Inquiry Project in Urban Middle Schools: Lessons Learned

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Constructing Extended Inquiry Projects:

Curriculum Materials for Science Education Reform

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Science education standards advanced by the American Association for the Advancement of Science (1993) and the National Research Council (1996) urge less emphasis on memorizing decontextualized scientific facts and more emphasis on students investigating the everyday world and developing deep understanding from their inquiries. Broadly conceived, inquiry refers to “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (NRC, 1996, p. 23). By emphasizing scientific inquiry, the standards challenge the education and science communities to transform the very heart of students’ experiences in science classrooms. In support of the standards, new approaches to science instruction feature inquiry as essential for student learning (Krajcik et al., 1998; Lunetta, 1998; Roth, 1995). These approaches assume that students need to find solutions to real problems by asking and refining questions, designing and conducting investigations, gathering and analyzing information and data, making interpretations, drawing conclusions, and reporting findings.

The spirit of the science education standards represents a dramatic shift in what needs to be taught in k-12 science classrooms. In order to enable teachers to accomplish the ambitious agenda advocated by AAAS and NRC, educational researchers and professional educators need to create a research and development program to support reform (Marx, 1998). Such an agenda needs to address the full range of issues associated with reform: curriculum and pedagogy, management and policy, teacher professional development, new learning technologies, and community engagement. By studying the intersection of these issues and developing programs of research-based practice around them, partnerships of researchers and educators can begin to create the know how to help teachers meet the new standards (see Blumenfeld et al., this volume).

In this article we report our work on one of these issues—curriculum materials to support reform. Researchers at the University of Michigan have been working together with the Detroit Public Schools to reform science education for middle schools. The collaborative work between DPS and UM takes place within two projects funded by the National Science Foundation--the Detroit Urban Systemic Program and the Center for Learning Technologies in Urban Schools (LeTUS), which takes as its core challenge the infusion of technology to support learning into urban classrooms. We are documenting situations that influence technology acquisition, exploring how technology can be embedded in science curricula, identifying problems that present barriers to success, and finding local solutions to these problems.

When we began this collaborative effort, we found that a major challenge for imbedding technology use in urban schools was the lack of curriculum materials that match science content with the appropriate use of learning technologies. To meet this challenge it became necessary to develop materials that simultaneously are suitable for use in schools that serve diverse populations, promote inquiry, and make extensive use of learning technologies as the vehicle for students to develop deep understanding of scientific concepts and processes.

Our approach to developing curriculum materials entails collaboration among teachers, school and district administrators, university scientists, educational researchers, and curriculum specialists (Krajcik, et al., 1994; Singer, et al., 1998). Through this process we have developed, enacted, and revised several curriculum projects. Our development process is based on design principles that are derived from theoretical and empirical literature on teaching and learning and the literature on science education standards. In this article we describe these curriculum design principles, grounding them in a social constructivist perspective, and provide examples of how the principles become manifest as curricular activities.

Assumptions for Designing Curriculum Materials

The assumptions that provide the foundation of our curriculum design principles are derived from a social constructivist perspective. Social constructivism is an approach to learning in which students learn concepts or construct meaning about ideas through their interactions with and interpretations of their world, including essential interactions with others (Krajcik, Czerniak, & Berger, 1999). Four salient features are fundamental to this theoretical perspective: 1) active construction, 2) situated cognition, 3) community, and 4) discourse.

When students are provided opportunities to actively construct their understanding of a discipline, deep understanding is more likely to develop (Krajcik et al., 199; Roth, 1994; Tinker, 1994). Perkins (1993, 1994) argues that by engaging students in performance they will have opportunities that promote deep understanding. This performance perspective suggests that students construct knowledge by engaging in a "variety of thought-demanding ways with the topic, for instance to explain, muster evidence, find examples, generalize, apply concepts, analogize, (and) represent in a new way."(Perkins, 1993, p. 29). Actively constructing knowledge or engaging in a performance of understanding requires that learners become immersed within the context of the discipline (Perkins, 1993, 1994; Roth 1994). Such disciplinary contexts provide situations within which novices can learn through increasingly autonomous activity in the presence of social and intellectual support. Lave and Wenger (1991) argue that abstract and generalized knowledge gains its power through the expert's ability to apply it in specific situations. Hence, in order to deeply understand the principles of a discipline, students must actively see how knowledge or skills function within the context of the discipline.

