Learning Progressions Provide a Clear Map for Designing Standards-Based Assessments

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OVERVIEW

Criticizing the various science education standards as a dense thicket of undifferentiated content is easy to do, and I would say mostly warranted. Although critique is easy, and critics are plentiful, the usual response is to create yet another damned list of facts—when what is needed desperately is a clear map with directions to navigate the thicket. Interpreting the standards through learning progressions may be the way to attain that clear map. The piece by Smith, Wiser, Anderson, and Krajcik (this issue) could prove to be a seminally important piece on learning progressions, a concept that has garnered recent attention. Smith et al. provide guidance not only for assessment but also for instructional design and implementation, and do so far beyond the particular example of matter and the atomic-molecular theory that they used to build their argument.

As any fan of backward design would argue, starting from a set of research-based, progressive learning performances, then seeing what content it takes to get there, simply makes sense as a process. A learning progression, as the name implies, takes an idea (matter and the atomic-molecular theory) and answers, through the literature on student learning, what makes the most sense to expect as a testable learning outcome from a child at the K through 2 level. It then revisits those outcomes as prior knowledge and asks the same question for Grades 3 through 5, and then Grades 6 through 8. Learning performances treat concepts developmentally, as a series of suc-

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cessive approximations whose refinement increases, rather than as fixed binaries (where the learner either "gets it" or "doesn't get it").

Smith et al. (this issue) barely veil their critique of the cultural literacy model that underpins the undifferentiated thicket of standards and then successfully chart their compelling alternative. The argument advanced in this piece is further strengthened by the Smith et al.'s recognition that basic scientific epistemology provides a sturdy foundation for growing recommendations for assessments, and by implication, for teaching and learning.

ON THE NATURE OF LEARNING PROGRESSIONS

There is a great deal of detail in this piece. For the sake of potentially interested readers, I extract a set of the key propositions that speak to the authors' work, in addition to providing additional commentary and/or perspective.

Why build learning progressions in the first place? According to Smith et al. (this issue)

> These standards consist mostly of brief statements of propositional knowledge that students of different ages should understand. Because they do not provide operational definitions of understanding, they must be elaborated before they can be used as a basis for assessment. (p. 5)

With an overarching emphasis on epistemological understanding, *learning* and *learning progressions* become the same idea. And although *progression* is itself a metaphor for a scheme based on understanding prior knowledge, Smith et al. (this issue) do not seek to privilege any one path over another, particularly (to their credit) because there is no evidence to back such a claim:

> First, learning progressions are not developmentally inevitable but depend on instruction. Second, there is no single "correct order." There may be multiple pathways by which certain understandings can be reached. Which pathway is taken may be influenced by prior instructional experiences, individual differences, and current instruction. Third, actual learning is more like ecological succession, with changes taking place simultaneously in multiple interconnected ways, than like the artificially constrained and ordered accounts that we can give in this article. Finally, the learning progression that we can suggest is partly hypothetical or inferential. We do not have long-term longitudinal accounts of learning by individual students. (p. 5–6)

The most provocative critique—and one that is barely stated explicitly—asks how rational any set of standards is when some suggested order of ideas has no empirical basis in understanding how learners come to understand those ideas.

ON THE DETAILS FOR MATTER AND ATOMIC-MOLECULAR THEORY

Smith et al. (this issue) freely acknowledge that hard work lies ahead, and that it will take cooperation from different parts of the academy: "Thus, developing items that have desirable psychometric properties in addition to providing insight into children's thinking would require cooperative work by measurement experts and learning researchers" (p. 10). I would take this further and say it should also include scientists who understand learning beyond the cultural literacy model, materials developers who can integrate these ideas into instructional design, and teacher educators who can provide oversight for creating clear and appropriate expectations for teacher practice.

The following passages all speak to me, as a scientist and science educator, as thoughtful and grounded ideas that are indicative of the way Smith et al. (this issue) have built their argument for designing assessments on an epistemological foundation—and thus the "what we do and how we know/do it" ideas about science are given equal and integrated status in assessing understanding as "what we know":

> We conceptualize scientific knowledge as including both propositional knowledge and the practices in which that knowledge is embedded, and we include aspects of both knowledge and practice in our learning performances …. Finally, we believe the organization we have adopted makes much clearer than the original standards how a robust understanding of the atomic-molecular theory must be built from a wide range of earlier macroscopic *and* epistemological understandings. (p. 25)

