

# **Developing Standards that lead to Better Instruction and Learning<sup>1</sup>**

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## **I. Introduction**

Science content standards have driven the science education reform movement in the U.S. for over two decades. Scholars have stated that standards are the most important element in the education system because they provide clear and measurable expectations for what students should know and make explicit the goals that the education system has for student learning. As such, administrators, teachers, curriculum designers and policy makers use standards as a guide for development of curriculum materials, the selection and development of assessment, decisions on instructional priorities, and for designing professional development. Because standards play such a key role in the educational system, it is paramount that standards are written with clarity, accuracy, thoughtfulness and what is known about student learning. Although we hope the remarks made in this paper apply to the design of all standards, because our background is in science, science education and the learning sciences, the focus we take on writing this paper is on constructing science standards that can be more useful to teachers, administrators, policy makers and researchers.

Given the importance of standards, it is unfortunate that the U.S. science standard documents, including the National Science Education Standards (NRC, 1996), Benchmarks for Scientific Literacy (1991) and most district and state science standards, have been criticized for containing too many ideas and having a fragmented nature that ultimately leads to superficial learning of a broad scope of ideas (for instance, Schmidt, Wang, & McKnight, 2005). Often standards are written as declarative statements that express the ideas that students should know instead of specifying how ideas should be used. Additionally, standards documents do not prioritize ideas, but tend to treat all ideas as equally important.

The trouble with covering too many ideas is that students do not learn how ideas are related to one another or how they can be used to explain and predict phenomena. As such, although the science education reform effort in the U.S. that has been driven by standards has resulted in some improvements in achievement, many students still do not develop integrated understanding of key ideas. Failure of U.S. students to develop integrated understanding is seen in international comparisons that show students in the United States do not perform as well as those in other developed countries on tests of scientific knowledge (Schmidt, Wang, & McKnight, 2005).

Many factors contribute to the poor performance of U.S. students on international assessments. One of the most important predictors of student learning identified by researchers from the Third International Mathematics and Science Study (TIMSS) was curriculum coherence both within and across years (Schmidt, Wang, & McKnight, 2005). A coherent curriculum can help support students to develop integrated understanding of important and complex ideas and skills across time (Shwartz, Weizman, Fortus, Krajcik, & Reiser, 2008). The lack of coherence seen in U.S. curriculum and subsequent failure of students to develop integrated understanding can be tied to the science standards that focus on covering a broad set of ideas instead of focusing on a core set of coherent ideas (NRC, 2006). Moreover, most standards fail to take into consideration what we know about student learning and do not pay attention to how ideas develop across time, failing to help students develop deeper understand as they continue in school (NRC, 2006). As we will show below, building standards based of what is known about student learning is a key to improving standards that can promote meaningful learning.

Because of the importance that standards play in developing learning tasks and assessments that can promote and guide learning, a strategy for developing rigorous and

thoughtful standards is necessary. In this paper, we first propose a model for what standards should look like based upon what is known about learning. We next discuss a process for developing more useful standards that will better support the development of assessment and learning tasks, a process we call construct-center design. We end, by showing how this process can then be used to develop assessments and various learning tasks.

## **II. What Standards Should Contain**

As a nation we can no longer afford to have standards that are fragmented and superficial, as student learning will continue to deteriorate unless changes are made. Rigorously specified standards are needed to guide the development of assessment and learning tasks if we are to improve the teaching and learning of science. Several arguments exist for articulating rigorous and explicit standards for science instruction. Standards when designed appropriately provide a vision for what science should be taught and how those ideas can develop across time (NRC, 2006). As such, standards should provide a guide to teachers, administrators and designers for aligning assessments and instruction.

In deciding what standards should contain, we use recommendations suggested by NRC's Systems for State Science Assessments (NRC, 2006). Wilson and colleagues suggest that standards need to have a clear conceptual framework, build from sound models of student learning, and describe performance expectation and proficiency levels. In addition, standards should be: 1) clear, detailed, and complete, 2) reasonable in scope, and 3) rigorously and scientific accurate.

