Middle School Science Curriculum: Coherence as a Design Principle

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Abstract

Coherent curricula are needed to help students develop deep understanding of important ideas in science. Too often students experience curriculum that is piecemeal and lacks coordination and consistency across time, topics, and disciplines. *Investigating and Questioning our World through Science and Technology* (IQWST) is a middle school science curriculum project that attempts to address these problems. IQWST units are built on five key aspects of coherence: 1) learning goal coherence, 2) intra-unit coherence between content learning goals, scientific practices, and curricular activities, 3) inter-unit coherence supporting multidisciplinary connections and dependencies, 4) coherence between professional development and curriculum materials (CM) to support classroom enactment, and 5) coherence between science literacy expectations and general literacy skills. Dealing with these aspects of coherence involves trade-offs and challenges. This paper illustrates some of the challenges related to the first three aspects of coherence and the way we have chosen to deal with them. Preliminary results regarding the effectiveness of IQWST's approach to these challenges are presented.

The science literacy reform and need of new curriculum

The on-going reform in science education calls for attainment of science literacy for all learners. Decreasing achievements of students in science (Institute of Educational Sciences, 2005) and declining numbers US citizens choosing a career in science, coupled with the growing demand for a scientifically proficient workforce (National Center for Education Statistics, 2003) calls for a change in the way science is being taught. Policy and position papers (AAAS, 1990, 1993; National Research Council, 1996; O'Sullivan, Lauko, Grigg, Qian, & Zhang, 2003; Schmidt, 2003) recommend the development of new curriculum materials that will promote scientific literacy. The recommendations focus on 1) coherence, 2) scientific inquiry, and 3) contextualization.

1. Focus on coherence: Science programs should integrate content and practices to support the coherent understanding of overarching ideas. Focusing on few fundamental scientific concepts and developing deep understanding of these concepts is recommended (Fensham, 2002; Yager & Weld, 1999). The concept of coherence will be broadly discussed in the following section.

2. Science as an inquiry-based discipline: Curriculum should be inquiry-based to introduce students to scientific practices which represent the disciplinary norms of scientists as they construct, evaluate, communicate, and reason with scientific knowledge (National Research Council, 1996). Inquiry-based curriculum can help students develop important habits of minds. These include taking into consideration evidence, looking for alternative explanation, question claims based on superficial characteristics, to name but a few (AAAS, 1993). Several pedagogies have been developed that implement this recommendation (Blumenfeld, Krajcik, Marx, & Soloway, 1994; Edelson 2001; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Kolodner et al., 2003; Songer, Lee, & Kam, 2002).

3. Contextualization: Students often do not see science as relevant to their life outside of class. Introducing scientific concepts in authentic and relevant contexts makes science meaningful, enhances intrinsic motivation, and fosters student learning (Blumenfeld & Krajcik, 2006; Blumenfeld et al., 1991; Deci & Ryan, 1987; Edelson, Gordin, & Pea, 1999).

In this paper we describe the IQWST middle school science curriculum, which aims to address all three recommendations. We discuss the design principles aimed at obtaining coherence, as well as the tensions and trade-offs that arise when all three recommendations are considered.

The concept of coherence

The literature refers primarily to three aspects of coherence. The first is learning goals coherence. Schmidt, Wang, & McKnight (2005) refer to coherence as a set of any particular ideas that must evolve particulars to deeper structures. The Atlas of Science literacy (AAAS, 2001) suggests a way for organizing and sequencing ideas to build a deep an interconnected understanding of concepts. However, there is little empirical evidence to support the development of curriculum to reflect the ideas as described in the Atlas.

The learning goals coherence should be reflected in curriculum and be developed both within a particular grade level and across grades. Schmidt, Wang & McKnight (2005) found that coherence of curriculum is the most dominant predictive factor of student learning as measured by TIMSS. They define curricular coherence as the alignment of the specified topics, the depth at which the topic is to be studied, and the sequencing of the topics within each grade and across the grades. Curriculum coherence is required to allow cognitive coherence, meaning a coherent understanding of a specific set of ideas. Roseman and Linn (in print) define this type of coherence: "By coherent understanding we refer to students' ability to link their scientific ideas to make sense of experiences and observations and to explain new situations" (p.3).

An evaluation of existing curricula (Kesidou & Roseman, 2002; Stern & Roseman, 2004) revealed that most curricula deal with an extremely broad range of topics, and do not focus on coherent age-appropriate learning goals. The key concepts were usually buried among detailed or even unrelated ideas. The curricula did not take into account student beliefs and prior knowledge in a way that would help teachers to respond to them effectively. The existing curricula did not engage students with relevant phenomena or supported students' understanding and reasoning skills. As a result, they failed to support students and teachers in attaining the learning goals. The reviewers recommended developing new science curricula that build on research to better support teachers and students. Attempts to develop coherent curriculum materials have been few, often funded by NSF, and have typically focused on the development of stand-alone units that do not support coherence across disciplines, within a school year or across school years.

IQWST Curriculum – responding to the need for new curriculum

Investigating and Questioning our World through Science and Technology (IQWST), an NSF sponsored middle school science curriculum development project, is an attempt to respond to the needs and recommendations described above by developing a coherent science curriculum for middle school that supports diverse students. IQWST units are research-based, inquiry-driven, and aligned with the national science standards (Reiser, Krajcik, Moje, & Marx, 2003, Krajcik, McNeill & Reiser, 2007). The project aims to develop a coherent understanding of both science content and practices in an inquiry-driven context. IQWST addresses the challenges of building coherent curriculum by carefully analyzing the learning goals, selecting relevant motivating contexts for learning these ideas, engaging student in a variety of practices in a manner that becomes progressively more demanding and less scaffolded, and sequencing ideas across units and disciplines as will be described in the following paragraphs. Each unit focuses primarily on few selected learning goals and science practices, is contextualized in real life situations, engages students in prolonged inquiry in a project-based environment (Blumenfeld & Krajcik, 2006), and provides appropriate teacher supports (Davis & Krajcik, 2004). Based on prior experience with project-based units (Krajcik et al., 1998; Singer, Marx, Krajcik, & Chambers, 2000) and an analysis of the inquiry standards (Reiser et al., 2003), IQWST supports four scientific practices (Fortus et al., 2006): A) modeling, B) data gathering, organization, and analysis (DGOA), C) constructing evidence-based explanations, and D) designing investigations. A scientific practice involves both the performance of scientific work and understanding the underlying meta-knowledge that explicates why the practice takes the form that it does. In order to link scientific practices to content, we define scientific practices as specifying ways in which students should be able to *use* knowledge meaningfully, rather than what they should *"know"*. Learning these practices is essential if students are to understand science as a way of knowing and not just a body of facts. However, little research has considered how to help learners develop these practices over time (Pellegrino, Chudowsky, & Glaser, 2001). Moreover, little is known of how to design such curricula, especially those that aim to support the development of both content knowledge and scientific practices, motivate students, and are cognitively appropriate.

