Proficiency in Science: Assessment Challenges and Opportunities

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Abstract

Proficiency in science is being defined through performance expectations that intertwine science practices, crosscutting concepts, and core content knowledge. These descriptions of what it means to know and do science pose challenges for assessment design and use, whether at the classroom instructional level or the system level for monitoring the progress of science education. There are systematic ways to approach assessment development that can address design challenges, as well as examples of the application of such principles in science assessment. This review considers challenges and opportunities that exist for design and use of assessments that can support science teaching and learning consistent with a contemporary view of what it means to be proficient in science.

Introduction

We face extraordinary promise for the future of science learning, juxtaposed with significant challenges in achieving the vision of what it means to be proficient in science (*1*). Among those challenges is determining how the proficiency of our students will be assessed relative to that vision, and doing so in ways that support teaching and learning rather than inhibiting them. Educational assessments ought to be statements about what scientists, educators, policy makers, and parents want students to learn and become. It is well established that what we choose to assess will end up being the focus of instruction. So, it is critical that science assessments – both external and internal to the classroom -- best represent the proficiencies we

desire. This paper argues that much of what is needed to effectively assess science learning, either at the classroom level or for purposes of system monitoring, has yet to be created and that design and implementation challenges are significant. Even so, there are promising cases from which to learn and build (*2*).

Shared Perspectives on Proficiency

A disjuncture exists between students' knowledge of science facts and procedures, as assessed by typical achievement tests, and their understanding of how that knowledge can be applied through the practices of scientific reasoning, argumentation, and inquiry (*3,4*). This problem is recognized in reports spanning K-16+ that simultaneously present a consistent description of what proficiency in science should be (*1,5-11*). Seldom has such a consistent message been sent as to the need for change in what we expect students to know and be able to do in science, how science should be taught, and how it should be assessed. The emergent definition of proficiency is perhaps most clearly expressed in three major elements of the U.S. National Research Council (NRC) Framework for K-12 Science Education (*1*): (i) Core or "Big" ideas within disciplinary areas; (ii) Practices of Scientific and Engineering Reasoning, and (iii) Crosscutting Concepts. Collectively they define what it means to know science, not as separate elements but as intertwined aspects of knowledge and understanding (see also *12*). It is not just the description of each and their intersection that matters, but also that the meaning of proficiency is realized through performance expectations about what students at various levels of educational experience should know and be able to do. These statements move beyond vague terms such as "know" and "understand" to more specific statements like analyze, compare, explain, argue, represent, predict, model, etc., in which the practices of science are wrapped

around and integrated with core content. It is also recognized that proficiency develops over time and increases in sophistication and power as the product of coherent systems of curriculum, instruction and assessment.

The virtue of such a view is that science educators are poised to better define the outcomes desired from their instructional efforts which in turn guides the forms of assessment that can help them know whether their students are attaining the desired objectives, as well as how they might better assist them along the way. It is very important for the science education community, and policy makers and the public more broadly, to develop a shared perspective on what constitutes high quality and valid science assessments across K-16+ if assessments are to support teaching and learning and attainment of the desired science education outcomes.

Proficiency, Performance Expectations, and Assessment Design Challenges

The NRC Framework uses the logic of progressions to describe students' developing proficiency in these three intertwined domains- practices, crosscutting concepts, and core ideas- in a coherent way across grades K through 12. The Framework builds in the idea of a progression of student understanding across the grades by specifying grade band end point targets at grades 2, 5, 8 and 12 for each component of each core idea. The Framework provides sketches of possible progressions for acquiring each practice or crosscutting concept but does not indicate the expectations at any particular grade level. The Next Generation Science Standards (NGSS) (*7*) build on these suggestions and include tables that define what each practice might encompass at each grade level, and similarly define the expected uses of each crosscutting concept for students at each grade level.

