The Evolution of Water:

Designing and Developing Effective Curricula

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Introduction

Water quality is a popular subject to develop curricula around, and justifiably so due to its relevance to students' lives and the worthwhile content that can be learned within this context (Manzanal, Barreiro, & Jiménez, 1999). In this paper we present our methods for the design and development of challenging reform-based curricula, using water quality as a means of demonstrating this process. We are working in the context of the Center for Learning Technologies in Urban Schools (LeTUS). LeTUS is a joint partnership with the University of Michigan, the Detroit Public School System, Northwestern University, and the Chicago Public School System. The goal of the Center is to infuse the use of effective learning technologies in urban Detroit and Chicago schools at a systemic level. In order to accomplish this goal, the Center utilizes the framework of project-based science (PBS), using a combination of custom-developed curricula, innovative technologies, and intensive professional development for middle school science teachers in these urban settings. Among other issues, we found that the school system needed appropriate curricula to most effectively use innovative technologies to support learning. Therefor, we took as part of our mission of systemic change the development of curriculum projects. These projects are guided by seven design principles that draw from ideas about thinking and learning related to social constructivist theory.

The purpose of this paper is to share our experiences with the educational community in the hope that others may be informed and supported by the work that we have done. Additionally, we would like to be able to share and learn from our colleagues at other institutions whom are also developing innovative curricula and technology. By clearly articulating our design principles and methods in the context of a common theme such as water quality, we believe that others will be able to understand and adapt our curricula to fit their needs and framework, while possibly informing us of how we might improve our materials and methods.

This paper first presents an outline of our theoretical perspective on thinking and learning, and a description of our seven design principles based on this model. Next, we describe in detail the water quality curriculum project, "What is the water like in our river?", and highlight the ways that our design principles are brought to bear in this project. In the next section we discuss our development process and cyclical method of curriculum revisions. We use the development and revision of the water quality project as an example of this process. In the final section of this paper, we return to the benefits of collaboration with our peers and reflect on the ways that this presentation of our design and methods may inform other reform efforts.

Design Principles of Project-Based Science

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

Theoretical Underpinnings

Our curriculum materials are based on a model of thinking and learning that is grounded in a social constructivist perspective (Blumenfeld, et al., 1997). A social constructivist approach to learning is one where students construct understanding or meaning about ideas and concepts through their interactions with the world and others, and their interpretations of these interactions (Lave &Wenger, 1991). Fundamental to this perspective are the salient features of *active construction*, *situated cognition*, *community*, and *discourse*.

Students *actively 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; 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). 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. They appropriate the symbolic forms of others and the functionality of those forms through language. Hence, the learner becomes a member of a *discourse* community.

From this perspective on social constructivism, we have developed an approach to teaching and learning that we call project-based science. This approach to learning through inquiry embeds the pervasive use of technologies in collaborative classroom settings (Marx, et al. 1997). In the next part of this section, we describe the principles we have derived from social constructivist theory and the literature on science education standards that guide the development of projects (Singer et al, in press). The descriptions of each design principle are followed by an example from the water quality project, "What is the water like in our river?", which exemplifies how our design principles are brought to bear in our curriculum materials. Appendix A provides an overview of this example project. The “Time” and “Sub-questions and associated content” columns depict how the project unfolds over time. In addition to illustrating the progression of the project, the far right column of the table (“Instructional component”) describes how the design principles are evinced within the project.

The Seven Design Principles of Project-Based Science Learning Environments

Contextualization

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), thereby situating learning for students. The driving question uses students’ real world experiences to contextualize scientific ideas, while the use of subquestions and anchoring events support students as they apply their emerging scientific understandings to the real world, thus helping them see value in their academic work. 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. By using subquestions and insuring that the students understand the relations among the driving question and its subquestions, we help students keep the driving question in mind throughout the project. Careful construction of the questions allows them to cumulate over the project 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, 1992) help render abstract ideas more concrete and thus provide a cognitive mooring around which newly learned ideas can be linked with prior understandings.

The context for this curriculum project relates hydrology and geological concepts to a problem of substantial interest to urban communities – water quality. This curriculum project is “driven” by the question “What is the water like in our river?”. Through the investigation of this question, students have opportunities to interact with natural phenomena and learn about processes that influence the source of their local drinking water. The driving question, “What is the water like in our river?”, is broad and open-ended in order to be authentic and encompass worthwhile science content. Therefor, the project uses related subquestions that help students link learning activities back to the driving question. The project is organized around three main sub-questions (Appendix A) developed to insure that the curriculum materials address science content and processes associated with district curriculum standards.