Focusing on key ideas

In order to create a coherent set of learning goals, a decision of what these learning goals may be first needs to be made. IQWST units are explicitly standard-driven. Following Wiggins and McTighe, (2005), who suggested the method of *backwards design*, where identified learning objectives guide curriculum design, we use an approach which is called ‘learning goals driven design’ (Krajcik, McNeill & Reiser, 2007). Once the key ideas are identified, the relevant standards are unpacked and elaborated, which involves separating each standard into the basic concepts that are embedded within it, defining exactly what it means to understand each concept, what are the pre-requisites for understanding them, and what does research say about students’ common conceptions regarding each concept.

To prevent superficial learning, we chose to focus only on the big ideas of science. Often the big ideas align with key standards, but not always. A focus on big ideas allows us to aim for depth rather the coverage of a multitude of standards. The criteria for selecting the big ideas are (Smith, Wiser, Anderson, & Krajcik, in press):

A. Explanatory power within and across disciplines and/or scales.

B. Powerful way of thinking about the world – the big idea provides insight into the development of the field, or has had key influence on the domain.

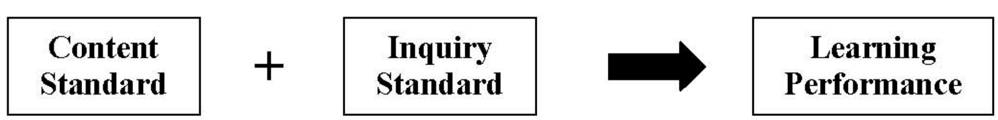
C. Accessible to learners through their cognitive abilities and experiences with phenomena and representations (age-appropriateness).

D. Building blocks for future learning: the key content standards are vital for understanding of other concepts and help lay the foundation for continual learning.

E. Can help individuals participate intellectually in making individual, social, and political decisions regarding science and technology.

Since the units focus on a few key ideas rather then just one, the key ideas are introduced so that one idea helps explain another, making connections explicit and deepening the level of complexity over time. Activities and phenomena are sequenced so that the early ones tie into only one or two learning goals, while the later ones draw on several.

Since the content standards state what students should *know*, rather then what students should be able *to do* with that knowledge, we devised a variety of “learning performances” which build on Perkins’ definition (1992) of “understanding performances.” Learning performances not only specify what students should be able to *do* with their knowledge, but also guide *how* students will learn the content standards. This contrasts with Perkins’ ideas of what performances can be used to assess student understanding. The learning performances were constructed by combining science content with inquiry standards (Krajcik, McNeill & Reiser, 2007).



For instance, the main content standard for the 6th grade chemistry unit is: “All matter is made up of atoms” (4D/M1, AAAS, 1993). An inquiry standard that the unit focuses on is: “Student inquiries should culminate in formulating a model” (National Research

Council, 1996). We combined the two to form a learning performance: “Students gather data of behaviors of air and create a model that account for all investigated phenomena”.

After the key ideas have been identified, the need to be organized into a set of coherent ideas, as the next section illustrates.

Learning goals coherence

Designing a coherent curriculum involves creating a set of inter-related units that incorporate explicit connections and interdependencies between the ideas and practices that students learn in each unit within a grade and as they advance through the grades (Newmann, Smith, Allensworth, & Bryk, 2001; Schmidt et al., 2005). What happens in one unit depends on and builds off what happens in a prior unit, and sets the stage for what happens in another. Units cannot be taught stand-alone, they are tightly integrated together to form a coherent whole. We have identified three levels of coherence, each associated with its own design challenges that need to be addressed.

1. Learning Goals coherence: How should a coherent set of learning goals be distilled from the national standards? What should be the criteria for focusing on specific standards, and not addressing others? How should the selected learning goals be linked to create a coherent set? Our assumption was that without a coherent set of learning goals we could not expect students to develop a deep understanding of the scientific concepts.

2. Intra-unit coherence: How do we coordinate between the learning goals, practices, and classroom activities, all within a project-based framework? A project-based framework may suggest different foci and a different sequence of ideas than learning goal coherence (Sherin & Edelson, 2004), as will be discussed later in the paper. The challenge is how to support students in constructing deep understanding and competence with the scientific practices and ideas while sustaining contextualized inquiry.

3. Inter-unit coherence: How do we sequence the learning goals and practices across units and years? Previous research and development has focused on developing independent units (Fortus et al., 2004; Kolodner et al., 2003; Marx, Blumenfeld, Krajcik, & Soloway, 1997; Singer et al., 2000; Songer et al., 2002); the issue of coherence across units is a relatively new endeavor.

Inter-unit coherence needs to be addressed from several aspects: within one discipline across grade levels (for example, what would be a coherent set of biology units for 6th-8th grades?), but also across disciplines, such as how can we link ideas about transformations of energy developed in the physics unit to ideas regarding chemical reactions or energy transformation in eco-systems which are addressed in chemistry and biology units?

IQWST can be seen as a series of learning progressions of scientific ideas and scientific practices that are interwoven throughout the entire curriculum. A learning progression outlines (a) a model of the target idea appropriate for learners, (b) the starting points based learners' prior knowledge and experiences, (c) a sequence of successively more sophisticated understandings, and (d) instructional supports that help learners develop the target science concepts and principles or practice (Smith et al., in press). IQWST’s approach for addressing these issues will be described along with examples drawn from two specific units, including preliminary results from pilot studies.

Contextualized inquiry

Why would a 6th grade student care and be engaged in studying about the particle nature of matter, or about interactions of light with matter? What meaning do ecosystems have for students? While we can present a strong rationale for the importance of specific key ideas and this rationale will be meaningful to experts that already have a coherent understanding of science, a different need to know has to be created for students.