In building a framework for what standards, and science standards in particular, should look like we propose using five principles of learning (Bransford, Brown & Cocking, 1999; Pellegrino, Chudowsky & Glaser, 2001).

- First, integrated understanding is built for a relatively small number of core and important ideas that is foundational to one or multiple disciplines (Stevens, Sutherland, & Krajcik, 2009). We refer these core ideas as big ideas. Big ideas provide explanatory power and as such allow scientists and students to explain a vast range of phenomena. Big ideas are central to the discipline and are therefore linked, in this case, to goals for science literacy. Big ideas provide a means for relating and connecting concepts, models and principles to support learners in developing integrated understanding of a discipline (Smith, et al., 2006; NRC, 2006).
- Second, an individual makes sense out of various ideas and experiences to construct meaningful understanding by connecting related concepts, principles and factual knowledge to each other. In this process, individuals create conceptual frameworks that integrate their understanding. Conceptual frameworks allow a learner to use relationships between the various ideas to solve problems, make predictions, observe patterns, and organize and structure new information. Thus, we need to consider how the big ideas and the associated critical concepts are connected to each other.
- Third, because integrated understanding is built upon conceptual frameworks structured around big ideas of a discipline we need to consider what are the critical ideas of which students need to develop understanding that are associated with these big ideas. Determining critical concepts involves breaking up the big idea into smaller components to explicitly specify the concepts that are crucial for developing an understanding of the big idea.
- Fourth, because new understandings are constructed on a foundation of existing understanding and experiences, we need to consider the essential prior knowledge students need to develop understanding of the big ideas.

- Fifth, learning complex ideas takes time and often happens as students work on tasks that force them to synthesize their understandings. Big ideas can provide a framework for organizing standards that allows educators to consider how learning within the discipline can occur over time. As such, the big idea can be revisited throughout K-12 schooling, so that knowledge and reasoning becomes progressively more refined and elaborated.

In order to be useful for designers of curriculum materials and assessments, standards documents should also include the challenges students face in learning those ideas, what students find challenging at a particular grade level and what phenomena or instructional tasks can help students develop these ideas. Below we describe a process we use for developing standards.

### **III. A Process for Developing Rigorous Standards**

To develop rigorous standards, we use a process modified, adapted and extended from the learning-goal-driven design model for developing curriculum materials (Krajcik, McNeill, & Reiser, 2008), the backwards design process (Wiggins & McTighe, 1998) and the evidence-centered design model for developing assessments (Mislevy & Riconscente, 2005). We have referred to this process as the Construct-Centered Design (CCD) approach (Shin, Stevens, & Krajcik, in press).