Socialization into the culture of a discipline is promoted by extensive and repeated exposure to the community of practitioners in the discipline (Perkins, 1993). Communities of practice in disciplines share a culture and like all cultures, members have developed tools for conducting activities and regulating interactions of the community.

Learners appropriate many cultural tools, ranging from the meanings of words, to methods of identifying and solving problems, and even to the epistemologies of formal disciplines. By being immersed in the culture of a community of practice (e.g. science, math, history), students learn ways of knowing in the discipline, what counts as evidence, and how ideas are substantiated and shared.

Participation within a community requires the use of language to exchange and negotiate meaning of ideas among its members. Learners are introduced into the language community by more competent others. Learners appropriate the symbolic forms of others and the functionality of those forms through language. While the intrapsychic functions of language enable the learner to construct understanding, the interpersonal functions allow the learner to engage in discourse. Hence, the learner becomes a member of a discourse community. The movement between the interpersonal and intrapsychic uses of language constitutes one of the essential sites of learning.

From this perspective on social constructivism, we have developed an approach to teaching and learning that we call project-based science. Project-based science is an approach to teaching that engages students in curricular units (we call them “projects”) that last from 4-10 weeks. These project encompass science content that relates to national science education standards and local school district curriculum frameworks. This approach to learning through inquiry embeds the pervasive use of technologies in collaborative classroom settings (Marx, et al. 1997). In the next of this section, we describe the principles from social constructivist theory and the literature on science education standards that guide the development of projects.

Curriculum Design Principles

We have derived seven curriculum design principles from our conception of social constructivism and other important components of curriculum development, including a consideration of stakeholders and national policy bodies such as NRC and AAAS. These principles provide a foundation for the design of inquiry curriculum projects. Table 1 presents the seven design principles we have been using. Curriculum materials created by using these principles can promote understanding of scientific concepts and inquiry strategies and address the needs of diverse students (Krajcik et al., 1998, Singer et al. 1998, **AERA 2000**).

Insert Table 1 about here

Context

The first design principle, contextualization, addresses two social constructivist features--situated cognition and community. The contexts for curriculum projects are created through the use of driving questions. Driving questions serve to organize and guide instructional tasks (Krajcik, Czerniak, & Berger, 1999; Krajcik et al. 1999), thereby situating learning for students. The driving question uses students' real world experiences to contextualize scientific ideas and uses subquestions and anchoring events to help students apply their emerging scientific understandings to the real world, thus seeing value in their academic work.

Driving questions help engage students in the culture of a scientific community. The source of the questions being asked and investigated is an important feature of the curriculum design process. The driving question is initially developed based upon its potential meaning for students, which is determined through repeated conversations with teachers, community members and content experts. The learning environments designed to help students answer the driving question immerse them in a scientific culture, including practices such as debating ideas, designing and conducting investigations, reasoning logically, using evidence to support claims, and proposing interpretations of findings.

Driving questions tend to be broad and open-ended; they need to have this character in order for them to be authentic and encompass worthwhile science content. Because of this open-endedness, however, students have may have difficulty recognizing what science principles are relevant and necessary in order to construct a meaningful response to the driving question. Methods for facilitating students through these difficulties are addressed through the use of related subquestions and anchoring events that help students link learning activities back to the driving question.

Our projects are relatively long term because they involve answers to complex questions. Questions that middle school students find engaging, such as "Are there poisons in my house?", "How can I stay on a skateboard?", or "Is the water in the steam fit to drink?" can involve substantial science. In order to link the science to the driving question, students need to learn many related concepts, processes, and skills that a novice may not recognize as being directly related to the driving question. By using subquestions and insuring that the students understand the relations among the driving question and its subquestions, we can help students keep the driving question in mind throughout the project. Careful construction of the questions allows them to be progressive and help learners construct a greater understanding of the scope and depth of the driving question.

Contextualization is also supported by the creation of anchoring events that enable students to visualize how the project's substance relates to their community, family, or themselves. Anchoring events (Cognition and Technology Group at Vanderbilt, 1990) help render abstract ideas more concrete and thus provide a cognitive mooring around which newly learned ideas can be linked with prior understandings. Ideally, anchoring events directly engage learners with the scientific phenomena that are addressed by the driving question. Projects that address environmental themes are particularly well suited for the creation of anchors that engage students directly with phenomena. For the driving question "What affects the quality of air in my community?" students can walk around their school and the immediately surrounding community taking pictures that demonstrate their questions about how air quality might be affecting their environment. The pictures can be displayed around the room and viewed throughout the project to anchor learning in the students' personal experience.