In IQWST each unit is organized around a rich open-ended question, which is called a driving question, and provides a context that drives the learning of the unit's key concepts. This contextualization provides a purpose for learning the science content and helps students value the usefulness and plausibility of the scientific ideas. A good driving question meets the following criteria: Is it worthwhile? Is it feasible? Is it authentic? Is it meaningful (Krajcik, Czerniak, & Berger, 2003)? The process of deciding on a driving question involves interviewing students regarding their interests and expectations as well as discussing possible driving questions with teachers, scientists, and science educators.

Some examples of driving questions are: "Can we believe our eyes?"; "How can we smell things from a distance?" The investigation of a driving question leads to the formulation of sub-questions, which are collected, sorted, and presented on a driving question board (Singer et al., 2000). The driving question board is a visual reminder and an organizational tool for the various scientific concepts, both for teachers and students.

How to develop and sequence key ideas while sustaining a contextualized investigation?

A major design tension arises from the need to coherently organize pre-specified learning goals and in parallel remain faithful to the content and contextualization dictated by the driving question (Krajcik, McNeill & Reiser, 2007).. Real-world problems can easily branch out and lead students to seek knowledge that is not included in the learning goals. Similarly, the driving question may be linked to some of the learning goals, but not all of them. Answering a driving question may emphasize some learning goals over others, leading to uneven coverage of them and potential lack of coherence. Much effort is invested in selecting driving questions for IQWST units that support a coherent sequence of learning goals. Other than the three criteria mentioned earlier (is it worthwhile, authentic, and feasible?), there are two other important selection criteria for a driving question. One is that answering the driving question involves knowledge embedded in the key ideas for the unit. The driving question should allow the introduction of related sub-questions, each focused on a different idea or different aspects of the key idea. The last criterion is that the driving question should to be motivating for students. The motivational potential of a driving question is assessed through interviews and surveys of students and teachers (Drago, Shwartz and Krajcik, 2007).

Besides linking the learning goals together in a coherent manner, the driving questions need to sustain inquiry over a period of 6–8 weeks. A unit is divided into learning sets, each which is composed of lessons. Each learning set deals with a single aspect of the driving question. The lessons incorporate a broad range of phenomena. Some phenomena are chosen to promote understanding of a key idea; others are chosen to create “a need to know.” For example, some of the 8th grade chemistry unit activities focus on getting evidence that cellular respiration is a process that transforms energy through a chemical reaction of oxidizing glucose. These activities aim at understanding one of the key ideas of the unit. Other activities, such as using pedometers during exercise, reading nutrition facts on food labels and discussing obesity and ways to avoid it, are aimed both understanding related learning goals and contextualizing the learning of the scientific concepts. Each learning set ends with an activity that returns to the driving questions and integrates the ideas learned till that point.

As the curriculum aims also to develop scientific practices, the activities are designed to match the developing skill of the students at the various practices. The complexity of the required practices increases over time, while the scaffolding provided decreases. The curriculum also supports the development of the meta-knowledge about the practices by encouraging students to reflect on their learning and actions.

The next section illustrates two examples of how these issues were addressed in two 6^{th} grades units. In particular we describe how the units are coherent in building deep understandings of big ideas. We also illustrate how the units build upon each other.

Examples of IQWST's approach to learning goals coherence

This section illustrates two examples of how the requirements of coherence were addressed in two 6^{th} grades units, one focusing on the physics of light and the other on the particle nature of matter. Each example is accompanied by pre-posttest results and by statements made by teachers and students that participated in pilot enactments held in 2005-06.

6^{th} grade physics unit – "Can I believe my eyes?"

The 6th grade physics unit focuses on how light provides us information about the world. The nature of light, its interaction with matter, and vision are ideas that are accessible to middle school students, describe a powerful way of thinking about the world, and are important in laying a foundation for future learning. Light is important to other domains, such as biology and earth science, as the energy source that drives the biosphere, atmosphere, and hydrosphere. Understanding the nature of light is needed to participate in discussions on the energy crisis and global warming. It is also an excellent context for introducing other big ideas, such as the dependency of science on empirical evidence, the limitations of our senses, the value of instrumentation, and the centrality of modeling in science. The big idea of light as a provider of information was the framework that allowed us to combine the following standards-based learning goals in a coherent manner:

1. Light is in constant motion and spreads out as it travels away from a primary or secondary source.
2. Light from a primary or secondary source must enter the eye in order for the source to be seen.
3. Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection).
4. Absorption of light can cause changes in matter.
5. Colors of light can be combined or separated to appear as new colors.
6. Human eyes can detect only a limited range of light wavelengths.
7. Different wavelengths of light are perceived as different colors.

These ideas, reflecting the basics of how light provides us information about the world, were elaborated and clarified, providing the specific content that needed to be addressed. Once this was done we searched for a suitable context for learning these learning goals how to sequence them.

Sequencing these learning goals in a coherent manner is crucial. For example, in order to understand why different objects have different colors, students first have to understand how light interacts with matter (learning goal #3) and how we see colors of light (learning goal #5). Changing the order of learning the learning goals will have a negative impact on how ideas build off one another. Even the order of dealing with reflection, transmission, and absorption is important, within a single learning goals, has implications for coherence. Unlike reflection and transmission, absorption of light is never directly observed. Its existence can only be implied from energy conservation and later from the notion that light can make things happen when it is absorbed (learning goals 4). We hint at the idea of energy conservation, setting the stage for it to be revisited in greater detail in the 7th grade unit on energy transformation. We also prepare students for further investigation of the role light plays in the water cycle, in plant growth, and in atmospheric behavior, to be learned in further depth in biology and earth science units. In showing these connections, we set the stage for future learning and strengthen inter-unit coherence.

Alongside with these learning goals, the unit focuses on the scientific practices of modeling and data gathering, organization, and analysis (DGOA). As this unit is the first unit in the entire middle school sequence, it provides students with the very beginning of experience in these practices. We focused on scientific modeling because of its centrality in the practice of science and because it supported the unit’s coherence. Many view science as a process of building and refining explanatory models (Lehrer & Schauble, 2006). The practice of modeling is introduced early in the unit and is developed in conjunction with the content. The construction, critiquing, testing, and revising of a model of light's role in providing information about the world is a dominant theme throughout the unit.

The driving question of the unit is *Can I believe my Eyes?* We have found this question to be highly motivating, an issue with which the students readily identify. It allows us to make connections with a wide variety of real-world phenomena. The students are introduced to the driving question in the first lesson through an anchoring activity (CTGV, 1992). It is presented as a "secret message" printed in red and green letters on a black background inside a box. When illuminated with red or green light only vowels or consonants appear. Only when illuminated with white light is the entire message visible.