The first sub-question of this project is “What do we know and need to know about our river?” This sub-question focuses students in expressing their initial understanding and provides a means for engaging students by having them ask questions that specifically interest them. To explore this question, students “walk” and observe a local river. This walk is supported by the use of a CD-based visual “virtual river tour”. This walk, its subsequent class discussion, and emergent artifacts (observations and questions) constitute the project’s first anchoring event. The walk serves as an anchoring event by providing opportunities for students to link their learning to their experience. The observations recorded and questions raised during this walk are revisited throughout the course of the project.

Standards Based

The second curriculum design principle is associated with all four social constructivist features. National standards (Rutherford & Ahlgren, 1989; AAAS, 1993; NRC, 1996) provide frameworks 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, and emphasizing that learning should be situated in the life of the child.

One of the curriculum goals for this inquiry project is that students utilize models to understand factors that affect the flow, shape and water quality of rivers. Through iterative cycles of planning, building, testing and discussing a variety of models the curriculum addresses many middle school objectives recommended by the *Benchmarks for Science Literacy* (AAAS, 1993). These objectives include: fundamental hydrology concepts such as the flow of water over land into rivers and lakes, and the pollution of natural waterways (Benchmarks 4B, #7 and #8); scientific processes such as understanding and working with models (Benchmarks 11A, #2 and 11B, #1 and #3); and inquiry skills such as identifying and controlling variables (Benchmark 1B, #2).

One of the ways we support the development of standards throughout the project is the use of benchmark lessons. These lessons foster understanding and connections between key scientific concepts. During benchmark lessons, teachers also introduce domain specific terminology and processes. For example, during the exploration of the sub-question “Where is my river located?” the teacher uses pedagogical strategies in benchmark lessons, such as the POE—Predict, Observe, Explain—cycle, questioning methods using KWL--Know, Want to Know, Learned, whole class and small group discussions, and teacher demonstrations. In the exploration of this particular sub-question, students construct a series of physical models that illustrate the key ideas. The first physical model involves the building of a watershed model. Students then predict, observe and explain the patterns of how the water flowed. Additional physical models are used later to explore the relationships of land usage on the flow path and quality of a river. Students utilize stream tables and alter factors such as the type of land cover (bare soil, vegetation, pavement), introduction of non-point source pollutants, and current velocity. Based upon changing and observing these variables students explore the concepts of erosion, deposition, and non-point source pollutants.

Inquiry

It is the extended engagement in sustained inquiry 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. Inquiry allows students to experience a range of scientific phenomena. Investigations not only allow students to make observations but also to manipulate variables to see how phenomena change under different conditions. By engaging in sustained investigations, students learn scientific processes, such as analyzing data and supporting conclusions using evidence, and how these processes work together to generate new information.

Exploration of the sub-question "What impacts water quality?" begins with students working in groups to collect and analyze data from controlled experiments that explore the affect of fertilizer and acid on aquatic plant growth. The experiment provides students an opportunity to use several scientific processes. Students form their own hypotheses and procedures, select variables of interest and collect data, organize the data in charts and tables, and perform simple analyses of the data (e.g., drawing graphs). In addition to the aquatic plant experiment, students also collect and analyze data from their local river. During this exploration the students have the option to conduct a variety of tests (pH, phosphates, nitrates, fecal coliform, dissolved oxygen, temperature, turbidity, etc.) and are able to calculate an overall water quality rating for the river.

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.

One primary strategy for fostering collaboration is the extensive use of small and large group discussions. For example when introducing the sub-question "What do we know and need to know about our river?", a class discussion is used to review student generated questions, information, and artifacts. In this discussion, past student experiences and the contextualizing river walk are explicitly connected to information about various pollution sources presented earlier. Through this discussion students develop sub-questions to facilitate their investigation of the driving question

Another activity engages students in small group collaborative work in order to conduct their investigations. For example, when examining factors that affect the growth of aquatic plants, students identify, plan, and conduct experiments in small collaborative groups. The groups plan the experiment by selecting variables, developing hypotheses and procedures, collecting and analyzing data, developing conclusions, and sharing findings in the form of group presentations. During this collaborative exercise students must reach consensus on the meaning of their findings they investigated and provide the class with evidence for their conclusions.

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. 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 (Scardamlia & Bereiter, 1996; Edelson, Gordin, and Pea. 1999)..