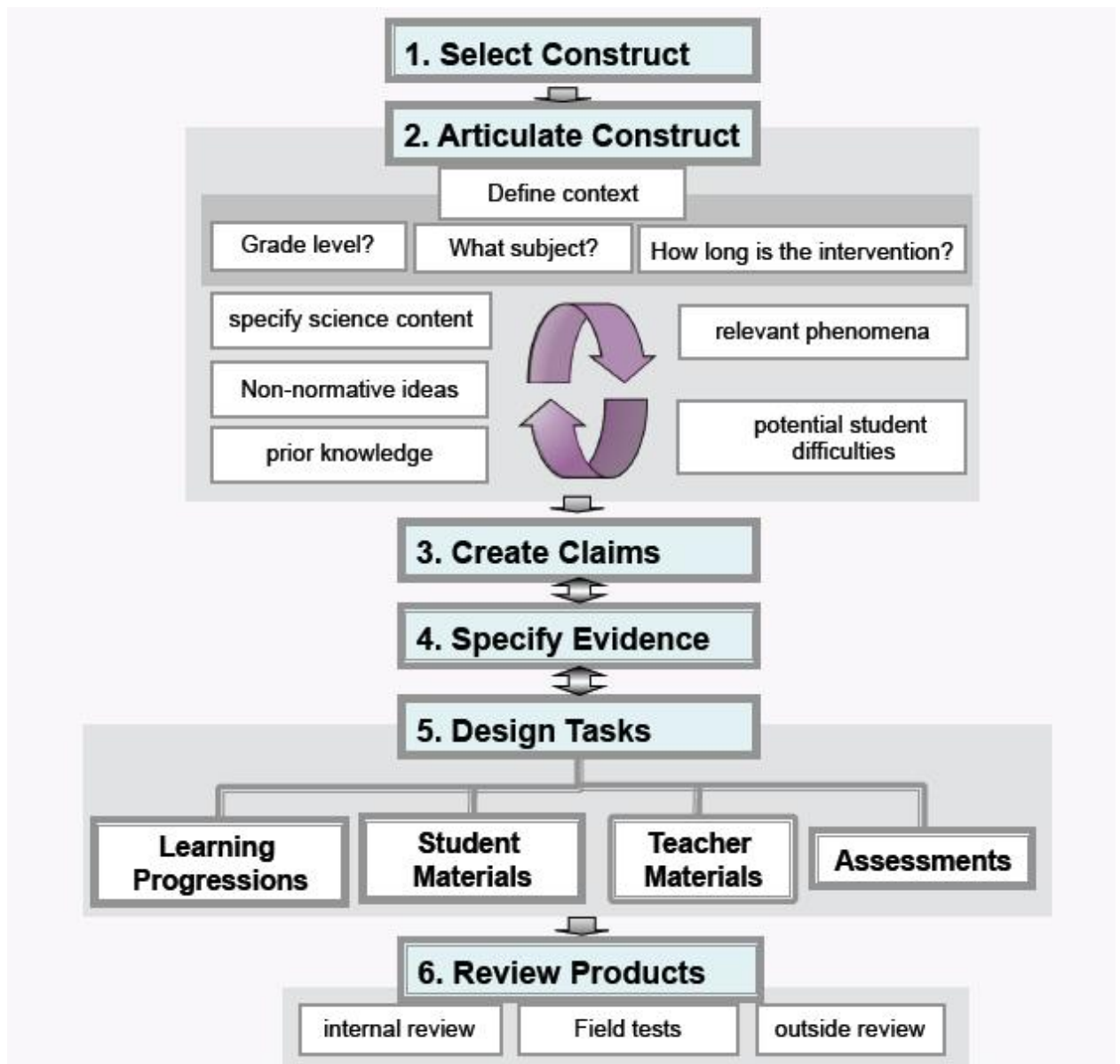
The construct-centered design approach includes six stages: 1) selecting the construct, 2) articulating the construct, 3) creating claims, 4) specifying evidence, 5) designing tasks including assessments and learning tasks, and 6) reviewing products by gathering multiple forms of feedback. Figure 1 illustrates the processes of these different stages and their iterative nature essential for aligning standards, learning tasks, and assessments. Because of the specific nature of the standards this process develops, we often use the term learning goals interchangeably with standards. The first four stages correspond to the design and specification of the standard or

learning goals. The process as a whole shows how to align standards to assessments and instructional materials.

In listing the various components of process, we do not mean to imply that the process is a linear. The CCD approach is interactive and highly recursive, with information specified at one component clarifying and modifying other components that occurred earlier in the process. The feedback loops are critical for developing more rigorous and specific standards and for the alignment process. In the sections that follow, we describe how rigorous standards can be developed using this process. Below we only describe the key aspects of the CCD process (to learn more see, Shin, Stevens & Krajcik, in press).

### **III a. Selecting the Construct**

Consistent with our theoretical framework discussed in section II, our approach focuses on ideas that can serve as important foundations for continual learning as these ideas can systematically focus learners' science education experiences, rather than the current approach of covering all concepts superficially and that do not give priority of some ideas over other. One strategy for building coherence within the standards document is to focus on a relatively small number of big ideas of the discipline instead of the broad coverage currently represented in typical standards documents (Duschl, et al., 2007). In designing science standards, science experts, science educators and teachers need to decide on what are the big ideas. Once the big ideas are selected, learning research needs to be used to determine what is appropriate for students to understand at a particular grade range or level. In figure1, the first step is referred to as selecting the construct. We define the construct as the big ideas that students are expected to learn and researchers and teachers want to measure (Messick, 1994; Wilson, 2005).