This integrated perspective of what it means to know science suggests that assessment should help determine where a student can be placed along a sequence of progressively more "scientific" understandings of a given core idea that by definition includes successively more sophisticated applications of practices and crosscutting concepts. This is an unfamiliar idea in the realm of science assessments, which have more often been viewed as simply measuring whether students know about particular grade level content. It means that assessments must strive to be sensitive both to grade-level appropriate performances and to intermediate performances that may be appropriate at somewhat lower or higher grade levels. This is particularly important for the design of assessment materials and resources that can be used in classrooms to support instruction.

The NRC Framework states that assessment tasks must be designed to gather evidence of students' ability to apply the practices and their understanding of the crosscutting concepts in the contexts of problems that also require them to draw on their understanding of specific disciplinary ideas. It suggests using a model put forward in Science Standards for College Success (*13*) by expressing standards in terms of performance expectations. The organization Achieve, and its partners in NGSS development, have elaborated these guidelines into standards that are clarified by descriptions of the ways in which students at each grade are expected to apply both the practices and crosscutting concepts, and of the knowledge they are expected to have of the core ideas. The NGSS appear as sets of performance expectations related to a particular aspect of a core disciplinary idea (see the draft example in Figure 1). Each performance expectation asks students to use a specific practice in the context of a specific element of the disciplinary knowledge relevant to the particular aspect of the core idea. Across

the set of expectations at a given grade level, each practice and crosscutting concept appear with multiple standards.

Performance expectations also may include boundary statements that identify limits to the level of understanding or context appropriate for a grade level and clarification statements that offer additional detail and examples. But standards and performance expectations, even as explicated in the NGSS, lack sufficient detail to create an assessment.

From NRC Frameworks, Standards, and Performance Expectations to Assessments

The design of valid and reliable science assessments hinges on elements that include but are not restricted to what is articulated in disciplinary frameworks and standards such as those illustrated above (*14,15*). In the design of assessment items and tasks related to performance expectations one needs to also consider: (i) the kinds of conceptual models and evidence in which we expect students to engage; (ii) grade-level appropriate contexts for assessing performance expectations; (3) options for task design features (e.g., computer-based simulations or animations, paper-pencil writing and drawing) and which of these are essential for eliciting students' ideas about the performance expectation; and (4) the types of evidence that will reveal levels of student understanding and skill.

Recognizing that assessment involves evidentiary reasoning (*14*), it has proven useful to be more systematic in framing assessment development as an Evidence Centered Design process (ECD) (e.g., *15,16*). The process starts by defining the claims that one wants to be able to make about student proficiency -- the ways in which students are supposed to know and understand some particular aspect of a domain. Examples might include aspects of force and motion, heat and temperature, etc. The most critical aspect of defining these is to be as precise as possible

about what matters and express this in the form of verbs such as model, explain, predict, etc. In essence, the performance expectations found in the NGSS are claims about student proficiency.

Claims about the student must be linked to forms of evidence that would support those claims. Evidence statements capture features of work products or performances that would give substance to the claims. This includes which features need to be present and how they are weighted – what matters most, least, or not at all. If evidence in support of a claim about a student's knowledge of the laws of motion is that the student can analyze a physical situation in terms of the forces acting on all the bodies, then the evidence might be drawing a free body diagram with all the forces labeled including their magnitudes and directions.

The precision that comes from elaborating the claims and evidence statements pays off when it is time to design tasks or situations to provide the requisite evidence. Tasks are not designed or selected until it is clear what forms of evidence are needed to support the range of claims appropriate to a given assessment situation. The tasks need to provide necessary evidence and should allow students to "show what they know" in ways that are as unambiguous as possible with respect to what the performance implies about student knowledge and skill (*17*).