One of the major types of technology that are utilized in this project is the dynamic modeling tool Model-builder. Model-builder enables students to make qualitative models of cause and effect relationships. When using Model-builder, learners create objects (“things” in the system being modeled) with which they associate measurable, variable quantities called factors. Students then define relationships among factors to show how they affect each other. Relationships can model immediate effects or effects over time. The application provides opportunities for testing a model and a “Factor Map” for visualizing it as a whole. Students define objects, factors, and relationships among the qualities of factors. For example, in a model of water quality, river and land represent objects. Factors of land include the amount of run-off and the amount of fertilizer sprayed in the community. Factors of river include the amount of phosphates in the water and a general quality rating. A relationship can then be expressed qualitatively: As the amount of fertilizer sprayed increases, the amount of phosphates in the river increases. After a model is built, students test it to verify that their conjectures are correct. The application enables smooth transitions between building and testing. By closely linking design and testing, students are able to make connections between the configuration of relationships they included in their model and the resulting representation of the model’s behavior as shown on meters and graphs.

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. As artifacts are constructed and critiqued they foster discourse within the classroom. Students may explain how their artifact is related to the driving question or subquestion or represents a specific concept. By promoting 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 of students’ emerging understanding of content, process, and 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, 1993). Artifacts used as final products allow students to demonstrate the full scope of the knowledge and skills they constructed during the course of the project.

Students develop three major types of artifacts during this curriculum project. These artifact types include models (physical and computer based), laboratory reports, and presentations. During the exploration of the sub-question “Where is my river located?” students create a series of physical and dynamic computer models. After each of these models is constructed, small groups of students present and explain them to their classmates. For example after the completion of the stream table models, student groups become “experts” in one of three types of water flow modes in different land uses (rural, residential, or urban). These expert groups share their expertise to their classmates by utilizing and explaining a short video segment of water flowing through their specific setting. The class compares the different results and relates them to their river.

The project culminates with the construction of a response to the driving question. Students construct a final artifact, which is a group plan and presentation requiring students to use their knowledge of ideas and processes associated with water pollutants. The presentation provides opportunities for students to apply their knowledge to explain the driving question, such as comparing water quality data from different locations and sharing their predictions for the sources and chemical composition of pollution in their river.

Scaffolds Between and Within Projects

The use of scaffolds to support student learning is strongly linked to the community of learners and discourse features of social constructivism. Projects are designed to guide learning as students are introduced to challenging science concepts and processes. Learning materials scaffold students by reducing complexity, highlighting concepts or inquiry strategies, and fostering metacognition. 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.

Middle school students have difficulties with several aspects of inquiry including asking questions, 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 driving question board (DQB) is a support structure that assists in these cognitively demanding tasks. The DQB provides a public location where the class can identify what they know, what they need to know, and what they have learned. Students and teachers use this space to explicitly relate 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. The teacher adds information to the DQB continuously during the project, such as student-generated subquestions, decisions about how to conduct investigations, and representations of data. In particular, conjectures that students raise about possible meaning of data are posted, to highlight the importance of interpretation in inquiry.

Constructing, simulating, verifying and validating models pose a serious challenge for students (Mandinach & Cline, 1989). Current procedures for teaching models are complex, requiring considerable prior knowledge and mathematical ability on the part of students. To scaffold novices in the challenges associated with creating dynamic models, we use the computer application, Model-builder, which requires minimal prior knowledge from other domains. 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 events such as the river walk and building physical models of watersheds. In these physical watershed models, the students use paper to represent land, a spray bottle to represent rain, and the water flowing over the paper represents rivers and lakes. These activities focus students on factors that affect the flow of water. Next, the teacher guides the students through transitioning tasks that conclude with introducing students to the new learning technology. Small group and whole class discussions focus students on key model parts, how they changed during the modeling activity and how they were measured. The teacher uses these ideas in class discussion to introduce the key Model-builder terms “objects” and “factors”. As a result of this transitioning activity, the students use the key ideas from the physical models to construct their computer models. The computer models are re-visited and used as a means to link new and previously learned concepts and relationships about watersheds and pollution.

Table 1 summarizes the relationships among the seven design principles, the social constructivist features described in the first section of this paper, and the rationales that unite the principles and features. In the next section, we present our process of developing and revising curriculum materials that embody these design priciples.