**Figure 1: The CCD approach.**

In addition to concepts related to subject matter of the disciplines, big ideas can also include themes and scientific practices. Big ideas for science subject matter might include energy, the particle nature of matter, evolution and plate tectonics. Themes are ways of thinking rather than scientific theories and principles and may cut across various fields and used by scientist in various fields (AAAS, 1993). Themes might include size and scale, consistency and change, and structure and function. We define scientific practices as the various scientific ways

individuals can learn about and explore the natural world (Duschl, Schweingruber,& Shouse, 2007) and include creating and using models, constructing scientific explanations and designing and conducting investigations.

The big idea that we will use as an example in this paper is forces and interactions on the molecular and nano scales. This big idea states that all interactions can be described by multiple types of forces, but the relative impact of each type of force changes with scale. On the nano and molecular scales, a range of electrical forces with varying strengths tend to dominate the interactions between objects. We select this big idea, as it was previously identified as a big idea of nanoscience (Stevens, Sutherland and Krajcik, 2009) and it is a component of our work in developing, articulating and validating a learning progression for the nature of matter (Shin & Krajcik, 2008; Stevens, Delgado & Krajcik, 2009).

### **III b. Articulating the Construct**

The next step is to articulate the big idea based on expert knowledge of the discipline and related learning research (see Figure 1, step 2). This process, called unpacking, involves defining the critical ideas contained within the construct, which we define as breaking up the construct into smaller components to explicitly specify the critical concepts that are crucial for developing an understanding of the big idea. Being related to the construct is not enough; the concept must be necessary for building understanding of the construct. Unpacking is guided simultaneously by fidelity to the scientific ideas and by considering learning and pedagogical concerns.

The scope of a big idea is extensive, so the development of integrated understanding of it must occur over an extended period of time. Because understanding of big ideas develops across time, we need to define the target learners because students at different grade ranges have different knowledge and experiences that influence their learning, as such defining the target

students helps define the construct appropriately, and also guides preparation of level-appropriate instructional materials, instruction and assessment. Thus, unpacking also includes defining how the construct develops across time. The concepts within the constructs are unpacked to define what it means to understand them at levels appropriate for a particular grade band of students. To begin we define the upper and lower levels. In the example used in this paper (see Table 1), the upper level was defined based upon the big ideas of nanoscience (Stevens, Sutherland, & Krajcik, 2009), the national standards (AAAS, 1993; NRC, 1996) and current learning research related to those ideas. We define a lower level by examining what other standard documents state, in particular the Atlas of Scientific Literacy (AAAS, 2001), and by examining the learning research (Smith, et al., 2006) in this area. If the learning research does not exist, research needs to be conducted to determine what students can learn at a particular level. As such, the unpacking process begins to specify the depth of understanding that is expected from students.

As a step towards defining *how* students should know the critical ideas, the prior knowledge that is required both within and from other related constructs is specified. The unpacking process also includes: identifying potential difficulties students might have learning the content; clarifying non-normative ideas that might interfere with students learning the content; providing possible phenomena that may help students learn ideas and develop their understanding; and identifying strategies for effectively representing the concepts based on previous learning research. We include these aspects in the unpacking process because they help to create the specificity that is needed to guide the development of assessments and learning tasks.

Table 1 shows the unpacking of a critical idea associated with the selected big idea. This critical idea states that electrical forces govern interactions between atoms and molecules. Space

prohibits us from providing more information (see Stevens, Sutherland & Krajcik, 2009 for additional information).