Science as Sense-Making

> Organizing assessment around these practices highlights that scientific theories have the goal of making sense of and acting on the world. (p. 8)

Science as Basic Questions

> What are things made of … ? What changes and what stays the same … ? How do we know? (p. 11)

Scientific Knowledge Is Valued for Its Reliability

> Measurements are more reliable than commonsense impressions. (p. 45)

Science Builds

> In later elementary grades, children experiment with melting and freezing a broader variety of substances, and with dissolving. They can measure weight and volume to establish that adding and removing heat from objects changes some properties (temperature, solid vs. liquid state, volume) but not weight or kind of material (p. 21)

Science Explains

> An inherent part of mastering the atomic-molecular theory is appreciating the nature, function, and revisability of models. To appreciate the explanatory power of the atomic molecular theory, middle school students also need to learn that the properties of objects and substances that it explains (other than mass, volume, and weight) are fundamentally different from the properties of atoms and molecules (e.g., the malleability of a substance is explained by the arrangements of its molecules and the forces between atoms, not by the malleability of atoms per se). (p. 23)

The only criticism I have about the epistemological issues is the exclusion of experimental design. It does not appear distinctively, nor (unless I missed it) is it commented on. Is design not a developmentally reasonable goal by the eighth grade? Actually, I am willing to accept that it is not reasonable, particularly if there is a research-based answer to the question, but it would be nice to see that discussion included.

The chemistry content is fine. In fact, I encountered a new term (*material kind*) that is used by analytic philosophers to differentiate substances made up of a homogenous aggregate of atomic or molecular species (macroscopic water is comprised of molecular water: HOH). Although this term is not in general use in chemistry, it is nonetheless worth consideration. The term helps clarify a perennial confusion about the way the word *matter* is used and successively redefined as a person learns chemistry.

I also applaud the authors for explicitly addressing the *mass* versus *weight* issue and their courage for stating that differentiating different scientific meanings from common usage is not appropriate for young learners:

> We use *weight* rather than *mass* intentionally at this level as this is the word that is already meaningful to children based on their everyday experience. The distinction between weight and mass can more properly be assessed in older students who have learned about gravitational attraction. (p. 47)

ON THE ASSESSMENTS

I start with a story that has a moral: An artificial satellite can hang motionless in earth's orbit at what is called a Lagrange point. From that point, one can see the planet as a whole, its gross features, and their relationships: The Big Picture. If its telescope is trained on a particular place on the planet's surface, you might discover that there is detail in those features that you miss in the longer distance view, but you have paid a price: You can no longer see the big relations, either.

Mercifully, these authors understand this moral.

They argue that nitpicking details (*mass* vs. *weight*) makes no sense for a child in the first grade who still thinks that the bigger it is, the heavier it is. It is an operationally useless distinction. And lest any reader complain about not telling the truth (the whole truth, and nothing but the truth), remember that most architecture (and certainly all beginning architects learn it this way) is based on a flat-Earth model! Plumb lines separated by any distance on our planet are not parallel, so plumbed walls are not "square," but within a certain distance, it is good enough. The interesting question is how large a structure needs to be before you take the curvature of the earth into account—but you can bet this does not (and should not) show up in a middle school shop class. It is not operationally useful. All understanding proceeds through successive approximation.

Throughout their examples, Smith et al. (this issue) present a coherent argument for exactly what level of performance might be expected, based on an understanding derived from research, about a given topic and a given level.

The recommendations are concrete and explained thoroughly, although there is an inevitable danger in highlighting one idea (e.g., density). A casual reader might think that one idea is being privileged by the authors instead of being used as an example whose learning progression can be described at different educational levels. In identifying the characteristics of a good measurement of length or the changing dimensions of the aluminum cylinder, Smith et al. (this issue) provide multiple examples of possible assessment that range from simple paper and pencil tasks to more performance-based ones that might be appropriate for researchers looking at greater depth of understanding. Perhaps not coincidentally, these assessments tell a compelling story that is reminiscent of the force concept inventory (FCI) that has become so popular in physics education: a research-based assessment tool. Like the FCI, many teachers will look at the assessments suggested by Smith et al. and believe one of a few things, if not all of them: (a) This is too easy for anyone to get wrong, (b) any teacher who cannot get a class to get this all correct should be fired, and/or (c) I could certainly teach any class in about 5 minutes how to get this right. And like the FCI, the assessments suggested by these authors will reveal much to teachers who use them with their students.