Design Strategies for Developing Science Instructional Materials[1]

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1. Introduction: Need for new instructional materials

Instructional materials can serve as learning materials for both students and teachers. They can serve a primary source of science content, present specific views about the nature of scientific practices, and how scientific knowledge is developed. Materials can also serve as a primary influence on how teachers should teach science. Yet, several reviews of curriculum materials have presented a rather grim view of the value of science instructional materials. AAAS's Project 2061 undertook an ambitious review of middle school curriculum materials to determine how currently available learning materials align with national learning goals and pedagogical criteria rooted in the literature (Kesidou & Roseman, 2002). They found that the middle and high school programs that they examined were unlikely to result in students developing understandings of key learning goals (Kesidou & Roseman, 2002). Their critique showed that the materials covered many topics at a superficial level, focused on technical vocabulary, failed to consider students' prior knowledge, lacked coherent scientific explanations of real-world phenomena, and provide students with few opportunities to develop explanations of phenomena. Clearly, there is a need for instructional materials that align with national science education standards and that take into account what is known about the teaching and learning of science, for all students regardless of culture, race, or gender. To address this important need, we are designing middle school materials that align with national standards, are structured around the ideas of project-based science (Krajcik, Czerniak, & Berger, 2002), and use ideas from current findings in research on learning, instruction and assessment as major design principles (Bransford, Brown, & Cocking, 1999; Pellegrino, Chudowsky, & Glaser, 2001).

1.1 Project goals

The goals of this project include developing, testing and revising the next generation of middle school curriculum materials that support urban, suburban and rural students in learning important science content based on national standards. We strive to design these materials based upon a research base of work on design, cognition, and social interaction in the learning of science

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(Bransford et al., 1999; Pellegrino et al., 2001). In the first phase of our project, we are developing two units for middle school students as a means to develop and study a framework for project-based units and a process to design them. The two units encompass two different types of scientific investigation, experimental and observational/historical investigations, and engage students in multiple ways of learning content through inquiry, including generating explanations, designing experiments, modeling phenomena, analyzing data, and engaging in scientific argumentation.

One unit engages middle school students in developing understandings around substances and their properties, the nature of chemical reactions and the conservation of matter. The second unit engages students in developing understanding of species interactions in ecosystems, including structure/function and adaptation, competition, and natural selection. The materials engage teachers and students in one semester of ambitious meaningful inquiry-based science teaching and learning. The materials include student readers of *considerate text* that link to classroom activities, investigations that engage students in learning the content, and varied assessments that probe student understanding.

Another goal for the project is to investigate mechanisms for curriculum-focused professional development. One way in which we will provide professional development is through making the materials educative for teachers (Ball & Cohen, 1996). We will also provide an on-line resource that addresses issues of both content and pedagogy through case libraries of teaching practice (Brunvand, Fishman, Marx, & Maybaum, 2002; Fishman, in press; Shrader & Gomez, 1999).

This paper reports on the design principles and processes we used to develop the instructional materials. We will also discuss major challenges faced in the design process. Other papers report in this session report on the individual units and (McNeill et al., 2003; Tzou et al., 2003) and professional development process (Fogelman, Marx, & Fishman, 2003).

1.2 Design principles

We have designed the units around a system of key design principles for supporting ambitious learning in science. These principles are based on our prior research (Edelson, Gordin, & Pea, 1999; Reiser et al., 2001; Singer, Marx, Krajcik, & Chambers, 2000) and build on the literature on student learning, instruction and assessment (Bransford et al., 1999; Pellegrino et al., 2001). Below we present a short description of each of these principles.

Structuring Units around Learning Goals: We begin by identifying the content learning goals for each unit, habits of mind, the nature of science, and the prerequisite knowledge that students need. Our goal is to have children learn a few standards in depth rather than superficially. The learning outcomes specify in general what we want students to understand. However, they do not specify how students use that knowledge in tasks. We construct learning performances

(Perkins, 1998) (described below), to redefine the scientific idea in the standard in terms of the knowledge and skills that are the target of learning. We identified a range of performance that varied from description and explanation to more ambitious uses of knowledge such as application to new contexts. Without identifying the performances we expect, it is difficult to design for and assess the deeper conceptual understanding required by new standards.

Motivating and Contextualizing the Inquiry: Both the chemistry and ecosystems units are structured around investigations that require students to apply concepts and strategies to investigate a rich set of data. Students ask questions, plan experiments, and collect, analyze and share data and information. The investigations also allow students to experience scientific phenomena and processes, and to examine new information.