**Table 1: Unpacked ideas for critical idea electrical forces govern interactions between atoms and molecules.**

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**Electrical Forces**

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- Electrical forces depend on charge. There are two types of charge—positive and negative. Opposite charges attract; like charges repel
- The outer shell of electrons is important in inter-atomic interactions. The electron configuration in the outermost shell/orbital can be predicted from the Periodic Table.
- Properties such as polarizability, electron affinity, electronegativity affect how a certain type of atom or molecule will interact with another atom or molecule. These properties can be predicted from the Periodic Table.
- Electrical forces generally dominate interactions on the nano-, molecular and atomic scales
- The structure of matter depends on electrical attractions and repulsions between atoms and molecules
- An ion is created when an atom (or group of atoms) has a net surplus or deficit of electrons
- Certain atoms (or groups of atoms) have a greater tendency to be ionized than others
- A continuum of electrical forces governs the interactions between atoms, molecules and nanoscale objects.
- The attractions and repulsions between atoms and molecules can be due to charges of integer value, or partial charges. The partial charges may be due to permanent or momentary dipoles.
- When a molecule has a permanent electric dipole moment, it is a polar molecule.
- Instantaneous induced dipole moments occur when the focus of the distribution shifts momentarily, thus creating a partial charge. Induced-dipole•induced-dipole interactions, result from the attraction between the instantaneous electric dipole moments of neighboring atoms or molecules.
- Induced-dipole•induced-dipole interactions occur between *all* types of atoms and molecules, but increase in strength with an increasing number of electrons.
- Polarizability is a measure of the potential distortion of the electron distribution. Polarizable atoms and ions exhibit a propensity toward undergoing distortions in their electron distribution.
- In order to predict and explain the interaction between two entities, the environment must also be considered

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(Adapted from Stevens, Delgado, & Krajcik, in press)

Understanding students' ideas is critical in determining when and how it might be appropriate to introduce the concepts to students. In addition, knowledge of student non-normative ideas aids the development of assessments that measure students' progress. Thus, including both will aid developers of instructional materials and assessment. Table 2 shows some of the potential non-normative ideas students hold regarding electrical forces. See Stevens, Sutherland and Krajcik (2009) for additional non-normative ideas.

**Table 2: Potential non-normative ideas students hold regarding electrical forces**

- Students may believe that charge-charge interaction results in neutralization, not bond formation. (Boo 1998; Pallant & Tinker, 2004)
- Students often do not know the forces responsible for holding particles together in the liquid or solid state (Stevens, Shin, Delgado, & Krajcik, 2007)
- Hydrogen bonds occur between two hydrogen atoms (Taber and Coll, 2002)

### **III c. Creating Claims Linked to the Construct**

The unpacking results in declarative statements of that understanding and does not specify the type of reasoning students need to engage with those ideas. To be useful as a guide to the development of assessment and instructional materials, standards need to specify how students will make use of that declarative knowledge. An important part of student learning involves the ability to connect ideas and apply knowledge to new situations (Bransford, Brown & Cocking, 1999). Based upon the unpacked big idea (see Figure 1, step 2), we create set of claims that specifies the kinds of reasoning students should be able to do with the content (e.g., solve problems, make observations, and construct explanations). As such, claims specifically define what cognitive activities students will need to apply to show that they have meaningful understanding of the content. To define the cognitive activities that students will apply, we draw upon the scientific practices specified in the habits of mind (AAAS, 1993), the science inquiry standards (NRC, 1996) and the various cognitive activities from the revised Bloom's Taxonomy (Anderson & Krathwohl, 2001). For example, students should be able to provide examples of phenomena, explain patterns in data, or develop and test hypotheses.

One way to think about how to make claims is to integrate critical science ideas with a particular cognitive activity. The first three columns in Table 3 illustrate this process. In this example, students use their understanding of intermolecular forces and the imbalance of electrical charge (critical idea) to construct an explanation (cognitive activity) of why two

objects attract each other. This process builds from earlier work performed by Krajcik and colleagues (Krajcik, McNeill & Reiser, 2008) to develop learning performances.