Standards based

The second curriculum design principle is associated with all four social constructivist features. National standards (Rutherford & Ahlgren, 1989; AAAS, 1993; NRC, 1996) were crafted by a broad coalition of organizations and leaders in the scientific and educational communities. These documents provide a framework for curriculum to communicate the language of the disciplines and engage learners in the nature of science and practices of the scientific community. The AAAS and NRC documents contain chapters that specify the sequence and substance of science concepts, specialized language, and practices and methods for asking questions and solving problems.

In addition to communicating the language, tools, and approaches of the scientific community, national standards also make claims about how to help learners understand the nature of science, advocating a pedagogical approach that promotes the active construction of knowledge.

> Student understanding is actively constructed through individual and social processes. In the same way that scientists develop their knowledge and understanding as they seek answers to questions about the natural world, students

> develop an understanding of the natural world when they are actively engaged in scientific inquiry – alone and with others. (NRC, 1996, p. 29)

Moreover, the standards promote a pedagogical approach emphasizing that learning should be situated in the life of the child.

> Inquiry into authentic questions generated from student experiences is the central strategy for teaching science. Teachers focus inquiry predominantly on real phenomena, in classrooms, outdoors, or in laboratory settings, where students are given investigations or guided toward fashioning investigations that are demanding but within their capabilities (NRC, 1996, p. 31).

In addition to the driving question situating the project in the lives of learners, it also must facilitate the learning of worthwhile science concepts. Once a driving question is framed, it is assessed based upon the potential concepts and processes that are needed to develop a knowledgeable response. These concepts and processes are then compared against the local, state and national curriculum standards. To meet curriculum standards and help students develop deep understanding of content, benchmark lessons are employed. Benchmark lessons help students learn difficult concepts, illustrate important laboratory techniques, or develop investigation strategies (Hunt & Minstrell, 1994). Benchmark lessons can also be used to model thinking or stimulate curiosity. A wide variety of student-centered teaching strategies can be used to construct benchmark lessons (Krajcik, et al., 1999).

Inquiry

Curriculum standards provide a framework for socializing students to the nature of science. Sustained inquiry is the accepted norm in the scientific community for solving problems and it is the extended engagement in this process that facilitates students' immersion in a scientific community (NRC, 1996; Perkins, 1993). Extended inquiry also provides a mechanism to facilitate discourse. As students collect, analyze and share information they must negotiate the meaning of data. By engaging in sustained investigations, students learn scientific processes and how these processes work together to generate new information. More competent community members (e.g. teachers, scientists, health professionals) may provide guidance and insight during the planing, conducting, or analysis portions of an investigation. How tight an investigation is scaffolded is determined by several factors including the complexity of the concepts, difficulty of the measuring techniques or technologies, students' familiarity with the inquiry process, and the teacher's understanding of the science being investigated.

Collaboration and Student Discourse

Projects are designed to foster student collaboration within a learning community. Students communicate with each other, teachers, community members, and scientists to find information and solutions to their questions and to discuss their findings and understandings. Projects are designed to extend student learning experiences beyond the classroom by posing driving questions that situate the science with issues that are likely to be of interest to scientists, community based organizations, and families. Students' investigations and benchmark lessons are facilitated through collaboration. Collaboration during these activities may involve students interacting with peers in small groups or as part of large class discussions, or students may interact with more knowledgeable community members.

The collaboration principle is difficult to enact in classrooms. Science involves very active collaboration among participants that is difficult to emulate in the physical space, time schedules, and norms of interaction in schools (e.g., classrooms should be orderly and quiet). In a very real sense, the collaboration principle in inquiry violates what Tyack and Cuban (1995) call the grammar of schooling—all of those taken-for-granted practices that in the aggregate constitute "real school." Moreover, the discourse elements of collaboration require a range of teacher understanding that is very challenging. The discourses of formal science disciplines represent the knowledge and the ways of knowing of the disciplines. Many teachers are not nor have they ever been actual practitioners of the science disciplines that they are asked to teach. For example, they might find it difficult to formulate researchable questions, design controlled investigations to examine those questions, represent data in various ways, or interpret findings in the face of conflicting or variable data. In a word, they may not be fluent in the discourse practices they are being asked to introduce to students. Problems such as these require careful attention in the design of the collaboration activities so that both teachers and students can engage them productively.