Driving questions. The context for the inquiry is created through the use of a driving question, a rich, open-ended question that connects with authentic interests and curiosities students have about the world (Blumenfeld et al., 1991; Singer et al., 2000). The science concepts and skills are key to understanding and answering the driving question. The science is learned in the context of its application to meaningful problems (Edelson, 2001). As the materials are field tested, we modify the driving question to reframe it into a question about which students care and find motivating.

Real World Phenomenological Experiences. We use anchoring events to help students apply their scientific understandings to the real world. An anchoring event might engage students in observations of their environment or it might also be an initial investigation.

Literacy Links. We attend to scientific literacy issues such as highlighting how scientific language, discourses, and writing genres differ from the technical discourses of other content areas and from everyday discourse. We provide multiple opportunities for students to predict, observe, and explain their ideas about scientific phenomena in oral and written discourse.

Preparing Students for Inquiry: Helping students develop understanding of subject matter requires that teachers know what students already understand and believe about the world. These prior conceptions serve as foundations for building new understandings. Teachers can only use students' prior knowledge if they know what it is. We use prior research and analyze student conceptions in our pilot work. For instance, in chemistry, we know that students are likely to hold a continuous model of matter rather than a particulate model. Contextualization activities help relate the ideas to be learned to students' prior ideas. For example, benchmark lessons and bridging activities challenge students to make predictions or explain findings and elicit prior understandings on which new understandings can be built (Edelson et al., 1999; Krajcik et al., 1998), and staging activities help students develop investigation strategies in more teacher-directed and structured contexts (Reiser et al., 2001).

Supporting Inquiry: To support students in inquiry we use several strategies that support learners in these practices, which may be unfamiliar.

Learning technologies. The learning technologies we use mirrors those used by scientists but are designed for learners (Edelson et al., 1999; Krajcik, Blumenfeld, Marx, & Soloway, 2000; Reiser et al., 2001). Learning technologies help students and teachers communicate, explore phenomena, find information, conduct investigations, analyze and visualize data, develop products and communicate with others. To involve students in authentic inquiry, we need to provide them with more powerful tools than have been traditionally available, so they can access, analyze, and interpret scientific data.

Collaboration and Discourse. One of the most compelling aspects of project-based pedagogy is its emphasis on dialogue and collaboration among students, an emphasis that supports several science education standards. The opportunities to engage in dialogue and collaboration available in project-based pedagogy speak specifically to standards related to (a) communicating scientific procedures and explanations, (b) asking questions and querying other scientists' explanations as a part of developing legitimate skepticism, and (c) recognizing science as a human endeavor (American Association for the Advancement of Science, 1993; National Research Council, 1996).

Scaffolds. Scaffolds are instructional supports that allow students to take part in tasks that otherwise would be less accessible or productive. Scaffolds are designed to help guide learning as students are introduced to science concepts and processes. Teachers scaffold learning by sequencing, modeling, coaching, and giving feedback. Scaffolded learning materials reduce complexity and highlight concepts and inquiry strategies. For instance, in both the chemistry unit and biology units, we scaffold students constructing and articulating scientific explanations.

Anchored in Multiple and Varied Phenomena and Representations: The materials allow students to have experiences with varied phenomena and representations. Science is about explaining phenomena. Without experiencing the phenomena either through first-hand experience when feasible or vicariously when not feasible, students just learn empty words. Students need to experience phenomena to have a concrete representation to tie the various explanations together. Students experience the phenomena in various investigations, anchoring events, staging events and benchmark lessons. The materials provide learners with multiple and varied representations of the learning outcomes. Representations provide various ways for students to interpret and make sense of scientific ideas. The units provide opportunities for students to see and investigate numerous phenomena and representations.

Artifacts and Culminating Activities: Throughout the units, embedded assessments allow students to create artifacts or products. Artifacts represent students' emerging understanding of the content (Blumenfeld et al., 1991). Artifacts are created as students conduct investigations. Artifacts include the products that students create as they do investigations, and provide a representation of what students have learned. Students create artifacts that can be shared, critiqued, and revised to further enhance understanding and serve as a basis for assessment (Loh et al., 2001).