#### **III d. Specifying Evidence for Claims.**

The next step for defining standards involves deciding on what evidence you will accept as proof that student understanding adequately meets the claim (see Figure 1, step 4). The evidence specifies the aspects of student work (e.g., behaviors, performances) that would be indicative that a student has the desired knowledge to support a specific claim or set of claims. It is important to realize that the evidence will change depending on the student level. Often the same claim can be used for students at different levels but how students respond to the tasks and what evidence we will accept for an appropriate response will change with the level. This step helps to further specify the expected level and depth of understanding that the target learners should demonstrate.

The fourth column in Figure 3 shows an example of evidence for the claim (see Short, Lundsgaard, & Krajcik, 2009 for further details). The evidence we describe is for a student at the senior high school level. In specifying the evidence, researchers and designers need to link back to the unpacking to specify the evidence that is needed at a particular the level. This is why unpacking the content idea and determining what students can understand at various levels is such a critical aspect of the CCD process, as it is specifies the evidence that is needed for determining if students have the level of understanding in the claim. It is important to realize that at a less advanced level (a middle grade band), the evidence for the claim would be less sophisticated. As the example illustrates, engaging in the process of developing claims and evidence requires serious consideration of both content and the type of the cognitive activity we want students to engage in.

**Table 3: Example of one claim for electrical forces, the associated evidences, and the task used to illicit such evidences.**

<b>Critical Idea</b>	<b>Cognitive Activity</b>	<b>Claim</b>	<b>Evidences</b>	<b>Task</b>
Intermolecular Forces	Construct an Explanation	Students will be able to explain attraction between two objects in terms of the production of opposite charges due to imbalance of electrons.	<p><i>Student work product will include:</i></p> <ul style="list-style-type: none"> <li>- Students explain the production of charge by noting that only electrons move from one object to another object.</li> <li>- Students note that neutral matter normally contains the same number of electrons and protons.</li> <li>- Students note that electrons are negative charge carriers and that the destination object of the electrons will become negative, as it will have more electrons than protons.</li> <li>- Students recognize that protons are positive charge carriers and that the removal of electrons causes the remaining material to have an imbalance in positive charge.</li> <li>- Students cite the opposite charges of the two surfaces as producing an attractive force that hold the two objects together.</li> </ul>	<p><i>Learning Task:</i> Students are asked to predict how pieces of tape will be attracted or repulsed by each other.</p> <p><i>Assessment Task:</i> Students are asked to explain why the rubbing of fur against a balloon causes the fur to stick to the balloon.</p>

Specifying claims and evidence are a critical part of the development of standards as they provide the performance expectations for students at a particular level. In addition, clearly representing the knowledge and skills students should develop provides a guide for the coherent development of instructional materials and assessment.

#### **IV. Developing and Reviewing Products.**

The rest of the CCD process is for developing products based upon the claims and evidence (see Figure 1, step 5). In our work, we have used CCD to develop four types of products: student materials, teacher materials, assessments and learning progressions. To illustrate how standards specified in the manner supported by the CCD process, we will briefly discuss designing an assessment task to illustrate the complete process. A similar process can be used for the development of learning tasks.

#### **IV a. Designing assessment tasks**

A key aspect of our work is the design of assessment tasks. Assessment tasks measure whether learners' hold the knowledge and skills stated in the claim and can be used formative and summative purposes. The assessment tasks are designed to elicit or generate students' performances to allow for a judgment to be made about whether sufficient evidence exists to support the learning *claim*. A single assessment task may provide evidence for more than one claim, but multiple assessment tasks may be necessary to assess a single claim. The last column in Table 3 shows an assessment task aligned with the claim and evidence in the table. In this example, students are expected to explain why the rubbing of fur against a balloon causes the fur to stick to the balloon. For a student to demonstrate an understanding of the claim, their response must include the evidence described above in 4<sup>th</sup> column of Table 3.