Table 1: Curriculum Design Principles

Design Principle	Description	Instructional Component
Context	Meaningful, defined problem space that provides intellectual challenge for the learner	· Driving Questions · Sub-Questions · Anchoring Events
Standards based	Publication by larger community experts that defines the language and methods of the larger community	AAAS –Benchmarks NRC–National Standards Benchmark lessons
Inquiry	The accepted method of the scientific community for solving problems. It is a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena (NRC, 1996 , p. 214)	Asking Questions Data collection, organization and analysis · Sharing and communicating data
Collaboration	Interaction students, teachers, and community members to share information and negotiate meaning	· Small group design meetings · Think, pair, share learning strategy · Group presentations
Learning Tools	Tools that support students in intellectually challenging tasks	· Data Collection · Communication · Modeling
Artifacts	Representations of ideas or concepts that can be shared, critiqued, and revised to enhance learning.	· Concept maps · Scientific models · Lab reports
Scaffolds	A series of methods which fade over time to control learning activities that are beyond the novices' capabilities so that they can focus on and master those features of the task that they can grasp quickly (Schunk, 1996)	· Learner centered design · Teaching strategies · POE: Predict, observe, explain · Driving Question Board

From Singer et al, in press

Process of Design and Revision of Curriculum Materials

The Center for Learning Technologies in Urban Schools has developed a process for formulating and improving curriculum materials that has proven to be successful in the creation of challenging inquiry based curriculum for diverse learners that embeds technology. Our development and iterative process of revision of curriculum materials is represented in figure 1.

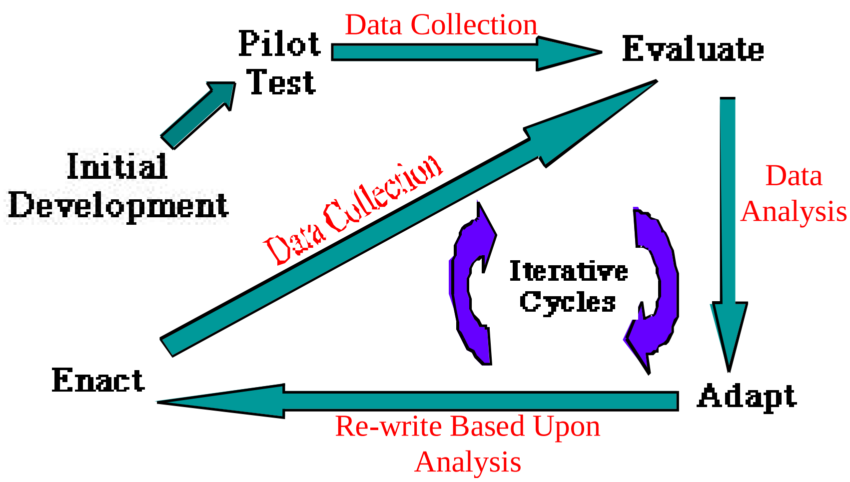

Figure 1: Development and Revision Cycle of LeTUS curriculum materials (Singer, 2000)

Each of our curriculum projects is developed using the same general process. Initial design and development takes place within curriculum-specific work circles consisting of teachers, university educators and researchers, and content experts. Initial development takes place in several steps. First, using national and local standards and curriculum frameworks the work circle maps out the content coverage and appropriate presentation of ideas and representations. Second, the driving question and associated contextualization activities are developed based on relevance and interest to urban middle-school students and worthwhile content coverage needed to address the question. The third steps is to develop the sequence and structure of the inquiry activities and benchmark lessons to align with our seven design principles, with particular attention paid to the integration of appropriate technology to support learning.

An initial, usually abbreviated pilot test of the project is conducted in one or two classrooms in Detroit. These pilot tests are characterized by intensive observation and professional development, as the classroom teachers, university researchers, and students negotiate the successes and difficulties of the newly formulated project. We gather and analyze the data collected from this pilot to determine where teachers and students had difficulty and what parts of the curriculum may be missing. In addition to observational data, we also collect student artifacts and conduct student and teacher interviews. Following the pilot there is a second phase of intensive curriculum development and revision which uses this data and analysis to improve the project. Such revisions include reworking or replacing lessons or investigations, adding teacher support within the materials, developing and working in the transition and reflection/meaning-making activities, and evaluating content and process objectives for their linear development throughout the unit.

From this point the project transitions into an iterative cycle of enactment, analysis, and revision. During enactment, teachers receive professional development in the form of individual in-class support and larger group workshop sessions. Additionally, in-depth data collection is conducted during each enactment. This includes videotaped observations of classroom enactment, pre- and posttests administered to measure content and process skill gains, individual student interviews for content and process skill understandings as well as attitudes towards the project and science in general, a survey to gauge student attitudes about science, collection of student artifacts, and teacher exit interviews.