Science Assessment Example Cases

Given the relative newness of the NRC Framework it is no surprise that comprehensive sets of assessment examples that align completely with the NGSS performance expectations do not exist. Many of the tasks that have been used for classroom assessment, and those found in large-scale state, national and international tests, focus primarily on science content or on aspects of scientific inquiry separate from content. With few exceptions, such assessments do not integrate core concepts and science practices in the ways intended by the NRC Framework or NGSS. Nevertheless, we can draw from example cases to illustrate what is needed, many of

which have used an ECD approach to guide assessment design and validation. The examples are diverse in several ways including the science content and practices represented, age and grade level, intended use – at the classroom, state, national or international level, whether the consequences of student performance have low or high stakes - as well as the innovative use of technology.

   Classroom Instruction and Assessment. Several projects have developed assessments for use in classroom instruction with a particular emphasis on the integration of core science concepts with one or more of the science practices such as modeling, evidence-based explanation and argumentation, and/or the design of investigations to test hypotheses, analyze results and construct explanations from data. Some of the clearest examples can be found in a volume edited by Alonzo & Gotwals (*18*) focused on learning progressions, and in a special issue on assessment of the *Journal of Research on Science Teaching* (*19*). Additional examples include the SimScientists (*20,21*), Science ASSISTments (*22*), and BioKids projects (*23*).

   Several of these projects illustrate the feasibility of designing tasks and situations, whether in paper and pencil format or mediated via simulations embedded in technology, that challenge students to reason with and about core science concepts in life and physical science. They demonstrate ways to obtain forms of evidence that can serve multiple purposes such as measurement of student proficiency as well as diagnosis of student thinking for instructional improvement. The SimScientists project has shown how assessment situations and tasks involving dynamic simulations of science phenomena can be built from a principled design process that supports classroom formative assessment as well as summative assessment in large-scale state programs (*21*).

National and International Large-scale Assessment. Much of what students and teachers experience as science assessments is external to regular classroom instruction and comes in the form of large-scale state tests, e.g., administered in response to the U.S. No Child Left Behind legislation. While the quality of such state assessments varies, none approximates the performance expectations discussed in the NRC Framework and NGSS. In contrast, there are two large-scale assessment programs that more closely exemplify aspects of science proficiency that involve science practices – the U.S. National Assessment of Educational Progress (NAEP), and the Programme for International Student Assessment (PISA).

The NAEP 2009 and 2011 assessment was constructed from a framework document that identified specific areas of content in the life, physical and earth and space sciences as well as a set of science practices: (a) Identifying Science Principles, (b) Using Science Principles, (c) Using Scientific Inquiry, and (d) Using Technological Design. Item types fell into two broad categories: selected-response items (such as multiple choice) and constructed-response items (such as short answer). To further probe students' abilities to combine their understanding with the investigative skills that reflect practices, a subset of the students completed hands-on performance or interactive computer tasks (*3,4,24,25*). In contrast to NAEP, which is administered to 4th, 8th and 12th grade students, the PISA assessment is administered only to 15 year olds. The most recent PISA science assessment results are based on a framework that includes science proficiencies that overlap with the science practices of the NRC Framework and NGSS, as well as aspects of the NAEP framework (*26,27*).

What is especially important about both NAEP and PISA are the sets of simple and complex science assessment tasks that demand reasoning about science content as described in the NRC Framework and NGSS. Both assessment programs are a source of examples of the

types of performances that align with the descriptions of proficiency discussed earlier. Neither NAEP nor PISA represent static assessment programs. Both undergo major revisions to the framework used to guide assessment design and task development and both are moving to increasingly incorporate technology as a key aspect of task design and assessment of student performance. It is likely that the NAEP framework will be revised within the next decade and work is already underway in revising the PISA science framework for 2015. Changes in both will ostensibly move in directions that even more closely align with the NRC Framework. Thus, both might constitute reasonable ways to monitor overall progress of science teaching and learning in U.S. classrooms in ways consistent with implementation of the NRC Framework and NGSS.