After observing the anchoring activity, the students generate questions they would like to answer about light and sort them into four categories that the teacher presents (How does light allow me to see? How does light interact with matter? How can light have different colors? Is there light that I cannot see?). These categories are drawn from the learning goals of the unit and become sub-questions that are the foci of the unit's four learning sets. The learning goals are dealt with in the learning sets in a developmental sequence, in a way that new knowledge builds on previous knowledge, enhances it, and fosters coherence.

Each learning set builds off those that precede it, building coherence. For example, the first learning set leads the students to understand that light needs to "bounce" of an object to their eyes to be seen. But how does light bounce? Does it always bounce? Are there other things it can do? These are the central ideas considered in the second learning set. The ideas in the second learning set would not have made any sense to the students, nor would there have been any reason to consider them, had they not been through the first learning set. We expect this kind of sequencing and coordination to lead to coherent understanding.

An understanding of all but the last two learning goals is necessary to explaining the anchoring activity. This is an example where there was a trade-off between maintaining intra-unit coherence and dealing with all the learning goals. We dealt with this by deriving a full explanation of the anchoring activity at the end of the third learning set and then shifting the focus away from the fact that light may not show everything there is to the idea that there may light that cannot be seen. Both ideas are examples of situations where you may not be able to believe your eyes.

Table 1 illustrates the sequencing of key activities in the light unit. The vertical columns represent the coherence of the learning goals, the practices, and the investigation of the driving question.

Insert Table 1 about here

Throughout the unit, while investigating the sub-questions posted on the driving question board, models of light and its role in vision are developed, applied to explain new phenomena, critiqued, modified, and re-applied. By the end of the unit students have answered most of the questions on the driving question board.

Teachers' feedback provided positive feedback for the sequencing of activities and practices, as this statement indicates:

> "I really liked that the students were able to change their models as they learned more. It seemed that the lessons lead them to ask questions about the next day's activities and that was very cool! Students asked questions about light and what they noticed outside of school –they were starting to become lifelong learners because they were seeking information!"

Interviews revealed that students perceived modeling as beneficial:

> "I liked building the model – it helps to show how you have to see the object and the light, and how it has to be a straight path of light."

Students were also asked about the difference between the experience they had in this unit and others they had before. The following three statements (made by different students) reveal their appreciation of the coherence of the unit:

> "It was more serious, not jumping between subjects, understanding better"; "I felt I understand, felt more focused"; "In other science units we didn't do experiments and got less homework. We didn't talk so much in class. I feel I understand better, because it explains more than in other units."

6th grade chemistry – "How can I smell things from a distance"?

This section demonstrates how the coherence design principles were implemented in the development of the 6th grade chemistry unit.

The key idea that lies at the heart of the 6th grade chemistry unit is the particulate view of matter. This idea that "all matter is made up of atoms" has large explanatory power, not only in chemistry but also across disciplines, and is a fundamental building block for future learning, as Nobel Prize winner Feynman writes:

> "If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis … that all things are made of atoms - little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence, there is an enormous amount of information about the world, if just a little imagination and thinking are applied" (Feynman, Leighton, & Sands, 1964).

As IQWST units are standards-driven, the appropriate benchmarks were chosen as the focus of the unit:

> All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. 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 (BSL 4D/M1, AAAS, 1993).

> Atoms and molecules are perpetually in motion. In solids, the atoms are closely locked in position and can only vibrate. In liquids, the atoms or molecules have higher energy, are more loosely connected, and can slide past one another; some molecules may get enough energy to escape into a gas. In gases, the atoms or molecules have still more energy and are free of one another except during occasional collisions. Increased temperature means greater average energy of motion, so most substances expand when heated (BSL 4D/M3,

AAAS, 1993).

These ideas, reflecting the basics of the atomic theory, were elaborated and clarified, providing the specific content that needed to be addressed. After creating content learning goals we addressed what should be the context in which these learning goals would be studied, and how to create an age-appropriate coherent sequence of activities.

We chose to contextualize the unit with the following driving question: “How can I smell things from a distance?” Answering driving question requires some knowledge of the atomic-molecular theory. The question was found to be motivating for students, and enabled the introduction of many related topics. For example, the sub-question “what makes a banana smell different then the smell of geranium” allowed us to introduce the idea that different substances with different molecular structures have different properties, while the sub-question “how do the molecules of the liquid source get into the air” allowed us to introduce evaporation. This driving question also allowed us to make many links to real-world phenomenon. For example: How does the nose function as a detector? How do scents allow us to detect danger (such as rotten food and adding mercaptan to natural gas)? How can sharks smell blood under water?

Most traditional curricula introduce the atomic theory in a few sentences. Students are expected to believe it, to accept it as a fact. On the other hand, the IQWST 6th grade chemistry unit does not introduce the idea explicitly until the middle of the unit. It allows students to gradually construct their own particulate view of matter. Students are asked to suggest a model of matter that can be used to explain a series of phenomena. The initial models reflect students' pre-existing conceptions, and are the starting point for building coherence. Instead of ignoring students' pre-existing conceptions, they are repeatedly revisited and revised. In order to construct a model of matter that will account for all presented phenomena, the students gradually move from a continuous or mixed view of matter to a particulate one. They develop their understanding of matter in conjunction with their understanding of models. Later in the unit, they apply their knowledge in explaining an additional series of phenomena, such as phase changes. This approach, drawn from Novick & Nussbaum's constructivist approach, (Novick & Nussbaum, 1978; Nussbaum, 1985; Margel, Eylon, & Scherz, (in press)), is time-consuming - about 2/3 of the unit is devoted to constructing a particulate model of matter with the students.

Following is a description of the main activities in the unit's three learning sets, demonstrating the sequence of activities that allows students to build their ideas throughout the unit.

The unit begins with students smelling menthol or another strong odor and raising questions related to the phenomenon of smelling. The first learning set helps students understand that all matter is made of particles. The sub-question under investigation is: *"How does an odor get from the source to my nose?"* Initially, students create models of how they think they can smell substances from a distance. Students create drawings along with written explanations to represent their ideas. This activity reveals students' prior conceptions. Many students have a continuous view of matter; others have heard about atoms and molecules but have only a vague idea what these words mean, as this quote of a piloting teacher illustrates:

> Today, we said that our models should have a detector (nose), the source of the odor, a way to show movement, and "small stuff"...we elected the phrase "small stuff" after yesterday's discussion where the kids said they knew about things called atoms, elements, & molecules, but they really didn't know how those words were different, or what they really represented, besides the fact that they are all REALLY small things that they can't see. I told them that scientists mean something specific when they use those words, so we should wait until we had done a few more lessons before we tried to put them into our common lingo".