Each of these data sources are analyzed independently, and then brought together to form a whole picture of the project's enactment. Revisions to the curriculum project are made based on evidence from a combination of data sources. Examples of the types of revisions made from this data range from adding educative features to the curriculum materials to help teachers identify common student misconceptions, to the restructuring of a sequence of activities to further capitalize on the learning opportunities provided by technology tools.

Through each phase of this iterative process of enactment, analysis, and revision, the curriculum projects become more complete, as well as more usable by a broader range of teachers. The activities build on each other, the sequence becomes more appropriate for middle-school students, the activities make the concepts addressed in each project more salient, educative features are added, and pedagogical techniques are utilized. Each progressive iteration involves scale-up issues as well, such as increased numbers of teachers, students, and schools participate in the project. The ability for us to observe the curriculum projects in a variety of classroom settings enables us to fine-tune the curriculum materials to be user-friendly for teachers of all abilities across the district, as well as provide us a realistic view of the potential of our projects to help students learn science content and process skills.

In the next section, we present the development of the project "What is the water like in our river?". We will use this project to exemplify our development process.

Development of the project "What is the water like in our river?"

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). These projects encompass science content that relates to national science education standards and local school district curriculum frameworks. The projects currently are in various stages of the development process described above. However, the same development method has been used in each case. In order to exemplify this process, we next present the development of the water quality project, "What is the water like in our river?". The history of the development and revisions of this project is summarized in Table 2. This project is currently in its fourth iteration of analysis, adaptation, and enactment. Each phase of development and revision of the water quality project was conducted over the course of one academic year.

Table 2: An overview of the history of the development of the project "What is the water like in our river?"

Development Phase	Results of Analysis	Revisions Made
Initial development and pilot	· Initial design informed by teachers and community members · A primary goal was to embed the use of dynamic modeling and portable technologies	· Initial content coverage mapped out · Driving question and contextualization activities formulated · Sequence of inquiry activities developed
Second Iteration	· Focus of project needed to be clarified	· Clarification of Standards, Benchmarks, and local education objectives to focus on hydrology, geology, and modeling
	· Teachers needed more complete materials in order to be usable in a variety of settings	· Development of instructional sequence, scaffolds for students and strategies to support teachers
Third Iteration	· The project took too much time to enact · The project became decontextualized, students and teachers loss sight of the driving question	· Project activities were re-sequenced · Revisions tried to achieve a balance between content, context, and process
Fourth Iteration	· Students did not receive sufficient supports for developing their understanding of concepts and applications to the driving question	· We developed SORT (Support Opportunities Resource Tool), which includes a reader to provide additional opportunities and representations for students to develop their understanding
	· Teachers had difficulty contextualizing the project and did not refer often to the river walk	· As part of SORT we developed a CD-based "virtual tour" to enhance and support the river walk and allow students to return frequently to the event
	· Students had difficulty linking physical and dynamic models, in particular relationships between objects and factors	· Activities were re-sequenced and additional supports were added to make explicit connections to objects and factors in both physical and dynamic models

Initial Development and Pilot Test – Spring 1997

Initial development of the water quality project developed from activities that were currently taking place in several schools in Detroit as part of the Friends of the Rouge River water quality project. In this project students were studying the causes and effects of pollution in their local river, taking water quality measurements, and submitting them to the Friends of the Rouge project. Through conversations with teachers and community members, it was decided that the topic of water quality would be worthwhile to pursue for one of our curriculum projects. One of the first goals in the initial development of the water quality unit was to embed the use of dynamic modeling and portable technologies. From past experiences working in high schools, we understood that water quality is a productive context to introduce these types of technology tools. Activities were developed which integrated Model-It (an early form of Model-builder), a dynamic modeling software package developed at the University of Michigan. The use of probes with E-mate computers was also integrated into the first version of the water quality project.

Second Iteration – Spring 1998

Data collected from the initial pilot test indicated that one change that needed to be made to the water quality curriculum was the clarification of the national and local content and process objectives that were being addressed in this project. We decided to change the emphasis from chemistry to hydrology and geology aspect of water quality. For instance, the project now meets specific Benchmarks such as the flow of water over land and the pollution of natural waterways (4B, #7 and #8). Activities were revised and sequenced as to provide for this adjustment in focus of the unit. In addition, we found the need to provide teachers with a more complete instructional sequence with detailed suggestions for enactment. These materials also included scaffolds for student learning and strategies to support teachers, such as identification of student misconceptions, organizational methods, and specific teacher content information. It was at this point that we began to articulate the design principles of Project-Based Science and use them to design our curriculum materials.