Designing for Diversity: Students may bring particular kinds of knowledge and experience that are unique to their cultural, ethnic, and socioeconomic backgrounds (Moll, 1988). Students may also lack the prior knowledge and experience necessary to engage in dialogue and collaboration around particular scientific concepts simply because they have not had access to certain experiences (Rodriguez, 1997). In addition, students may bring epistemological stances and ways of knowing that diverge from those valued in science classrooms and communities. We use several strategies that make instructional materials accessible to students and that teach science in deep and meaningful ways. The strategies draw from, incorporate, extend, and challenge students' community-based ways of knowing and funds of knowledge, such as locating community problems related to the concepts under study, engaging youth in specific activities related to those problems (Merino & Hammond, 1998) and involving parents and community members as classroom participants who discuss their knowledge and experiences regarding science concepts and related community problems.

1.3 Core Design Tensions

The goals of meeting content standards and integrating inquiry pose a number of challenges that we will examine in this paper. Our work considers how to develop contextualizing contexts that truly meet the content standards identified. The learning focus that emerges as students become embroiled in problem scenarios may take the learning in directions not guaranteed to address the content standards. In addition, it is often difficult to construct a contextualizing problem in ways that address all the content needed, perhaps due to practical and safety constraints, what data is available, what phenomena are accessible in the classroom, or that problems in the world relevant to the target content may require too much additional background instruction to be worth the cost. Our research on blending inquiry and content goals examines these tensions, and develops strategies for addressing them in design.

2. Design Framework

In designing the units, we used a process called *assessment-driven design*, also termed *backwards design* by Wiggins and McTighe (1998). The central idea is to identify learning objectives and use the objectives to guide all phases of curriculum and activity design, continuously evaluating whether the activities are aligned with the target objectives. We combine these guidelines about process with considerations for criteria of sound pedagogy the curriculum needs to exhibit, drawn from the analytical procedure from Project 2061 (Kesidou & Roseman, 2002), such as taking account of students' prior conceptions, providing first hand experience with phenomena, providing a sense of purpose connected to the target science in each activity, and so on.

Although the idea of clearly identifying learning objectives is not new, and is a critical step in any good instructional design, the value in these approaches is to provide guidelines to critically evaluate the alignment between activities and standards at each step in the design. As we shall describe, our adaptation of this process places a high value on an articulation of target performance in advance of generating specific learning activities connected to a standard. The aim in these approaches is to avoid generating what Wiggins and McTighe (1998) critique as sequences of learning activities, loosely connected thematically to a topic, but without clear connections to specific learning goals. For instance, several water quality units have been developed that, while engaging students in potentially interesting and valuable activities by analyzing water quality data, do not consider learning outcomes and are not structured to ensure that students meet core learning outcomes.

Our assessment-driven design process includes several steps: 1) identifying and clarifying learning outcomes linked to national standards, 2) specifying learning performances to meet standards, 3) creating assessments and rubrics linked to the learning performances, 4) identifying learning tasks, 5) contextualizing the unit though a driving question and anchoring events, 6) producing an instructional sequence including both student and teacher materials, 7) pilot testing materials and 8) receiving feedback from teachers and external reviewers. Although we list these steps in a linear fashion, the process is dynamic with later components in the design process, such as instructional sequence, feeding back to inform earlier components, such as learning performance. Figure 1 illustrates the iterative nature of the process.