The emphasis is on students expressing their own ideas and revising them. This approach contrasts the traditional approach of providing students with the "right" scientific model, as this quote of another piloting teacher demonstrates:

> "With my five classes I had five different discussions when it came to comparing models. Some classes were looking for the "right" answer, while others got into it, and were just giving answers non stop. Most of my students understand that it's okay not to have the exactly right answer. It's a hard thing to overcome after six years of most teachers only looking for one "right" answer".

Another example of how ideas are built one on top of the other is found in the second lesson of the unit. Students learn that all matter has mass and volume, and that matter can exist in three states. These two ideas are important in terms of coherence: In order to meaningfully anchor what they gradually learn about the particulate nature of matter they need a working definition of matter (everything that has mass and volume). Also, many students at this point are not convinced that gas is matter. Understanding that gas is matter is fundamental to understanding air, and how odors travel in air. The activities which provide evidence that all matter has mass and volume, including gases, set-up the basis for linking macro evidence to molecular view of matter, as a leading strategy in explaining phenomena later in the unit. In other lessons of the learning set, students create models of air and use their models to describe and explain characteristics of gases. Only after constructing a view of gas as made of particles with empty spaces between them is the idea that the particles are in constant motion introduced. The students observe indicator paper held above a liquid (but not touching it) changing color. Explaining this observation involves the idea that particles originated in the liquid "traveled" and reached the indicator paper.

The same activity serves also as a transition to learning set 2, that focuses on the question *"Why do different substances have different odors?"* and introduces the idea that different properties results from different molecular arrangements, again an idea that builds off students understanding of matter as made of particles. The activity involves an observation that two liquids, which appear to be the same, are distinguishable by the fact they turn indicator paper different colors. While the particle model, created in the first learning set, emphasizes the similar features of all substances, the second learning set focuses on the differences in molecular structures. It emphasizes that every substance has unique properties, and that substances can be distinguished by those different properties. Students are introduced to the terms *element*, *atom* and *molecule*. Students use these terms, rather than only "particles", to refer to the particles in their model.

The students' models of matter are revised once again to explain why different substances have different properties. Different organic smells and their molecular arrangements are introduced to emphasize these ideas. Understanding the complex idea that different molecular structures result in different properties can not be addressed without having a particulate view of matter.

By the end of this learning set, students should be able to explain that different substances smell differently because they are made of different molecules. Different molecules can be made of either the same or different types of atoms, but those atoms are differently arranged.

The last learning set deals with the question *“How can a material change so you can smell it?”* and uses the particle model to explain states of matter and phase changes. Previously learned ideas of matter being made of particles with empty spaces between them, in addition to the idea of continuous particle motion, are required to understand states of matter and phase changes. This learning set builds on and reinforces these ideas.

The need to balance the tension between coherence of the content ideas and the investigation of the driving question required some trade-offs. For example: While most students realize that solids and liquids are matter, some of them hold the prior conception that gas is not matter (i.e. gas is ‘nothing’) (Driver, Guesne, & Tiberghien, 1985). While it could be simpler to start with a particulate view of a solid, as students will not question whether a solid is matter, using smell as the driving phenomenon requires an analysis of gases early on. Therefore, a lesson aimed at convincing students that gases are matter is needed before the activities aimed at construction of the particle model through investigation of behaviors of air. We build on students’ pre-existing experience with matter to conclude that matter is “everything that has mass and occupies space”. Students measure the masses of a deflated and inflated ball and of an air freshener before and after it was left open for the night, to conclude that gases are matter. Likewise, addressing the process of odor molecules traveling through the air is challenging to do before studying about phase changes. However, it allows us to use the process of smell propagation to provide evidence, early on, for the constant motion of particles.

In terms of coherence the three learning sets can be seen as three phases of building coherence: First, students construct their own particulate view of matter, then students align their conception of particles view with the scientific terms atoms and molecules, and finally students use their understanding of the atomic molecular theory both to answer the driving question, and to explain other phenomena.

Another goal of this unit is to advance students' understanding of the scientific practice of modeling. The 6th grade chemistry unit builds off students' experience with modeling and models in the 6th grade physics unit on light. The first activity of the chemistry unit engages them in the practice of modeling in a new context. In the physics unit students constructed 2D and 3D models of how light is involved in sight. In order to scaffold the construction of models, the class agrees early on that specific components have to be presented in the models: a light source, a light detector (such as the eye), and an object. They also agree on using lines and arrows to represent how light travels. Throughout the physics unit students use and revise their model to explain new phenomena, such as how light interacts with matter in different ways, and how light is composed of different colors. When moving to the chemistry unit, the students are asked to draw models of how they can smell things from a distance. The unit builds on students' prior experience with models in the physics unit to reach agreement on specific components that need to be presented in these models: an odor source, a detector (such as the nose), and a way to represent how odor travels. However the chemistry unit also introduces the idea that the same phenomenon can be represented in multiple ways – dynamic computerized simulations, drawings, and many physical models (beads, ball & stick models, students acting as molecules to represent motion at different temperatures) – each emphasizing different aspects of the phenomenon. The issue of simplicity is also discussed: when is it necessary to include different kinds of molecules in air and when is this distracting? When do we need to represent the inner arrangement of a molecule and when is it enough to represent a molecule as a circle?

Table 2 illustrates the sequencing of key activities in the smell unit. The vertical columns represent the coherence of the learning goals, the practices, and the investigation of the driving question.

Insert Table 2 about here

In the design of the two units described here we have followed design principles aimed at supporting coherence of both content ideas and practices in an inquiry-based unit. Although challenging and requiring trade-offs, preliminary results suggest that students develop a coherent understanding of both content and practice ideas, and their interest in inquiring into the driving questions and related topics is sustained over time. The next section presents some of the preliminary research findings.

Formative assessment – are we on the right track?

The goal of the pilot study presented here was to provide the developers with initial feedback about the effectiveness of the design approach. This section presents and discusses the scores of the pre-post test for each unit and a few anecdotal excerpts from student and teacher interviews.