Third Iteration – Spring 1999

The third iteration of analysis, revision, and enactment of the water quality unit found that across a number of teachers, there were two predominate issues that hindered the effectiveness of the project. The first issue was that the project took too long to complete. Being a spring project, teachers were trying to complete the water unit at the end of the school year and facing many scheduling difficulties. To alleviate time pressures teachers would rush through the development of ideas, such as asking students to complete chemical water tests without understanding the concepts behind the tests. These alterations came at the cost of bring closure and fostering a more complete understanding of the driving question and water quality for students. The second issue was that based on classroom observations and teacher interviews, the project seemed to become decontextualized and both teachers and students lost sight of the driving question. Both of these issues were addressed in the subsequent revision process. A number of activities in the unit were re-sequenced, and the certain issues were made more salient across the project. We also tried to reach a balance between content, context, and process throughout the project. For example, prior to the water quality testing activities in the field, students spent a substantial amount of time learning about the scientific principles behind each test, such as dissolved oxygen and pH. This set of activities posed several problems: the content and sequence was difficult for students to grasp, it took time away from other important activities in the project, and the purpose for learning about these tests and how they related to water quality became unclear. In subsequent revisions, this set of activities was re-sequenced to reduce complexity and emphasize the connections between the science content and water quality factors.

Fourth Iteration – Spring 2000

The most recent revisions made prior to the current enactment were minor in comparison to those made in previous iterations. These revisions are based on the data collected during the third enactment, in which 9 teachers at 7 schools and approximately 800 students participated in the water quality project. Presented below are three examples of revisions made to the current curriculum materials based on evidence gathered from this third enactment.

First, although the project was successful and we had documented increased learning gains over the course of the previous enactments, we felt that overall students were not fully accomplishing the learning goals that we had laid out for the project. We determined this fact by looking across the board at several of our data sources on the water quality project enactment – classroom observations, student interviews, analysis of artifacts, and posttest score gains. From this analysis we determined that one significant factor contributing to this observation was that students do not receive sufficient support for their developing understanding of the content and application of the concepts to answer the driving question. Therefor, we developed a suite of tools which we call Support Opportunities Resource Tools (SORT). The goal of SORT is to provide additional opportunities for students to engage with the content that is presented in class. One of these tools is a student reader to supplement the water quality project. This reader, and the other tools in SORT, is tied closely to the activities conducted in class, and is designed to provide other ways of thinking about those activities. SORT both reinforces representations used in class and presents new representations of the content and the context of water quality. This provides a place where students reflect, build explanations, and practice the use of ideas as they develop their understanding. For example, we noticed that in pre/posttest scores, there was little gain in students' ability to read maps of watersheds. This is an important objective in the Detroit Public Schools curriculum and appears on the state achievement test, but in the initial curriculum design students were given only one opportunity to work with this content. So this is one topic we addressed in the SORT student reader, connecting it to the context of the students' own local river. This exposure allows another opportunity for students to reflect on this concept and integrate it with other content related to water quality.

A second area of revision in the water quality project involved the driving question and anchoring experiences of the water quality project. Observation data indicated that teachers had a difficult time contextualizing the project. Many had difficulty organizing a river walk for their students, and frequently teachers did not return often to the river walk experience as a way of building on the driving question. Data from student artifacts and interviews also indicated that students did not see a connection between the content presented in class and the context of the water quality project. Direct engagement with natural phenomena is the ideal strategy for contextualizing projects, but a potential limitation of this strategy occurs if students do not have easy access to the phenomena being investigated, in this case a river. To address this issue, we developed a second tool as part of SORT, a CD-based 'virtual river tour' to enhance and support the river walk. The 'virtual tour' is a series of web pages that allow students to observe and compare three different locations of their local watershed. A map of the students' community is used to provide contextual clues of the locations so student can identify the sites in relation to their specific neighborhood. The use of multiple locations allows the virtual tour to enhance the initial contextualizing events of the project for all students. Comparison of multiple locations provides greater opportunities for learning than in previous project enactments. First, the tour facilitates student questioning by providing an enhanced set of experiences concerning differences in locations. Secondly, the tour provides opportunities for students to see connections between land use and river features. Furthermore, the tour allows the learning community to extend to additional schools located on the tour map. This feature has the potential to foster future communication and sharing of data between other schools participating in the project. Finally, the tour allows for a set of artifacts that serve as a cognitive anchor. The pictures can be re-visited to highlight specific concepts and provide continual connections to the driving question.