Learning Tools

The integration of learning technologies, new computer and telecommunications based tools that support students in intellectually challenging tasks, embodies all four social constructivist features. Our projects are designed to incorporate learning technologies that are appropriate for formulating answers to the driving question. The nature of the problem being solved and the accepted methodologies of the scientific community dictate the tools utilized in various projects.

Inquiry can be done in classrooms without learning technologies, but learning technologies expand the range of questions that can be investigated, data that can be collected, representations that can be displayed to aid interpretation, and products that can be created to demonstrate understanding. These technologies help students and teachers communicate (Levin, 1992; Pea, Edelson & Gomez, 1994), explore phenomena (Linn, 1996), find information (Wallace & Kupperman, 1997), conduct investigations (Rubin, 1993), and develop products and communicate with others (e.g., Fishman, 1996).

Learning technologies used in our projects mirror those used by scientists in the work place, but designed with learners in mind. The conceptual model used to develop these tools is learner centered design (Soloway et al., 19xx Quintana, 199X). This approach to the development of learning tools addresses technology issues that are unique to learners, including the design and deployment of scaffolds in software that are sensitive to when they are needed, fade when students no longer need help, and support complex processes that learners are not capable of completing without assistance (e.g., cueing metacognition or prompting learning strategy use). In addition, learner centered design suggests that tools should be broadly applicable in a range of projects and have commonalties in the user interface to reduce the amount of learning needed to use the tools.

Artifacts

As students conduct investigations and engage in benchmark lessons, they create a variety of artifacts. These artifacts can be shared, critiqued, and revised to further enhance understanding and serve as the basis for assessment. The parameters for the creation of artifacts are partially dictated by the context established by the driving question or related subquestions. Artifacts may also be constrained by the need to mirror representations of products constructed by community experts (e.g., simulations, models, and publication of data). As artifacts are constructed and critiqued they foster discourse within the classroom. Students may be required to explain how their artifact is related to the driving question or subquestion or represents a specific concept. By the promoting the public sharing, critiquing and revision of artifacts, active construction of student understanding is fostered.

Artifacts may be ongoing and allow for iterative points of assessment concerning the student's emerging understanding of content, process, and/or the driving question. In addition, artifacts also serve to bring closure to the curriculum project in the form of a final product and presentation (Perkins, 19xx). Artifacts used as final products allow the student to demonstrate the full scope of the knowledge and skills they constructed during the course of the project.

Scaffolds Between and Within Projects

The use of scaffolds to support student learning is strongly linked to the community of learner and discourse features of social constructivism. A fundamental notion is that the assistance of more competent others can be used to help learners accomplish more difficult tasks than they otherwise are capable of completing on their own. There is a hypothetical space between assisted and unassisted performance that Vygotsky (1978) identified as the zone of proximal development (ZPD). By identifying a learner's ZPD, a teacher can locate the psychological space in which assistance can help to propel the learner to higher levels of understanding. Because learners construct their understanding, the assistance provided in the ZPD has become known as scaffolding

Projects are designed to guide learning as students are introduced to challenging science concepts and processes. The teacher, learning materials, and technology each provide scaffolds within a project. Teachers model, coach, present key lessons and give feedback. Learning materials scaffold student learning by reducing complexity, highlighting concepts or inquiry strategies, and fostering metacognition. Technology scaffolds students by providing multiple representations, hiding complexity, and ordering and guiding processes (such as planning, building, and evaluating). Projects are also designed to support students by sequencing inquiry process and scientific concepts. Learning materials and benchmark lessons are chosen to illustrate particular strategies and the usefulness of technologies. The emphasis is on modeling skills and heuristics, such as how to create tables to keep track of data or how to transform data. This tight structuring affords students the opportunity to experience all phases of inquiry and to build a scheme of how phases of inquiry interrelate. Later, students are given more responsibilities for designing and conducting investigations. Projects are sequenced in order to revisit concepts and because the projects incorporate learning goals illustrated by local, state and national standards, these concepts are reinforced, helping students develop understanding that reflects the complexity of scientific knowledge.

Summary

Table 2 summarizes the relationships among the seven design principles, the social constructivist features described in the first section of this article, and the rationales that unite the principles and features. In the next section, we present an example of how this framework can be used to develop materials for middle a school, project-based science curriculum.

Insert Table 2 about here

An example project: "What affects the quality of air in my community?"