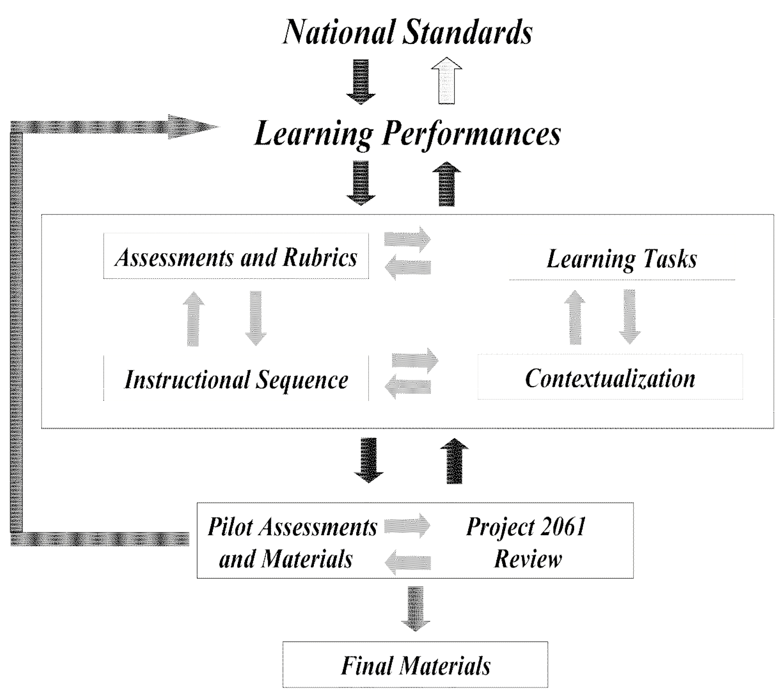

Figure 1. Our Assessment-Driven Design Process

2.1 Identifying cluster of standards

The first step in the design process is the identification of key learning goals linked to national science education standards, including the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993), the *Atlas of Scientific Literacy*, (American Association for the Advancement of Science, 2001), and the National Science Education Standards (National Research Council, 1996). Using these documents along with other documents such as *Making Sense of Secondary Science* (Driver, 1994), we created a concept map of key learning goals, prerequisite understandings, common student misconceptions, and understandings that went beyond the learning goals for the two key content areas selected. The maps helped us select the key learning goals on which to develop the units. Figure 2 shows a concept map of the standards selected for the species interaction in ecosystems unit.

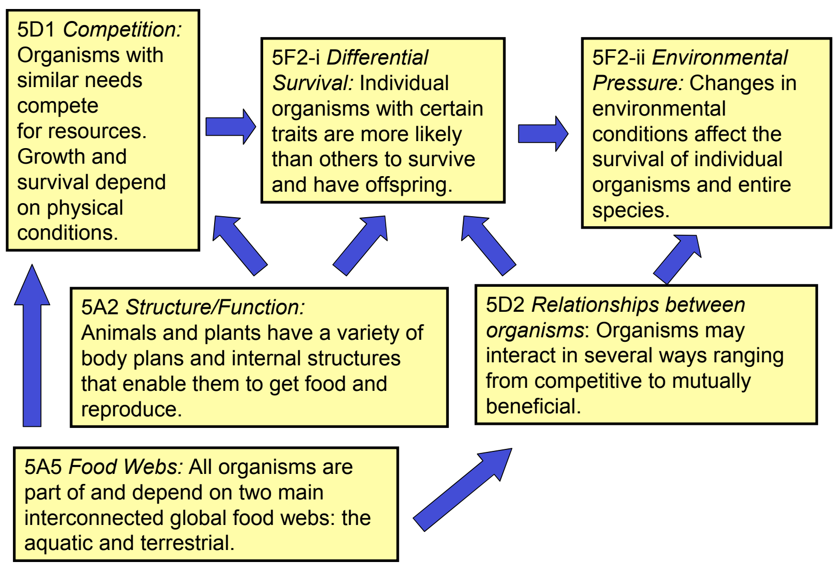

Figure 2. The benchmark map for the ecosystems unit

As a part of selecting the standards and constructing the map of their relationships, we clarified the meaning of each standard. Furthermore, later steps pushed us to continuously clarify what the standard means in terms of a precise statement of the science we want students to be able to use in reasoning. Considering how scientific ideas interrelate and in what kind of problem context students would apply this understanding in a range of cognitive performances forced us to resolve ambiguities in the description of the scientific idea and make additional aspects of understanding explicit. We used various resources including *Science for All Americans* (American Association for the Advancement of Science, 1990) to debate, clarify and elaborate on the intended science content in each of the benchmark. Figure 3 shows the clarification of one standard from the chemistry project.

4D: 1 – Part II Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances (AAAS, 1993).	Atoms can be arranged in particular ways including the formation of discrete molecules and arrays. A molecule is made up of atoms stuck together in a certain arrangement. An array has repeated patterns of atoms. The different arrangements of atoms give materials different properties. Materials with unique properties are different substances.

Figure 3: Clarification of a standard from the chemistry project

Often these debates and elaborations lead us to realize that some key understanding was missing in our concept maps. For instance, in clarifying the SFAA benchmark that states:

> When substances interact to form new substances, the elements composing them combine in new ways. In such recombinations, the properties of the new combinations may be very different from those of the old (AAAS, 1990, p.47; AAAS, 2001).

We realized that we had no learning goals related to students understanding what a property is. We found a learning outcome in the National Science Education Standards that would meet this need, and included it as a key constituent in our standards map.