A third area of revision made to the current curriculum materials involves the use of physical and computer-based dynamic models in the project. As mentioned previously, one of the primary objectives of this project is to develop student understanding of and ability to work with models. Observations of student activities and an analysis of student artifacts (previous models they have created) showed that students have difficulty linking the physical models they work with in the classroom, such as the watershed models described earlier, to dynamic models they create using Model-builder. In particular, students had difficulty connecting objects in the model with their associated features or factors, in both the physical and dynamic models. We revised the water quality project to specifically address this important benchmark. We modified the sequence of Model-builder activities to illustrate the close association between these models and the physical models the students work with in the classroom. Students first focus on physical models, where the notion of what models are and how they represent the real world is stressed. They move first from the physical watershed models to the dynamic computer based models, then return to more advanced physical models before revising their dynamic models again. This process is repeated over the course of the project, so students have the opportunity to create and modify dynamic models three times. The support materials for students, including both the activity worksheets and the reading materials in SORT, were adapted to make the link between physical and dynamic models more explicit. In particular, both the teacher and student materials focus on the identification of objects and their associated factors in the physical models and making the connection to the same concepts in the Model-builder models.

Conclusions

Our goal is the design and development of curriculum materials that can promote the learning of intellectually challenging science content by diverse student populations. An additional challenge is to explore the benefits learning technologies might have to promote learning. We assume that the power of new learning technologies is limited unless they become embedded in curriculum.

In this paper, we described a set of design principles that, when embodied in project-based curriculum materials, enable students to engage in inquiry, make use of new learning technologies, and promote student learning. These curriculum principles, derived from features of social constructivism, are consistent with recommendations by AAAS and NRC. Together with teachers and administrators from Detroit Public Schools, we developed five middle school science units: a sixth grade unit on mechanical advantage; seventh grade units on air quality and water quality; and eighth grade units on force and motion and communicable disease and the immune system.

In this paper we also discussed a process for developing these materials, focusing on the iterative revision process of analysis, adaptation, and enactment. This development process is rooted in the theories of thinking and learning that are substantiated in our curriculum design principles, and requires the use of in-depth data collection and analysis techniques to inform and justify curriculum revisions (Schneider and Rivet, NARST 2000). We have found that these are two critical features of our work, our design principles and design process, are intertwined with each other. During the iterative process of curriculum and revision, we strive continually to embody our design principles to the fullest extent possible. Likewise, the articulation of our design features stem from repeated attempts to represent and enact theories of thinking and learning.

Through our work, we have found that it is difficult to develop challenging curriculum for urban students. It takes many years and multiple iterations to improve curriculum. However, successive revisions based on multiple data sources can help build curriculum that engages students in phenomena and embed technology. The cyclic nature of our development and revision process helps us to focus on the content and inquiry skills that we really find important. This process also enables us to identify appropriate representations and an activity sequence which allows conceptual ideas to build through the projects. Working in teams with teachers, district administrators and content specialists, the cycles of development and revision allows us to create curriculum materials that we feel have the potential to scale to a district level.

Our design of curriculum represents one member of a family of social constructivist teaching and learning approaches. The design principles and the curriculum materials we have developed from them are only one possible interpretation of the literature. Other learning environments can also result from these theoretical concepts. For instance, Linn's Knowledge Integration Environment (Linn, 1998), Edelson's "Climate Visualizer" (Edelson et. al. 1999) and Songer's Kids as Global Scientists (Songer, 1998) are based on several of the same theoretical ideas as we have described. Although these curriculum materials bear some similarity to ours, important differences exist. For example, we stress contextualization as a critical feature while Linn has articulated more of the supports necessary for students to build evidence-based arguments. Curriculum materials developed as part of Edelson's Weather Visualizer provide explicit supports for the development of general inquiry skills. Songer's Kids as Global Scientists emphasizes the use of telecommunications to allow access to real time data. The work of all these curriculum projects and the work we report impact student learning. Thus, we believe that the results of design research in instruction can take many successful paths.

Through this presentation of our curriculum design priciples and development process, we are able to share our experiences with the educational community in the hope that others may be informed and supported by the work that we have done. We also believe that through this emerging conversation regarding science education reform, we will be able to learn from our colleagues at other institutions whom are also developing innovative curricula and technology. It is our hope that by conversing and sharing amongst all members who are striving for science education improvement, we will be able to work together to instantiate extensive and lasting reform.