The physics unit was piloted in twelve urban, suburban, and rural classrooms in Michigan, with a diverse population of 248 students. The chemistry unit was piloted in 2 suburban, classrooms in Michigan, with a diverse population of 60 students. The pre-posttest for each unit addressed the main learning goals and common misconceptions. These tests were developed according to a model elaborated by Singer, Marx, Krajcik, and Chambers (2000). The chemistry pre/post test was also developed by using a procedure for analyzing science assessment items developed by project 2061 to ensure the alignment between assessment items and the learning goals of the unit (DeBoer, Herrmann, & Gogos 2007). Examples of items from the physics and chemistry tests are included in Appendix 1.

The test included both multiple-choice and open-ended items, probing different levels of comprehension. Content validity and alignment with the learning goals were verified by external reviewers. Alpha Cronbach's reliability coefficients were 0.86 for the physics test, and 0.68 for the chemistry test. Reliability for sub-scales was also obtained.
The maximum possible score for the physics test was 44 and 36 for the chemistry test. Where applicable, we used items that had been validated by other researchers. Overall, the tests were difficult, mainly to prevent a ceiling effect.

Table 3 presents the pre/post scores and effect size of the physics unit. The results are aggregated according to type of knowledge (content or practice) required to answer the items and according to the difficulty of items. Low-levels items usually involve recall. Medium-level items require some reasoning, comparing two situations, understanding relationships between variables, etc. High-level items either require higher-order thinking (analysis, synthesis, critiquing) or are similar to medium-level items, but in a new context, one that students did not encounter in class. Overall, the results show significant improvement in all the learning goals and their understanding and ability to use models.

Insert Table 3 about here

Interviews with students revealed a connection between understanding the learning goals and the practice of modeling. Students were asked to draw and explain how light allows a person to see a tree. Prior to instruction, lack of understanding was common in students' drawings and explanations, while after instruction their drawings reflect an understanding of the learning goals. The use of the language they learned, like "straight unblocked path", and "light is going into her eyes" is apparent in the following typical example.

Before instruction the student explained:

> "Because it's not all dark so the person could see the tree, but in the dark he couldn't because there was no light."

After the first learning set:

> "From the light having a straight unblocked path into her eyes… The tree is an object for the sun to light up so she can see it…the light is going on the tree and into our eyes.

Table 4 presents the pre/post scores and effect sizes for the chemistry unit. The results provide evidence of students improving their understanding of the learning goals. Learning gains were especially evident for medium and high-level items. All gains are significant at the .001 level with df = 58.

Insert Table 4 about here

The results show significant improvement in understanding the main learning goals of the unit. The improvement is especially apparent in the medium and high-level items. Another interesting result is that the effect size for the modeling items was greater in the chemistry unit than in the physics unit, even though the pretest scores also increased. Classroom observations show that in the chemistry unit students were using ideas about models that they learned in the physics unit. This is demonstrated in the feedback of one of the piloting teachers provided after the first lesson of the chemistry unit :

> "This morning, my class was amazing...quite literally...kids jumping out of their seats to explain an idea in their models, or a way that their models were different or similar to the other models…. **I think it shows that the kids "get it" now when it comes to modeling…** "

These results indicate that our efforts to create an inter-unit coherent sequence of modeling activities may have helped students improve their understanding of models and modeling. It reinforces our belief that we are on the right track in our efforts to promote learning goal coherence in our design approach. Further research is needed to better support this assertion. In addition, the effectiveness of the IQWST curriculum needs to investigated for all IQWST units, at all grade levels.

Sequencing ideas across grade levels and disciplines

Until this point, we have described mainly how the development of ideas and practices lead to intra-unit coherence. While key ideas are identified for each unit in IQWST, as mentioned earlier, they are also sequenced through grade levels, within and across disciplines, to create inter-unit coherence. In order to address coherence of ideas across units, a series of theoretical learning progression were designed (Smith, Wiser, Anderson, & Krajcik, 2006). To demonstrate this, we discuss how a learning progression of the idea "matter is transferred from one organism to another repeatedly and between organisms and their physical environment" (5E/M2, AAAS, 1993) is implemented across units in IQWST. The unit that targets this idea is the 8th grade chemistry unit. However it is linked to many other related ideas learned in previous units. Table 5 identifies the various standards and their sequencing in the curriculum needed to support understanding of this key idea.

Insert Table 5 about here

As can be seen, this sequence of the ideas is not linear, but it provides opportunities to revisit, enhance, and apply knowledge in several units and grades to construct a coherent understand of the transformations of matter and energy in eco-systems and create a powerful view of the world. The same key ideas are actually addressed in different units, at different levels and highlighting different aspects. For example, in the 6th grade biology unit students investigate food and determine that food provides energy and building materials for all living things, and that food is made up of carbohydrates, proteins and fats. The 8th grade chemistry unit revisits this idea and investigates the molecular structure of these substances, concluding that they are polymers – long chains made of specific subunits. All the units make explicit links to ideas learned in other units. Using such a framework ensures that the key ideas are not visited just for a short time, but that they "stay" in the curriculum and are revisited repeatedly from different points of view. This helps students see connections and gradually build a coherent understanding.

This approach is different than that found in traditional curricula. For example, in a traditional curriculum, photosynthesis will usually be presented as a biology topic. The molecular aspects of the process, as well as understanding its importance in transforming light energy into chemical energy are not emphasized. Few middle school chemistry and physics curricula actually deal with the different aspects of photosynthesis (Schmidt et al., 2005).

Another example of an inter-unit learning progression involves the particle nature of matter. This key idea is first introduced in the 6th grade chemistry unit. The 6th grade earth science unit uses it in discussing the water cycle. The 6th grade biology unit uses this idea to discuss processes in living systems. The 7th grade physics unit uses it in investigating thermal, chemical, and electrical energy. The 7th and 8th grade chemistry units use it in investigating chemical reactions, photosynthesis and cellular respiration. This approach emphasizes that real-world phenomena are usually complex and the knowledge needed to make sense of them is not limited to a specific discipline.

Assessing the intra- and inter-unit coherence of the curriculum takes place in two stages: first each unit is piloted independently of the others; then the entire sequence is field tested. We have just begun the field tests. Our field test will help establish if the coherence of the curriculum actually help students develop deep understanding of the learning goals.