#### **V. Review Products**

The last step in the CCD process involves reviewing the products. For each step within this iterative process, the products must be reviewed internally and when appropriate, externally (see Figure 1, step 6). The internal review focuses on critique and revision of the products to ensure that they align with the claims and evidence. In reviewing assessment items, we also evaluated the items using the criteria of sufficiency, necessity and age appropriateness (Deboer, et al., 2008). External review includes feedback from teachers of the target students or from content or assessment experts. Conducting pilot tests and field trials with target students is an essential component that provides invaluable information about the products.

#### **VI. Relation to other Standards documents.**

As a component of this paper, we were also asked to examine the draft versions of the common core standards for 12th grade English and mathematics developed by the Council of

Chief State School Officers (CCSSO) and the National Governors Association. We do want to stress that we are not experts in mathematics and English education and that our research focuses on science education. As such, we are responding as non-experts to these documents.

With respect to the common core standards for 12<sup>th</sup> grade English we were pleased to see that they were written in the form a performance as performance describe how knowledge should be used. For instance, in the *Core Standards for Writing*, Standard 4 under *Standards for Student Performance* (page 2b) states: “support and illustrate arguments and explanations with relevant details, examples and evidence.” The *Standards for Student Performance* go on to state that when writing arguments students also need to “establish a substantive claim, distinguishing it from alternative or opposing claims” and “link claims and evidence with clear reasons, and ensure that the evidence is relevant and sufficient to support the claims.” These two following statements further clarify the above standard; however, we still believe that further unpacking of these ideas is necessary. What is missing is the evidence that necessary to determine if the student actually has met the standards. In addition, what is the evidence would show that a learner has met the performance? What would it look like to link claims with evidence and reason at a particular level? We see this document missing the unpacking of the standard and what is the evidence that learners met a performance at a particular level (in this case, the 12<sup>th</sup> grade level).

The reason we highlight these standards in the 12th grade English document is that these standards matches closely what the science education students should do with claims, evidence and reasoning scientific explanation and arguments. If the idea of using arguments/scientific explanations could build through the curriculum, learners would graduate with a much deeper sense of what it means to construct an argument. Although the forms of the claims, evidence and

reasoning would take on different forms, depending on the discipline (history, language arts, science), the idea of what an argument is would be developed. Such an approach would equip learners with deep and useful literacy skills required for the 21<sup>st</sup> century.

We also examined the Core Standards for Mathematics. Here the mathematical ideas are unpacked. See for instance the elaboration of the core concept of modeling on page 14. The mathematics group also then goes on to specify the skills or performance expected of learners.

## VII. Concluding Reflections

To make progress in the teaching and learning of all disciplines, highly specified and rigorous standards need to be developed, which will support the design of coherent curriculum materials and assessments. Using a framework based on what is known about student learning, we chose the construct-centered design process to illustrate an approach for developing such standards. Our process involves the following steps:

- 1) Select and identify the Big Ideas of a discipline (including ideas that link across disciplines)
- 2) Articulate the Big Idea
  - a. Unpack the Big Idea to specify critical concepts
  - b. Specify upper and lower levels and begin to specify intermediate levels
  - c. Identify non-normative ideas
  - d. Describe student challenges in learning the ideas at that level.
- 3) Create claims in terms of performances
- 4) Specify the evidence that shows that students have understanding of a claim at a particularly level.
  - a. Further specify levels of student development.

The CCD approach starts by selecting ideas in the disciplines that have explanatory power that allow students to explain a range of phenomena they experience in their lives. The approach goes beyond stating declarative statements and goes beyond stating students will “understand” to specify how the knowledge will be used in terms of performances in which students use the

content idea to solve problem, explain phenomena, and build models. The approach focuses on clearly defining the *evidence* that students need to demonstrate to show they met the claim. The evidence associated with the claim and based upon the unpacking of the construct is a unique characteristic of the approach. Developing standards to this level of specificity and including non-normative student ideas and potential difficulties students may have learning the content will help developers and teachers in creating assessments and instructional materials.

