things or trying to see what happens" (1997: 141).
- *Relation-based reasoning*, the next level, means reasoning about correlations among variables, though it assumes a straightforward, one-to-one relationship between outcome and cause and thus does not consider the possibility that more than one factor could affect the situation.
- *Model-based reasoning*, the highest level, entails developing theoretical models or systems that aren't limited to actual observations or variables.

In Driver and her colleagues' study, nine-year-olds used mostly phenomenon-based reasoning, and even 12- and 16-year-olds typically used relation-based reasoning, with the problematic assumption of one-to-one correspondence of cause and effect.

In my study, 1st graders' scientific reasoning looked surprisingly advanced. Almost half (49%) of the children from two 1st-grade classes surpassed Driver and her colleagues' nine-year-olds because these 1st graders thought about their study in terms of the relationships among variables. Even more impressive, 40% of the children went beyond this, positing additional variables that might influence the outcome and thus reflecting a tacit understanding that there is not a straightforward, one-to-one correspondence between cause and effect.

For example, one relatively academically weak pair asked, "How much farther can adult crickets jump than nymphs?" On the basis of their data, they concluded that although adults jump farther, "there's not that much difference." Asked how they could improve their study, they raised the possibility that two additional factors might influence the length of the insects' jumps. One suggested that fear might play a role — not unreasonable, given the children's knowledge that adults may eat the nymphs. The other child suggested that the jump span could be affected by how much the cricket eats before jumping.

Another, more academically advanced pair investigated whether noise affects the behavior of crickets, and, based on strong evidence, concluded that it does. Nevertheless, when asked, "How sure are you that 'noise does affect the behavior of crickets?' " only one of the two said she was confident. The other student not only suggested that they should replicate the study, she also suggested that the type of cricket might make a difference. This child also suggested that it might not be noise per se, but rather the quality of the noise (a "calmer" noise might have another effect).


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Thus, following instruction that aimed to maximize their reasoning power, these 1st graders far surpassed the rudimentary level of simply making observations or trying something to see what happens. They reasoned about investigations in terms of variables. Most impressive, many of them did not assume that they had fully explained a phenomenon they had set out to study simply because their data reflected a relationship. When asked whether they could be more sure or how they could improve their study, they searched for other possible variables, a surprisingly sophisticated way of thinking.

Conclusion

Clearly, we can't wait until middle school to address underachievement in science among

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U.S. students. Reform of elementary school science is a fundamental part of the solution. Rebuilding elementary school science would be costly, requiring substantial investment in curriculum development and teacher professional development. But because what students of any age are able to learn depends heavily on what they've already learned, failure to support the scientific capabilities of elementary school children will seriously handicap science learning at higher grade levels and will diminish the abilities of our K-12 graduates. K

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Engaging children in scientific inquiry means teaching them to use scientific processes in context.

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