References

American Association for the Advancement of Science (1993). *Benchmarks for Science Literacy.* New York: Oxford University Press.

Blumenfeld, P.C., & Marx, R.W., Patrick, H., & Krajcik, J. S. (1997). Teaching for understanding. In B.J. Biddle, T.L. Good, and I.F. Goodson (Eds.). *International handbook of teachers and teaching*. pp 819-878. Dordrecht, The Netherlands:

Cognition and Technology Group at Vanderbilt. (1992). The Jasper series as an example of anchored instruction: Theory, program description, and assessment data. *Educational Psychologist, 27* 291-315.

Edelson, D. C., Gordin, D. N., and Pea, R.D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *The Journal of the Learning Sciences* 8(3&4) 391-450. Lawrence Erlbaum Associates. Mahwah, NJ.

Krajcik, J., Czerniak, C., & Berger, C., (1999*). Teaching Children Science: A project-based approach.*. Boston, MA: Mc Graw-Hill.

Krajcik, J., Blumenfeld, P., Marx R. W., Bass, K. M., Fredericks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *Journal of the Learning Science*, *7*(3&4), 313-350.

Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Linn, M.C. (1998) The impact of technology on science instruction: Historical trends and current opportunities. *International handbook of science education.* D. Tobin and B.J. Fraser. The Netherlands: Kluwer.

Mandinach, E., & Cline, H.l (1989). Applications of simulation and modeling in precollege instruction. *Machine-Mediated Learning, 3*, 189-205.

Manzanal, R. F., Barreiro, L. M. R., & Jiménez, M. C. (1999). Relationship between ecology fieldwork and student attitudes toward environmental projection. *Journal of Research in Science Teaching*, 36(4), 431-453

Marx, R. W., Blumenfeld, P. Krajcik, S. & Soloway, E. (1997). Enacting project-based science. *The Elementary School Journal*, 97 (4), 341 – 358.

National Research Council (1996). *National Science Education Standards.* Washington, DC: National Academy Press.

Perkins, D. N. (1993). Teaching for understanding. *American Educator*, *Fall, 28-35*

Roth, W. M. (1994). Experimenting in a constructivist high school physics laboratory. *Journal of Research in Science Teaching, 31,* 197-223.

Rutherford, F.J., & Ahlgren, A. (1990). *Science for All Americans*., New York, NY: Oxford Press.

Scardamalia, M. and Bereiter, C. (1996). Computer support for knowledge-building communities. In T. Koschmann (Ed.). CSCL: *Theory and practice of an emerging paradign*m (pp. 249-268). Mahwah: Lawrence Erlbaum Associates.

Schunk, D., (2000). *Learning theories: An educational perspective.* Upper Saddle River, NJ: Prentice Hall, Inc.

Schneider, R. and Rivet, A. (2000). Curriculum revision as a research activity: Using classrooms to improve curriculum. Paper presented at the annual meeting of the National Association for Research in Science Teaching. New Orleans, LA.

Singer, J. (2000) Constructing Extended Inquiry Projects: Curriculum Materials for Science Education Reform. Presented at the annual meeting of the Association for Educators of Teachers of Science. Akron, OH

Singer, J., Marx, R., Krajcik, J., & Chambers, J. (in press) Constructing Extended Inquiry Projects: Curriculum Materials for Science Education Reform. *Educational Psychologist.*

Songer, N. (1998) Can technology bring students closer to science? *International handbook of science education.* D. Tobin and B.J. Fraser. The Netherlands: Kluwer.

Appendix A

Overview of the curriculum project "What is the water like in our river?"

Time	Sub-questions and associated content	Instructional component
Week 1	What do we know and need to know about our river? · General introduction to water quality · Introduction of driving question	· Sub-question · Anchoring events · Asking Questions · Driving Question Board
Weeks 2 - 5	Where is my river located? · Flow of water · Erosion and deposition · Land use and its impact on the river systems	· Driving Question Board · Small group and whole class sharing · Benchmark lessons · Physical Models (watersheds and stream tables) · Dynamic computer models (Model-builder)
Weeks 6 - 7	What impacts water quality? · Indicators of water quality? · Water pollutant sources and effects · Controlled experiments · Water quality testing	· Driving Question Board · Data collection, manipulation, organization, and analysis · Small group and whole class sharing · Presentations with reflections and critiques · Benchmark lessons · Dynamic 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