During the four academic school years from 1996 – 2000 the collaborative curriculum design effort of Detroit Public Schools and the Center for Learning Technologies in Urban Schools has developed and piloted six extended inquiry projects. These projects have focused on a wide range of concepts that include: a) physical science (force and motion), b) chemistry (particulate nature of matter, chemical changes, and physical changes), c) geology (hydrology, erosion and deposition), and d) biology (cells, microorganisms, immunity, and respiration). We present here the project, "What affects the quality of air in my community?" to illustrate how the design principles are manifested in an actual curriculum project. Table 3 provides an overview of this example project. The "Time" and "Subquestions and associated content" columns depicts how the project unfolds over time. In addition to illustrating the progression of the project, the far right column of the table ("Instructional component") provides a description of how the design principles are evinced within the various sections of the project.

Insert Table 3 about here

Introducing the Project with the Driving Question

The context for each curriculum project is established with the formation of a driving question. The development the driving question fir this project evolved from conversations with local community members, senior district administrators, and classroom teachers. During a parent-teacher meeting, community members described the air as having a foul odor during the summer months. This community concern in conjunction with the school district's curriculum framework and the teachers' knowledge of their school communities and students was then used as the basis for forming the project's driving question and subquestions.

Standards: Driving question. Once a driving question is framed, it is assessed based upon the potential concepts and processes that are needed to develop a knowledgeable response. These concepts and processes are then compared against the local, state and national curriculum standards. Fundamental concepts associated with "properties and changes of properties in matter" (NRC, 1996) are addressed by this driving question. A meaningful response to this driving question requires that students understand the arrangement of particles in air, the chemical structure of air pollutants, and the processes involved in the formation of air pollutants. Four subquestions were developed to insure that the curriculum materials addressed this science content.

Subquestion: What are the visible signs of air quality?

Context: Anchoring events. The driving question provides an overall context for the curriculum project and defines the larger learning environment; the subquestions introduce specific concepts. The project begins with the subquestion, “What are the visible signs of air quality?” This question focuses students on sources and effects of air pollution identified in their local community. To explore this question, students walk around their school and homes identifying potential sources and effects of air pollution. This walk, its subsequent class discussion, and emergent artifacts (observations and questions) constitute the project’s first anchoring event. The walk provides an opportunity for students to link their learning to their experience. This first anchoring event provides the opportunity for the teacher to introduce an essential inquiry support, the driving question board (DQB).

<u>Collaboration and scaffolds: Driving question board.</u> Middle school students have difficulties with several aspects of inquiry including asking questions, reflecting and making decisions concerning how best to proceed within an extended inquiry, and understanding how information, concepts, and smaller investigations relate to the driving question (Krajcik et. al, 1998). The DQB is a support structure that assists in these cognitively demanding tasks. The driving question board provides a public location where the class can identify what they know, what they need to know, and what they have learned. Students and teacher can use this space to make explicit decisions concerning the relationship of concepts to the driving question, discuss the state and future direction of the inquiry, and share and negotiate the meaning of experiments and information relevant to the driving question.

Standards: Driving question board. One of the curriculum goals for this inquiry project is that students should understand the nature of air (.e.g, air is a gas, a mixture of many small particles, and composed mostly of nitrogen and oxygen gases). Through the use of the DQB the teacher can facilitate connections between the questions the students raise and concepts needed to address the relevant ideas. One portion of this facilitation is the modification or rephrasing of questions to align with the previously designed subquestions described in the curriculum materials. For example, students' initial answers to the subquestion "What are the visible signs of air quality? Set the stage for ideas associated with the nature of air and the broader concept of particulate nature of matter.

Subquestion: So, What is air, anyway?

Context and Standards: Subquestions. The students' preliminary anwers to the first subquestion concludes with the class using the DQB to reflect and plan how the inquiry should proceed. As an outcome of this process the subquestions "So, what is air, anyway?" followed by "How are the pollutants formed?" are developed. These two subquestions are similar in that they guide and focus the investigation on ideas and skills that are needed to understand the driving question and are described by the scientific community (AAAS, NRC) as important for scientific literacy. To help the class explore these subquestions, the teacher uses benchmark lessons, artifacts, and anchoring events.

Standards: Benchmark lessons. Benchmark lessons focus on supporting students' understanding of a specific concept, skill, or process. A wide variety of student-centered teaching strategies may be used in the construction of benchmark lessons. Examples of strategies teachers can use in benchmark lessons include a) Predict, Observe, Explain (POE), b) Know, Want to Know, Learned (KWL), c) concept mapping, d) modeling, e) whole class and small group discussions and f) teacher demonstrations.