> A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample (NRC, 1996, p.154)

2.2 Learning performances

The next step is to identify a set of task performances that represent the understanding targeted in a standard. Building on Perkins' notion of understanding performances (Perkins, 1998), we call these *learning performances* to refer to the types of tasks and associated criteria that we establish as the instructional objectives. If we want to be able to assess whether students have mastered a standard, we need to translate the declarative statement of understanding into a set of observable behaviors. We need to move from the standards, which are a description of the scientific ideas, to an articulation of the knowledge and skills we want students to acquire. There are several arguments for moving from benchmarks to learning performances in guiding activity and assessment design. Our notions of learning performances build on the articulation of understanding performances by Perkins, our own work on inquiry processes (Edelson et al., 1999; Krajcik et al., 2000; Loh et al., 2001; Reiser et al., 2001; Sandoval, 2003), and the revision of Bloom's taxonomy (Anderson & Krathwohl, 2001).

The first point is that it is simply good practice in instructional design to be explicit about instructional objectives. While understanding may be our goal, we need to be explicit about what kinds of behavior we would take as evidence of understanding. In this view, learning performances illustrate the understanding we target as designers.

Second, understanding requires rich disciplinary specific applications of knowledge (Perkins, other refs). Learning is more than simply acquiring declarative content for use with general-purpose procedures. Learning involves building problem-solving structures within the discipline, and requires experience practicing the application of these processes (Collins & Ferguson, 1993; Reiser et al., 2001; Sandoval, 2003). Learning involves acquiring and participating in new sets of practices. For example, students need to learn to make arguments from experimental data, to propose arguments that can distinguish between interpretations of data, and so on. It is important to specify these processes as explicit learning objectives. Furthermore, these types of practices depend in part on the type of content. For example, building a scientific argument represents a fundamentally different set of processes when arguing from a sequence of experiments in an experimental science (such as microbiology or chemistry) from the process of constructing an argument from a synthesis of data comparisons (e.g. in arguing from earthquake or ecosystems data). Thus, identifying the specific performances that represent conceptual understanding and inquiry learning and the connection of these practices to types of content is key to the approach.

A third importance of learning performances arises from concerns about the educational reform challenges. Specifying learning performances makes explicit the changes in learning advocated in current science education reforms. One aspect of reforms is to create opportunities for more ambitious learning for all learners. An important step in implementing the reform is to articulate some consensus around what is to be learned, the motivation for the standards movement (NRC, AAAS). However, we need to go beyond descriptions of the science if we want to change the nature of what it means to learn science. Consider a standard, such as one of the benchmarks about ecosystems.

> Two types of organisms may interact with one another in several ways: They may be in a producer/consumer, predator/prey, or parasite/host relationship. Or one organism may scavenge or decompose another. Relationships may be competitive or mutually beneficial.

What do we mean by the understanding connected to this benchmark? Is our goal that students can recall the types of species interactions? Do we want them to be able to classify a pair of species, given a description of their behaviors, into one of these categories (predator/prey, parasite/host, etc.)? Or do we have more ambitious goals, that require applying the understanding to make sense of real problems, such as predicting how changes in one species would affect another based on the type of relationship between them? In order to be precise as to what kind of reasoning we want students to be able to do, we articulate learning performances for each of our benchmarks, that distinguishes between performances such as categorize, explain patterns, make predictions and so on.

Typically we construct several learning performances connected with each standard, representing a range of reasoning using that scientific idea. For example, the following benchmark is unpacked into three different performances.

Differential survival: Individual organisms with certain traits are more likely than others to survive and have offspring (5F2-i).

Learning performances:

- Students *identify and represent mathematically* the variation on a trait in a population.
- Students *hypothesize* the function a trait may serve and *explain* how some variations of the trait are advantageous in the environment.
- Students *predict, supported with evidence,* how the variation on the trait will affect the likelihood that individuals in the population will survive an environmental stress.

These performances then guide the design of activities. We create activities that provide the opportunity for students to practice, with support, these performances. The learning performances also guide the design of assessments, which are meant to identify whether students can successfully accomplish the performance, either in the learning activity itself (embedded assessments) or in assessments that follow the learning.

2.3 Assessment and activity design

Using the learning performance, we then identify key learning tasks that could serve as assessments of student understanding. Once learning tasks were identified we then created a base rubric that could be used across the entire project.

For instance, for the learning outcome:

> When substances interact to form new substances, the elements composing them combine in new ways. In such recombinations, the properties of the new combinations may be very different from those of the old (AAAS, 1990, p.47).

We identified the following learning performance:

> Students design an experiment to determine whether a chemical reaction occurred. They make predictions about what will happen, carry out their investigation, and explain how the evidence supports their conclusion that a chemical reaction either did or did not occur.