Developing scientific practices across units

While trying to develop a coherent and deep understanding of the content learning goals, IQWST units also tries to build coherence of scientific practices across units and grades. The units' sequence also takes into account a learning progression of the scientific practices. The first units provide students with multiple opportunities to practice and reflect on one leading practice and its associated meta-knowledge. The 6th and 7th grade physics and chemistry units focus primarily on modeling, as was previously described, 6th grade biology and 7th grade chemistry on constructing evidence-based explanations, and the 7th grade physics unit on the design of investigations. The later 7th grade units and all the 8th grade units integrate all the practices in more complex investigations.

In order to develop a coherent understanding of the practices within a unit, we follow the Scaffolded Inquiry Sequence (SIS) model developed by Hug and Krajcik (2002): motivate, unpack, model, clarify, and practice. The sequence of presenting each practice and increasing its complexity is another criterion in sequencing the activities within a unit. In each unit, scaffolds are provided to help students to engage in the practice. Discussions help students understand the meta-knowledge associated with the practice. McNeill, Lizotte, Krajcik, and Marx (2006) investigated the support provided for students' construction of scientific explanations by fading scaffolds. They found significant learning gains for students for all components of scientific explanation (i.e., claim, evidence, and reasoning), and that fading written scaffolds better equipped students to write explanations. This paper also presents some initial indications for students' ability to use modeling practices and meta-knowledge across units. Ideas that were learned in the physics unit emerged naturally and spontaneously in the early lessons of the chemistry unit. On-going research will provide additional insight for developing coherent understanding of scientific practices.

Discussion

In this paper we have described the efforts to address coherence in designing a middle school science curriculum. While the need for coherent curricula is well established (AAAS, 2000; Duschl, Schweingruber, & Shouse, 2007; NRC, 1996; O'Sullivan et al., 2003; Schmidt et al., 2005), there are few examples curriculum designers have to guide them in addressing coherence. The experience of IQWST provides some lessons learned regarding coherence, as well as raising some new challenges.

The complexity of the design process was amplified by simultaneously addressing different recommendations for a meaningful curriculum: coherence, contextualized inquiry, developing scientific practices, and using literacy in scientific contexts. While project-based units can create a great context for learning science – they do not necessarily build coherence. Each unit can be studied as an independent unit, and they can be taught in any order. IQWST units are contextualized units that need to be taught in a specific order. Within a specific discipline, as well as across disciplines, the units build-off the previous units, and specific links are made. Students are not expected to connect and synthesize ideas all by themselves. The curriculum helps them do so explicitly. It is necessary to find a delicate balance between the content learning goals, context, and scientific practices. IQWST attempted to create such a balance in which each of these aspects enhanced the learning of the others.

The focus on key ideas and the design of learning progressions seem to be a powerful mechanism which addresses all three levels of curriculum coherence: learning goals coherence, intra-unit coherence and inter-unit coherence. Future research on the cumulative effect of IQWST has the potential to have a large impact on standards expected of curriculum material and the way these materials are designed. Constructing and implementing a valid and reliable assessment of the entire curriculum is a challenge we face in field-testing the sequence.

The following paragraphs will present three challenges that we faced during the process of development, to illustrate the complexity of such a design. The first challenge deals with the relative rigidity of a coherent set of units. Occasionally a need to make changes to a unit's structure is raised. For example, while developing the chemistry units that deal with phase changes (6^{th} grade) and chemical reactions (7^{th} grade), the design teams faced the question: How do we deal with what holds the particles (atoms or molecule) together? For students to construct a rudimentary understanding of this issue, some understanding of electric forces is needed. While the nationals standards regarding the electric nature of matter were not originally addressed by us because they are not specified as middle school expectations, they are now weaved into the physics and chemistry units in a way that is connected to the context of these units. Nevertheless, adding a new learning goal involves considering what can possibly be taken out, or addressed in less depth and detail, to keep the length of the units reasonable. In a "scattered" curriculum, which is composed from a collection of independent units, the above challenges are much simpler then in a coordinated curriculum in which changes to one unit affects what happens in other units in complex links of content, context, and practices.

The second challenge we want to highlight deals with the need for the collaboration of people with diverse expertise. The IQWST development team involves science educators with different scientific backgrounds, learning scientists, teacher educators, specialists in technology, literacy, language and culture, and middle school science teachers. The development teams also get continuous feedback from scientists and Project 2061. A major concern of such a diverse design team is the proper use of terminology. For example, as more then one unit addresses transformations of energy, or concepts such as heat, property, or scientific explanation, it is important that all units use the same vocabulary in the same way. Another example is the use of the terms "information", "data" and "evidence" in scientific inquiry. Having identified that different units used these terms differently, we had to decide which term to use in which situation and when, in the process of an investigation, does data become evidence.

Last but not least is the issue of how explicit and transparent the needs of coherence are to teachers. IQWST materials are intentionally designed to be educative for teachers (Ball & Cohen, 1992; Davis & Krajcik, 2004). The materials clearly identify the learning goals, explicitly provide teachers with a scope and sequence of learning activities, provide information regarding necessary prior knowledge, alert teachers to their students' likely naïve conceptions, and suggest strategies for identifying and dealing with them. All these components, organized around science content knowledge and pedagogical content knowledge (Shulman, 1986), aim at helping teachers enact the units. The teacher educative features also highlight opportunities to make links between the various units. However, research on teachers' ability to use these materials effectively is on-going.

The IQWST curriculum is an attempt to follow research-based recommendations for designing a coordinated and coherent curriculum. Preliminary findings for individual units indicate some encouraging trends: (1) The materials are supporting student learning of the science content as defined by the learning goals; (2) The materials are supporting students in developing complex inquiry skills; (3) The materials are effective in supporting diverse student populations. The project provides a unique opportunity to investigate the issues of coherence and learning progressions of scientific ideas and practices when taught in a project-based approach.