During the exploration of the subquestions "So, what is air, anyway?" and "How are the pollutants formed?" a wide variety of benchmark lessons are employed. For the first subquestion, students use a "body syntonic" (Pappert, 19XX) strategy by constructing human models of the arrangement and motion of particles within a solid, liquid and gas. This strategy is also used when students participate in additional benchmark lessons to learn the chemical structure of the six criteria air pollutants and the other compounds found in air. During this second body syntonic activity students develop human models of "clean" and polluted air.

Artifacts: iterative assessment. At the beginning of the exploration into the subquestion "So, what is air, anyway?" students are prompted to create a picture that represents their understanding of the particulate composition of "clean and polluted" air. This artifact is revisited, allowing for iterative assessment of the students' emerging understanding. After subsequent benchmark lessons illustrating the arrangement and motion of particles, chemical composition of air (an experiment in which student calculate the percentage of oxygen in air), and construction of molecules found in air (students construct models of molecules by using gum drops and toothpicks and use the computer program *e-chem* to design animated models of the same molecules), students reflect on and reconstruct their pictures.

These pre and post air pictures serve as artifacts that assess the students' changing understanding of the particulate nature of matter and as metacognitive aids for students to reflect upon how their understanding of chemical composition and the arrangement of particles in air have changed. Students compare their initial and final pictures and create a written reflection that addresses how the pictures have changed, an explanation for why one version is more "scientifically" acceptable, and how this knowledge relates to the driving question. The exploration of this subquestion concludes with the students sharing their artifacts and then using the DQB to determine the next step in addressing the driving question.

<u>Subquestion: How are the pollutants formed?</u>

<u>Collaboration: Whole class and small group discussions.</u> The project continues with the students turning their attention to the question "How are the pollutants formed?". Students are guided to this subquestion through a review of the questions, information, and artifacts posted on the DQB. Explicit connections made during this discussion include the various pollutant sources read or seen during the school walk and the differences in chemical composition of "clean" and polluted air. Through this discussion

students determine that vehicles are a major source of pollution that were observed during their community walk. This finding leads the students to an experiment testing automobile exhaust. This experiment serves as both a benchmark lesson and an anchoring experience.

Inquiry: Data collection, manipulation and analysis. Exploration of the subquestion "How are the pollutants formed?" begins with students collecting and analyzing exhaust from different types of vehicles. The investigation focuses upon the question "Do all cars pollute the same?" The experiment serves as a benchmark lesson by providing students an opportunity to use several scientific processes. Students identify variables that might affect exhaust (e.g. number of miles, size of engine, percent octane used as fuel, time since last oil change), collect data for these variables, organize the data in charts and tables, and perform simple analyses of the data (e.g., drawing graphs). The experiment ends with teams of students presenting their experimental results and conclusions. Students are supported in this investigation by several scaffolds, including the teacher modeling data collection methods, public display of example artifacts (graphs, posters, charts), rubrics for self-evaluation, and peer assessment.

Context: Anchoring event. The exhaust experiment is also an example of an anchoring experience. As students conducted this experiment they made several observations concerning the vehicles being tested. One observation is that the fuel for the vehicle is a liquid while the exhaust is a gas. Furthermore, the teacher prompts students to reflect upon the chemical composition of gasoline (focusing primarily on octane) and the chemical structures of the compounds found in the exhaust (nitrogen oxides, carbon monoxide, carbon dioxide). The phenomena of changing states and composition are used to introduce the students to benchmark lessons addressing key chemistry concepts (e.g., chemical change and conservation of matter).

Learning tools: Modeling. The subquestion, “How are the pollutants formed?” concludes with the students developing computer models of several pollutant sources and their environmental effects. Constructing, simulating, verifying and validating models pose a serious challenge for students (Mandinach & Cline, 1989; 1994). Current procedures for teaching modeling in secondary schools are complex, requiring considerable prior knowledge and mathematical ability on the part of students. To support novices in the challenges associated with creating dynamic models, we use the computer application, Model-builder, which requires minimal prior knowledge from other domains.