Advanced Placement (AP) Science. A contemporary approach to rethinking science proficiency can be found in the redesign of the AP courses and assessments for biology, chemistry, and physics (*8,9,28,29*). The AP program offers college-level curricula to high school students. Starting in 2006, the College Board, which administers AP, with support from the National Science Foundation, initiated a process that started by redefining the focus, critical content, and science practices that should define proficiency at the end of each AP science course (*30*). This would then guide development of both a curriculum framework for each course as well as the high stakes assessment often used by colleges for purposes of granting course credit and/or advanced course placement.

Using the complementary processes of Backwards Design (*31*) and ECD, a framework was developed for each science discipline organized in terms of disciplinary big ideas, enduring understandings, and supporting knowledge as well as a set of seven science practices. This structure parallels that of the core ideas and science practices in the NRC Framework. Similar to

what is advocated in the NRC Framework and realized in the NGSS, performance expectations or learning objectives were defined within each discipline to reflect the blending of core ideas with science practices. Through application of ECD, sets of claim-evidence pairs were elaborated in each science discipline to focus and support course instruction as well as development of assessment tasks for new AP exams.

The first of those exams will be given in May 2013 in biology with chemistry to follow in 2014 and physics in 2015. To help teachers and students orient to the new course and exam, a wealth of materials including sample assessments were provided (*32*). To reflect the shift in focus demanded by integration of science practices with core content ideas, new item types were created and a greater emphasis is being placed on constructed response questions. Figure 2 provides an example of a short constructed response item that involves the integration of conceptual knowledge with aspects of the practices.

AP science redesign is still a work in progress. Much remains to be determined about the quality and impact of the new exams on student learning and classroom instructional practice. But AP science instruction and assessment are changing in ways closely aligned with the perspective on science proficiency described earlier.

The Road Ahead

Assessment is a key element in the process of educational change and improvement. Done well it can signify what it is that we want students to know and be able to do and help educators create learning environments that support attainment of those objectives. Done poorly it sends the wrong signals and skews teaching and learning. Our greatest danger may be a rush to turn the NGSS into sets of assessment tasks for use on high-stakes state accountability tests before we

have adequately engaged in research, development and validation of the range of tasks and tools needed to get the job done properly. Most especially we must insure that teachers are given the time, support and assessment tools to create instructional environments where their students have adequate opportunities to learn what is now expected of them.

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17. While this discussion of a principled approach to assessment design has focused exclusively on specific tasks and situations it is equally applicable to the design of an assemblage of tasks – an assessment or test that might be used for various purposes at the classroom level or beyond. Such a process also requires careful selection and assembly of tasks so that the desired inferences about student proficiency can be supported at the level of the overall instrument or it subparts. Thus, assessment design -- at multiple levels from separate tasks to larger instruments – needs to always be approached as a principled design process in which the claims one wants to make about student proficiency are supported by sufficient forms of evidence carefully chosen to meet the intended purpose and use of the assessment results.

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Grand Challenges:

1**. Design valid and reliable assessments reflecting the integration of practices, crosscutting concepts, and core ideas in science.** The performance expectations of the NGSS pose significant assessment design challenges. Considerable research and development is needed to create and evaluate assessment tasks and situations that can provide adequate evidence of the proficiencies implied in the NGSS. Such work will need to be done in instructional settings where students have had adequate opportunity to construct the integrated knowledge envisioned by the NRC framework and the NGSS.

2. **Use assessment results to establish an empirical evidence base regarding progressions in science proficiency across K-12.** Much of what is assumed in the NGSS regarding progressions needs to be validated through empirical research. The latter requires assessment tasks and situations that can be used across multiple age/grade bands so that we can determine how proficiency changes over time and with appropriate instruction. The empirical results can be used to support the design of more effective curriculum materials and instructional practices.

3. **Build and test support tools and information systems which teachers can use to effectively implement assessment for learning in the classroom.** For teachers to effectively implement assessment as part of their pedagogy they need tools for presenting tasks and collecting and scoring student performance. They also need smart systems that provide actionable information about the meaning and implications of student performance relative to instruction and student learning. Such systems will need to be designed in collaboration with learning scientists and teachers to insure their validity, usability, and utility.