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Table 1: Sequencing key ideas and activities – the physics unit

Activities	Content learning goal	Inquiry standard	Investigating the driving question
Anchoring activity: A message appears or disappears depending on the color of the illuminating light.	Generates a need to investigate the behavior of light.	Observing and describing a phenomenon.	Generates students *interest* in light and raises the driving question - ***When can we believe our eyes?***
Using “light-boxes” to establish the conditions for sight: a light source, object, eye, and straight unblocked path.	Light travels in straight lines. Light from an object must enter the eye for the object to be seen.	Collecting data and using it as evidence.	An example when we cannot believe our eyes (we know there’s something in the box, but cannot see it without light).
Creating material models to show how we see an object. A	Light travels in straight lines.	Creating and critiquing different	A consensus model will help in explaining the

consensus two-dimensional model is generated through class discussion.	Light from an object must enter the eye for the object to be seen.	models; creating a consensus model	anchoring activity and answering the DQ.
Using light sensors in a “light hunt”.	The eye is a passive detector of light.	Advantages of measuring devices	The light sensor provides evidence in cases when we cannot believe our eyes.
Investigating shadows and using the consensus model to explain the phenomenon.	Shadows are the result of the absence of light.	Using models to explain and predict new phenomena	Shadows are an example of seeing something that is actually absent.
Investigating the difference between scattering and reflection, transparent and translucent objects (transmission), and	Light can be reflected, transmitted, or absorbed when it reaches matter. The absorption of light can make	Collecting data, creating and using tables to organize it. Revising and enhancing	The anchoring activity involves scattering, transmission, and absorption.

how light that has not been reflected or transmitted makes things happen (absorption).	things happen.	models; using models to explain new phenomena.	
Investigating how we perceive different colors of light; mixing and separating colors of light.	Mixed colors of light appear as new colors. Colored objects selectively reflect, transmit, and absorb different colors of light.	Using and revising models to explain new phenomena.	Explaining the anchoring activity.
Investigating IR and UV light.	Non-visible light behaves like visible light but cannot be detected by our eyes.	Models are used to predict the behavior of UV and IR light.	Another aspect of the driving question – there is light we cannot see.

Table 2: Sequencing of key activities in the smell unit

Activities	Content learning goal	Inquiry standard	Investigating the driving question
Anchoring activity: smelling strong odors. Constructing and discussion the first model of how smell travels	Generates a need for developing an understating of matter	Modeling: introduces Students to creating *models* in chemistry.	generates student *interest* in odors
Measuring mass and volume of solids, liquids and gases (air). Students measure the decrease of mass of an air freshener over time	Revealing students conception of matter Have students recognize that air has mass and occupies space (volume). Students define matter as anything that has mass and occupies space.	Data gathering and analysis: Students practice collecting quantitative data and graph reading	Students recognize that gases, including air and odors are matter, therefore a need to know more about matter in general, is established

Studying the behaviors of air	Students realize that the particulate model of air explains all the presented phenomena, Students are able to use to idea of “empty space” in explaining the various phenomena.	Students use their models to explain presented phenomena. Students create and revise models to explain and account for all of the following phenomena: subtraction, addition, compression and expansion of gas in a closed	Students have a better understating of air, therefore can now move into explaining how do odors travel in air.

		container.	
Observing and modeling the change of color of indicator paper put above HCl and NH3 liquids	Students are provided with evidence that particles in the gaseous state are moving. The different effect of the two liquids on the indicator paper problematize the issue of "what makes substances different from each other"	Students revise and use their models to explain the observed phenomena. Dynamic simulation are introduced, limitations of drawing in representing movements are discussed.	Students apply the idea of particles movements to answer the driving question. The question "what makes substances different from each other" will be further investigated in the context of "why do different substances have different smells"?

Observing and modeling the time it takes for the indicator paper to change color, in different temperatures	Students learn that in the gaseous stat - the more energy is added, the faster the molecules move. Conversely, cooling a gas (without reaching the condensation point), reduces the energy of the molecules so they slow down.	Students use their models to explain the phenomena. Other types of models are introduced – students realize that multiple models can be used.	Students apply their knowledge to discuss the effect of temperature on the phenomenon of smell
Various phenomena of phase changes	Students use the particle model to explain states of matter and phase changes.	Students use their models to explain more phenomena	Students are able to explain how can a solid or a liquid "become" an odor

Table 3: pre/post scores and effect size of the physics unit

	Pretest	Posttest	Effect Size

Total	15.3	32.9	3.7***
Content Items	15.4	28.7	2.6***
Modeling Items	3.5	7.9	2.0***
Low-Level Items	2.0	2.4	.52**
Medium-Level Items	11.0	19.4	2.5***
High-Level Items	3.2	7.8	1.9***
Open-Ended Items	9.4	20.0	2.6***
Multiple-Choice	6.6	9.6	1.6***
Light Propagation Items	7.1	13.3	1.9***
Light-Matter Interaction Items	6.3	12.9	2.4***
Color Items	1.6	3.5	2.1***
Non-visible Light Items	.7	1.5	1.1***

** $p< 0.05$, *** $p < .001$

Table 4: Pre/post scores and effect sizes for the chemistry unit

	Pretest	Posttest	Effect Size
Total	16.7	27.9	2.8***
Content Items	16.7	27.9	2.8***
Modeling Items	10.1	18.2	2.8***
Low-Level Items	2.2	3.7	1.2***
Medium-Level Items	8.3	12.3	1.7***
High-Level Items	6.3	11.9	2.3***
Open-Ended Items	8.3	13.7	2.6***
Multiple-Choice	8.8	14.2	1.8***
Phase Change Items	5.3	10.0	2.4***
Particulate Nature Items	7.6	14.5	2.8***
Properties	2.0	2.8	0.7**
Characteristics of Matter	3.4	4.0	0.6**

** $p < 0.05$, *** $p < .001$

Table 5: Sequencing of standards across the curriculum to support a key idea

Key idea	Where it is addressed
All matter is made up of atoms (4D/M1, AAAS, 1993)	6th grade chemistry
Food provides the fuel and the building material for all organisms. Plants use the energy in light to make sugars out of carbon dioxide and water (5E/M1, AAAS, 1993)	6th grade biology – macroscopic perspective 8th grade chemistry – molecular level
Atoms that make up the molecules of existing substances rearrange to form new molecules of new substances" (AAAS, new benchmark)	7th grade chemistry
Conservation of matter in a chemical reaction (4D/M7, AAAS, 1993)	7th grade chemistry
Energy transformations and conservation in living things (5E/M3, AAAS, 1996)	7th grade physics.
Animals get energy from oxidizing their food, releasing some of its energy as heat.	7th grade chemistry - oxidation reactions
Food energy comes originally from sunlight (5E/M33, AAAS, 1996).	6th grade biology 7th grade physics - energy from the sun

	8th grade chemistry – photosynthesis
Matter is transferred from one organism to another repeatedly and between organisms and their physical environment (5E/M2, AAAS, 1996)	6th grade biology – food chains 8th grade chemistry – cellular respiration and photosynthesis