Model-builder helps students make qualitative models of cause and effect relationships. Through this technology, learners create objects (“things” in the system being modeled) with which he or she associates measurable, variable quantities, called factors. Learners then define relationships among those factors to show how they affect each other. Relationships can model immediate effects or effects over time. The application provides facilities for testing a model and a "Factor Map" for visualizing it as a whole. Students define objects, factors, and the relationship among the qualities of factors. For example, in building a model of air quality, air and vehicles represent objects. Factors of vehicles could include the amount of exhaust released and the number of cars in the community. Factors of air could include amount of carbon monoxide and a general quality rating. A relationship could be expressed qualitatively: As the amount of car exhaust increases, the amount of carbon monoxide in the air increases. After a model is built, students can test it to verify that their conjectures are correct. The application allows smooth transitions between building and testing. The close linking of design and testing allows students to make connections between the configuration of relationships they designed into their model and the resultant representation of the model's behavior as shown on meters and graphs.

<u>Scaffolds: Learner centered design</u>. Several scaffolds support the modeling process. In addition to the scaffolds intrinsic to the modeling software, the project also provides supports extrinsic to Model-builder (Soloway, et al., in press). Classroom supports for student modeling include experiences that provided content knowledge, tasks that ground the unfamiliar event (creating dynamic computer-based models) with a

familiar classroom event (making pictures), constraining the initial use of unfamiliar tasks, and guided manipulation of the learning technology.

In order to help students construct their initial models, the teacher engages them in a series of specifically scaffolded learning events. The first of these experiences introduces students to the content to be modeled. This content is derived from contextualizing events (e.g. school nature walk and car exhaust experiment) that focus students on potential sources and effects of air pollution. Next, the teacher guides the students through transitioning tasks that conclude with introducing students to the new learning technology. In the transitioning tasks students draw pictures of 6 - 7 things (objects) that either cause or are affected by air pollution. Small group and whole class discussions follow that focus students on their pictures, as the teacher helps the class reach a consensus about the objects they will include in their model. The class then constructs a representative class picture.

One support feature in Model-builder is the opening screen called the "worldview" that represents the possible factors and objects that can be included in a model. **(this previous sentence is not right, what whoudl we say?)** The transition phase concludes with the students making comparisons between their class pictures and the worldview. Through class discussion, similarities are drawn between the two representations. The specialized vocabulary terms "Object" and "Factor" are introduced. In addition to the transition activities, teachers scaffold students' initial computer modeling by providing tight constraints on the scope of the model so that the students are not overwhelmed by complexity.

Subquestion: How does our air measure up?

The construction of qualitative models is followed by the formation of a final response to the driving question. This final response is based on the construction of a final artifact, which is a group presentation requiring students to use their knowledge of ideas and processes associated with air pollutants. The knowledge students apply includes sources and effects of air pollution, chemical composition of air and air pollutants, and chemical formation.

Inquiry and learning tools: Data collection and visualization. The construction of the final artifact begins by students collecting and analyzing data from state and national agencies that monitor levels of the criterion pollutants. This analysis is facilitated with the use of the learning technology “Tool Soup” (Soloway, 19xx) Tool Soup is a suite of tools that, among other tools, includes data bases and a data-visualization tool. A database containing air pollution data for 10 large urban centers from around the United States is explored and analyzed by the students. Files contained in these data bases were originally obtained from national and state air monitoring stations.

Scaffolds: Teacher modeling. Teachers guide students’ initial exploration of the data base. The teacher leads the class through the collection, organization, and analysis of air pollution data for their local area. During this exploration the students explore how the pollutant levels have changed during a five year period. Based upon these data the class determines any patterns for the pollutant levels of six criterion pollutants. After this scaffolded exploration, small groups of students select a different city in the US and perform a similar analysis. It is at this point that the students begin the construction of their final artifacts.

The final artifact for this project is a performance in which small groups of students present a comparison of air pollution levels between their local area and the selected US city, description of the chemical composition of pollutants, chemical formation of pollutants, and sources and effects of pollutants. In addition to the content, performance expectations include the incorporation of multimedia or visual representations of data and active participation of all group members.

<u>Scaffolds and collaboration: Public criteria</u>. Prior to the construction of the artifact, students are provided with a rubric and checklist of the key components of the artifact. Students then watch a video tape of presentations from previous years in order to view and discuss the merits of a quality product. While watching the video clips students complete a rubric. At the completion of each presentation segment the strengths and weaknesses of the presentation are discussed. In addition to the use of rubrics and past presentation, students are also provided with checklists to facilitate this construction process. The checklists help groups organize their work and a means for the teacher to assess progress.