We next created the following learning task:

> In groups, students make soap by combining lard and sodium hydroxide over a heat source. After making the soap, students test the solubility, melting point, density, hardness, and color of the soap and of the lard. Then they use this data to write a scientific explanation. Students' explanations include a claim whether fat and soap are the same substance, provide evidence in the form of properties, and reasoning that lard and sodium hydroxide interacted to form a new substance, soap, which has very different properties from the reactants.

Finally, we created a base rubric:

	Level 1	Level 2	Level 3
Make a claim about the problem.	No claim or inaccurate claim.	Partially accurate claim.	Accurate claim.
Provide evidence for the claim.	No evidence or inaccurate evidence.	Some accurate evidence, but not sufficient. May include some inaccurate.	Provides accurate and sufficient evidence.
Provide reasoning that links evidence to the claim and problem.	No reasoning or inaccurate reasoning.	Provides some reasoning, but not sufficient. May include some inaccurate.	Provides accurate and sufficient reasoning.

2.4 Contextualization

Contextualization provides students with a need to know and helps students realize how the work they are doing is important to their lives. When students see what they are learning as important and connected to their lives, it is more likely that they will spend the cognitive energy to develop deep understanding of the ideas. We use driving questions as one way to contextualize the learning of science. A driving question helps to show the value of what students are learning and introduces and structures the project. Driving questions are designed to be meaningful to students, encompass worthwhile content and are anchored in a real-world problem. We attempt to create driving questions that are rich and open-ended questions that use everyday language to connect with authentic interests and curiosities students have about the world. We also attempt to create driving questions that can be used to tie together ideas presented in the curriculum (Krajcik, Berger, & Czerniak, 2002; Krajcik et al., 1998). Driving questions create a "need to know" for the scientific ideas, in which the science becomes instrumental to making progress on a problem in which students have become interested (Edelson, 2001; Sherin, Edelson, & Brown, in press; Sherin, Edelson, & Brown, 2000). As a component of the unit work, we engage students in active construction of knowledge by involving them in investigations and artifact development that provide opportunities for students to learn concepts, apply information, and represent knowledge around the driving question. We also realize that many problem scenarios just will not simply "grab" middle school students. In such cases, we use anchoring events to help students see the value and get hooked into the driving question.

The driving question for the chemistry unit is "How can I make new stuff from old stuff." In order to respond to the driving question students need to gain understanding of the key learning goals. Selecting the appropriate driving question posed challenges to us because many questions that middle school students might be interested in had phenomena associated with them that were either too complex to experience in the middle school, too trivial and not exciting to children, did not directly match the learning goals, or to dangerous from a health perspective. For instance, we could not use activities that involved polymers and that many students could become engaged because the synthesis of many polymers contain carcinogenic materials. We also felt that phenomena such as mixing vinegar with baking soda would not be exciting and engaging for many students because they may have experienced it this phenomena in middle school. We settled on "How can I make new stuff from old stuff" because it allowed us to select a range of phenomena that students could experience. As the primary phenomena we selected making soap because the starting materials have properties very different than the end product. Realizing that many students might not find the question "How can you make new stuff from old stuff?" engaging, we start the unit with an anchoring event in which students touch and explore the properties of lard, a reactant necessary to make soap. We than ask students if lard could be made into soap. Many students have never touched or seen lard, and as a result this anchoring event was a good hook to engaging them in the driving question.

3. Evaluation and pilot review of materials

We are conducting two types of evaluations of the materials, analytical and empirical. The analytical review is being conducted by Project 2061 using their curriculum review procedures (Kesidou & Roseman, 2002). The analysis process is drawn from the curriculum analysis process described in materials available from Project 2061.[2] The central goals of this analysis are to evaluate the instructional support provided for the chosen benchmarks. The key criteria for

[2] http://www.project2061.org/tools/textbook/mgsci/analysis.htm

this evaluation (e.g., engaging learners with phenomena), are represented in the design principles that guide the design work.

A critical phase of the design cycle is the pilot classroom trials. We have several important goals for the classroom trails. Our questions focus both on the student learning and teacher practice perspectives. We are conducting these pilot trials with six teachers for each unit at three sites, Detroit, Chicago, and South Carolina.

In our pilot evaluations, we conduct observations of most of the lessons, video of key whole class discussions and small group work, collect student generated artifacts and teachers' assessments of students' written work, and administer a written assessment before and after the unit to examine improvement on the unit's learning performances. We are also conducting detailed interviews with students in one site to understand the challenges that unfamiliar practices in inquiry science may pose. We are particularly interested in practices for which some students' intuitive beliefs and values may diverge from the expectations of scientific practice, such as practices in arguing for a position, defending one's ideas with data, critiquing an argument, and so on.