Figure Captions

Figure 1. Example of a set of possible Grade 4 standards in Life Science from the January 2013 preliminary draft of the Next Generation Science Standards.

Figure 2. A sample of a short constructed response item for the new AP biology exam.

4-LS1 From Molecules to Organisms: Structures and processes

4-LS1 From Molecules to Organisms: Structures and processes

Students who demonstrate understanding can:

4-LS1-a. Use simple models to describe that plants and animals have major internal and external structures, including organs, that support survival, growth, behavior, and reproduction. [Clarification Statement: Examples of structures include thorns, stems, roots stamens, ovaries, heart, brain, skin, or bones.] [Assessment Boundary: Students are responsible for the overall functions of major structures, but the mechanisms of how they function within a system are not assessed. Students are not expected to memorize different types of structures but should be able to use information given.]

4-LS1-b. Design, test, and compare solutions that replace or enhance the function of an external animal structure necessary for survival.* [Clarification Statement: Students might compare solutions for mobility based on the strength of different materials used.]

4-LS1-c. Construct models to describe that animals' senses receive different types of information from their environment, process the information in the brain, and respond to the information in different ways. [Clarification Statement: Examples of models could be diagrams or analogies.] [Assessment Boundary: Students are not expected to know the mechanisms by which the brain stores and recalls information, nor the mechanisms of how sensory receptors function.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education:*

Science and Engineering Practices	Disciplinary Core Ideas	Cross-cutting Concepts
Developing and Using Models Modeling in 3–5 builds on K–2 models and progresses to building and revising simple models and using models to represent events and design solutions. • Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. (4-LS1-c) • Identify limitations of models. (4-LS1-c) • Use a simple model to test cause and effect relationships concerning the functioning of a proposed object, tool or process. (4-LS1-a) **Constructing Explanations and Designing Solutions** Constructing explanations and designing solutions in 3–5 builds on prior experiences in K–2 and progresses to the use of evidence in constructing multiple explanations and designing multiple solutions. • Use evidence (e.g., measurements, observations, patterns) to construct a scientific explanation or design a solution to a problem. (4-LS1-b) • Apply scientific knowledge to solve design problems. (4-LS1-b) **Obtaining, Evaluating, and Communicating Information** Obtaining, evaluating, and communicating information in 3–5 builds on K–2 and progresses to evaluating the merit and accuracy of ideas and methods. • Compare and/or combine across complex texts and/or other reliable media to acquire appropriate scientific and/or technical information. (4-LS1-a) • Use multiple sources to generate and communicate scientific and/or technical information orally and/or in written formats, including various forms of media and may include tables, diagrams, and charts. (4-LS1-a)	**LSA.A: Structure and Function** • Plants and animals have both internal and external structures that serve various functions in growth, survival behavior, and reproduction. (4-LS1-a), (4-LS1-b) **LS1.D: Information Processing** • Different sense receptors are specialized for particular kinds of information, which may be then processed and integrated by the animal's brain, with some information stored as memories. Animals are able to use their perceptions and memories to guide their actions. Some responses to information are instinctive–that is, animals' brains are organized so that they do not have to think about how to respond to certain stimuli. (4-LS1-c) **ETS1.C: Optimizing the Design Solution** • Different solutions need to be tested in order to determine which of them best solves the problem given the criteria and the constraints. (*secondary to 4-LS1-b*)	**Structure and Function** • Substructures have shapes and parts that serve functions. (4-LS1-a), (4-LS1-b), (4-LS1-c) ------------------------------- **Influence of Engineering, Technology, and Science on Society and the Natural World** • Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands. (4-LS1-b)

The role of tRNA in the process of translation was investigated by the addition of tRNA with attached radioactive leucine to an *in vitro* translation system that included mRNA and ribosomes. The results are shown by the graph.

In a **short paragraph**, describe how the graph justifies the claim that the role of tRNA is to carry amino acids that are then transferred from the tRNA to growing polypeptide chains.