We see the approach as responsive to criteria that Wilson and colleagues outlined in *Systems for State Science Assessments* (NRC, 2006). Although the process is not complete or fully developed, we hope it provides a model that others can use and can further elaborate.

## References

- AAAS. (1993). *Benchmarks for science literacy*. New York, NY: Oxford University Press.
- AAAS. (2001). *Atlas of scientific literacy*. Washington, DC: American Association for the Advancement of Science.
- Bransford, J. D., A. L. Brown, et al., Eds. (1999). How people learn: Brain, mind, experience and school. Washington, D.C., National Academy Press.
- Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: National Academies Press.
- Krajcik, J., McNeill, K. L., Reiser, B., (2008). Learning-Goals-Driven Design Model: Developing Curriculum Materials that Align with National Standards and Incorporate Project-Based Pedagogy. *Science Education*, 92(1), 1-32.
- McNeill, K. L. & Krajcik, J. (2007). Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations. In Lovett, M & Shah, P (Eds.) *Thinking with data: The proceedings of the 33rd Carnegie symposium on cognition*, pgs 233 - 265. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- National Research Council . (1996). *National science education standards*. Washington, DC: National Research Council.

- National Research Council. (2006). *Systems for state science assessment*. Washington, DC: National Academies Press.
- Messick, S. (1994) 'The Interplay of Evidence and Consequences in the Validation of Performance Assessments', *Educational Researcher*, 23(2), 13-23.
- Mislevy, R. J. and Riconscente, M. (2005) *Evidence-centered assessment design: Layers, structures, and terminology*, Menlo Park, CA: SRI International.
- Pellegrino, J. W., Chudowsky, N., & Glaser, R. (2001). *Knowing What Students Know: The Science and Design of Educational Assessment*. Washington, DC, National Academy Press.
- Smith, C. L., Wisner, M., Anderson, C. W. and Krajcik, J. (2006) 'Implications of research on children's learning for standards and assessment: A proposed learning progression for matter and the atomic molecular theory', *Measurement: Interdisciplinary Research and Perspectives*, 4 (1), 1 – 98.
- Short, H., Lundsgaard, M.F.V., & Krajcik, J.S. (2009). The Development of Argumentation Skills and Content Knowledge of Intermolecular Forces Using a Nanoscience Context. Poster session at the Annual Conference of the National Association for Research in Science Teaching (NARST); Garden Grove, CA, April 17-21.
- Schmidt, W. H., Wang, H. C., & McKnight, C. C. (2005). Curriculum coherence: An examination of us mathematics and science content standards from an international perspective. *Journal of Curriculum Studies*, 37(5), 525-559.
- Shwartz, Y., Weizman, A., Fortus, D., Krajcik, J., & Reiser, B. (2008). The IQWST experience: Coherence as a design principle. *The Elementary School Journal*, 109(2), 199-219.
- Shin, N., Stevens, S. Y., & Krajcik, J. (in press). *Using Construct-Centered Design As A Systematic Approach For Tracking Student Learning Over Time*. Routledge, Taylor & Francis Group, London.
- Smith, C. L., Wisner, M., Anderson, C. W. and Krajcik, J. (2006) 'Implications of research on children's learning for standards and assessment: A proposed learning progression for matter and the atomic molecular theory', *Measurement: Interdisciplinary Research and Perspectives*, 4 (1), 1 – 98.
- Stevens, S., Sutherland, L., & Krajcik, J.S., (in press). *The Big Ideas of Nanoscale Science and Engineering*. Arlington, VA: National Science Teachers Association Press.
- Stevens, S. Y., Delgado, C. & Krajcik, J.S. (in press). The Development of an Empirically Derived Multi-Dimensional Learning Progression for Atomic Structure and Inter-Atomic Interactions. *Journal of Research in Science Teaching*.
- Wiggins, G. P., & McTighe, J. (1998). *Understanding by design*. Alexandria, VA: Association for Supervision and Curriculum Development.

Wilson, M. (2005). *Constructing Measures: An Item Response Modeling Approach*.  
Mahwah, NJ: Erlbaum.