Our goals for contextualizing the science in an extended inquiry project pose particular questions for our pilot evaluations. In particular, we are examining two related questions about the classroom enactments.

- Engagement in the driving question: Does the problem scenario work to engage learners? For example, are students motivated as they work on various aspects of the invasive species problem through several weeks of curriculum? We examine whether students retain interest in the problem, whether they continue to see the scenario as problematic and requiring investigation, whether they see the need and are able to connect what they learn to the problem scenario, and so on. We use field notes and videotapes to investigate these questions.

- Connection of science to the driving question: Apart from whether students are engaged in the scenario, we examine the effectiveness of the problem scenario as a context for learning the science. Even if students are engaged in the problem scenario content, students may see the science principles in lessons as unnecessary or may be unable to apply the science directly to the problem. We examine the effectiveness of the contextualizing context in terms of how well it works to motivate the specific science learning goals, and how well students are able to connect the science as they learn it to make progress on the problem context. Here we are particularly interested in if the context and instructional sequence we developed help students meet the learning goals. Pre and posttests, artifacts and interviews serve as the source of data for these questions.

We also focus on the teachers' perspectives, to understand their perceptions about the challenges and benefits for their students, and to examine the teaching challenges they face. The goal is to inform redesign both of the activities themselves and of more effective teacher support materials. To this end, we conduct weekly telephone conference calls with the pilot teachers in which they provide feedback on the challenge and successes of each lesson, as well as written feedback forms.

4. Challenges and Lessons Learned

We have identified a number of challenges for the creation of project-based science curricula from our design research attempting to blend project-based science with assessment-drive design. These challenges arise from the design tensions between the coherence of the contextualization and the need to address a collection of science standards and specific learning performances.

One challenge arises from the different goals inherent in creating science standards and problem contexts. There is a tension between the depth of a case-based approach and the breadth of defining scientific ideas. For example, consider the two benchmarks from our ecosystems unit.

- "In all environments—*freshwater, marine, forest, desert, grassland, mountain, and others*—organisms with similar needs may compete with one another for resources, including food, space, water, air, and shelter. In any particular environment, the growth and survival of organisms depend on the physical conditions." (AAAS, 1993, 5D1)
- "Two types of organisms may interact with one another in several ways: They may be in *producer/consumer*, *predator/prey*, or *parasite/host* relationship. Or one organism may *scavenge or decompose* another. Relationships may be competitive or mutually beneficial. Some species have become so adapted to each other that neither could survive without the other." (AAAS, 1993, 5D2)

These benchmarks are representative of the style of many science standards. Standards are written to codify important aspects of scientific ideas, and not as psychological models for the knowledge and skills that are learned. The benchmarks are written to enumerate all important exemplars of a concept or possible values of a category. For example the first benchmark lists six types of environments in which species compete, and five types of resources for which species may compete. The second benchmark lists four types of relationships between species. This encyclopedic nature of standards is in tension with the need to create a rich problem solving context that students pursue in some depth. In our ecosystems unit for example, we use an invasive species in the Great Lakes as problem context for one four-week part of the unit, and a crisis in the Galapagos Islands as a problem context for a second four week part.

The ecosystems unit teaches the concept of competition in the 5D1 benchmark, in part, by having students study how an invasive species affects native species, with whom it competes for food. Strict attention to the benchmark might suggest that the introduction of the notion of competition requires working through examples in all six types of ecosystems, and perhaps looking at competition for all five types of resources. For example, imagine introducing the notion of competition between species and then spending time to examine pairs of competing species from each type of environment. While some work through multiple examples is critical in order to generalize the understanding, doing so at the outset is in tension with developing the problem context and having students learn and apply this idea in some depth to that context.

We chose in our designs to focus on coherent "slices" through systems of benchmarks rather than exhaustively covering each benchmark as it is introduced. We have focused on ambitious learning performances that require analysis and application, and such learning goals require a sustained engagement with a problem context, rather than many quick excursions through different examples.

However, it is also important to help students examine the limits and extent of each scientific idea, and thereby construct appropriate generalizations from the cases. For example we do not want students believing that only animals compete and plants do not. Therefore we use a strategy, described by Tzou et al (2003), of building analogical comparisons between species as a core learning strategy. The unit develops the strategy of learning about what animals and plants need to survive with more familiar species so that students can map each new understanding to the invasive species problem. This process, along with readings following the activities that elaborate the core principles, enables us to achieve some of the breadth called for in the benchmarks, without creating an exhaustive excursion through all possible ecosystems and types of examples each time a new principle is introduced.