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Table 1.
Curriculum Design Principles

Design Principle	Description	Examples of Instructional Components
Context	Meaningful, defined problem space that provides intellectual challenge for the learner	· Driving questions · Sub-questions · Anchoring events
Standards based	Publications by experts that define the language and methods of the scientific community	· AAAS Benchmarks 1) NRC National Standards · Benchmark lessons
Inquiry	The scientific community's method for solving problems; the way by which scientists and students ask questions about and investigate the natural world	· Asking questions · Collecting, organizing and analyzing data · Sharing and communicating data
Collaboration	Interaction among students, teachers, and community members to share information and negotiate meaning	· Small group meetings · Think, pair, share learning strategy · Group presentations
Learning tools	Tools that support students in intellectually challenging tasks	· Data collection · Telecommunication · Modeling
Artifacts	Representations of ideas or concepts that can be shared, critiqued, and revised to enhance learning	· Concept maps · Scientific models · Lab reports
Scaffolds	Instructional supports that fade over time so that novices can focus on and master tasks that they cannot do without assistance	· Learner centered design · Teaching strategies e.g., Predict, observe, explain Driving question board

Table 2.

Summary of the Use of Design Principles in Curriculum Materials

Design Principle	Social Constructivist Feature	Rationale
Context	Situated	· Driving question and sub-question provide meaningful, specific space for student engagement
	Community	· Scientific culture determines the manner that questions are framed and the manner in which they are investigated
	Active construction	· Sub-questions and anchoring events focus students on relationships between newly constructed concepts and ideas
Standards	Situated	· Provides framework for the specific strategies for identifying and solving problems
	Community	· Developed by larger scientific community for means of enculturating novices into the nature of science
	Active construction	· Methodological approach advocated by the publication
	Discourse	· Provides framework for the specialized language of the community
Inquiry	Community	· The accepted approach by the scientific community for solving problems
	Active construction	· Extended inquiry engages students directly with the phenomena and supports the learning of key scientific concepts.
Collaboration	Community	· An essential part of a community is interaction among its members to share information and reach consensus decisions

Active construction	·	Collaboration among peers and knowledgeable experts necessitates the need for specialized language

Table 2.

Summary of the Use of Design Principles in Curriculum Materials

Design Principle	Social Constructivist Feature	Rationale
Tools	Situated	· The nature of the situation defined by the driving questions constrains the appropriateness of the tools utilized
	Community	· Tools mirror those used by members of the scientific community
	Active construction	· Tools engage learners in intellectually challenging tasks and scaffold their learning
	Discourse	· Learning tools foster communication among local and extended community members
Artifacts	Situated	· Parameters for the creation of artifacts are guided by driving question and sub-questions
	Community	· Artifacts mirror representations of products constructed by community experts
	Active construction	· Construction and critique of artifacts foster classroom discourse
	Discourse	· Public sharing, critiquing and revision of artifacts, promotes active construction of understanding
Scaffolds	Situated	· Use of sub-questions allows key concepts and processes to be made explicit
	Community	· More competent members assist learners in the zone of proximal development
	Active construction	· Learner centered design of technology, provides multiple representations, hides complexity and sequences processes

Table 3.

Overview of the curriculum project “What affects the quality of air in my community?”

Time	Sub-questions and associated content	Instructional component
Week 1	What are the visible signs of air quality? · Sources and effects of air pollution · Introduction of driving question	· Sub-question · Anchoring event · Asking Questions
Weeks 2 - 3	So, What is air, anyway? · Atoms, molecules, compounds · States of matter	· Driving Question Board · Small group and whole class sharing · Benchmark lessons · Modeling of compounds (e-chem). · Pre/Post representations of composition and arrangement of particles in air

Weeks 4 - 6	How are the pollutants formed? · Phase changes · Indicators of chemical changes · Chemical reactions · Conservation of matter	· Driving Question Board · Data collection, manipulation, organization, and analysis · Small group and whole class sharing · Presentations with reflections and critiques · Benchmark lessons · Modeling of sources and effects of air pollution
Weeks 7 – 8	How does our air measure up? · Sources and effects of air pollution · Atoms, molecules, compounds · States of matter · Chemical reactions	· Data collection, manipulation, organization, and analysis · Comparison and analysis of air quality data from multiple large urban centers – (Tool Soup) · Small group and whole class sharing · Final Presentations with reflections and critiques