Although this same parsing of the benchmarks occurred in the chemistry unit, it appeared much either to find coherent slices because of the nature of the benchmarks. For instance, benchmarks 4D7 – Part 1, 4D1 – Part 11 and 4D7 – Part II seem to fit together as a whole.

4D7 – Part I

No matter how substances within a closed system interact with one another, or how they combine or break apart, the total weight of the system remains the same (AAAS, 1993).

4D: 1 – Part II

Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances (AAAS, 1993).

4D7 - Part II

The idea of atoms explains the conservation of matter: If the number of atoms stays the same no matter how they are rearranged, then their total mass stays the same (AAAS, 1993).

In part, this may be due to some interesting differences between the kinds of science represented by the two areas. The chemistry standards are written to express general principles; while the biology ecosystems standards also express general principles, they also take care to enumerate types of examples, such as types of biomes, animals versus plants, and so on, and there is important science content in understanding the differences between some of these exemplars (e.g., what makes an animal different from a plant).

A second type of challenge concerned the difficulties of crafting a project context. Developing a motivating project challenge is a difficult endeavor in and of itself. A project context has to elicit students' interest, has to sustain that interest over several weeks, has to be rich enough so that different groups of students can construct different solutions to the challenge (rather than all ending up with the same "answer"), and has to be tractable for learners (Blumenfeld et al., 1991; Edelson, 2001; Krajcik et al., 2000; Krajcik et al., 1998; Reiser et al., 2001). While meeting these challenges, we also have to construct a project context that succeeds in drawing together all the scientific standards.

As we explored project contexts and associated driving questions for the two units, we experienced a number of things that can and do go wrong (some of which we were able to debug in the design process, others were uncovered in the pilot phase).

There is not always the alignment between the organizations of science one constructs in doing a top-down decomposition of the scientific ideas, as in the benchmarks and the Atlas, and the way science comes together in the real world to comprise problems (Sherin et al., in press). So we sometimes construct problem contexts that work for treating some subset of the target benchmarks, but are not relevant for others. For example, our invasive species context enabled us to get to some but not all of the benchmarks show in Figure 2. We could find no examples of invasive species' impact on an ecosystem well enough studied for a long enough period of time that we could teach natural selection in this context. We found other examples of population level changes across time (mircoevolution) and so built another project scenario around the crisis in the Galapagos Islands. This worked reasonably well in this instance, in that we have two four week projects comprising a two month curriculum. However, given the extended nature of inquiry, it is not always possible to keep adding more subunits to address all the content needed, and there is a tension between finding contexts and covering what would otherwise seem to be a coherent cluster of benchmarks.

Another difference in the way the world carves up the science may arise in the background requirements for a problem context. For example, some invasive species we considered would have required too many excursions into other background content for the scenario to make sense to students. Designers have to weigh the benefits of the project content against its costs in content demands outside the target benchmarks.

It is also key that the context not only exemplify the target science ideas in principle, but that enough data exists and enough is known about the context to support student inquiry. For example, we found one invasive species that was quite dramatic (snakehead in Maryland), but not enough is known about it and there are too few examples of invasion (and hence not much data), so building a case around this example was not possible.

Similarly, a phenomenon may exemplify the target standard but its implementation may be too complex or not practical due to cost or safety concerns. As mentioned earlier, starting from chemistry questions that might interest students led to phenomena that were either too complex to experience, seemed trivial (although interesting science to chemists), or were dangerous.

Development of a project context must consider these challenges, and negotiate a balance between questions that interest students or problem scenarios about which interest could potentially be cultivated, and the constraints provided by the fit of the contexts to the learning goals.

5. Conclusions

In this paper we have presented a broad overview of how we blend an assessment-drive design process with the pedagogical approach of project-based science. Specific examples of how this process has shaped the development of project-based units is described by McNeill et al. (2003) and Tzou et al. (2003). In general, we have found this process a change from our previous design approaches that keeps us more focused on ensuring that the project inquiry address specific core scientific content. We have identified the tensions between this assessment-driven approach and the needs of designing engaging coherent project-contexts. On balance, our experience convinces us that it is possible to blend the two approaches to get the "best of both worlds," a project-based unit with an extended inquiry that provides a context for ambitious engagement with science content.

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