Supporting Teacher Development in Enacting the RiverWeb[SM] Water Quality Simulator

Mary Ellen Verona[a], David Curtis[b], Donald Shaffer[c]
[a]*Maryland Virtual High School, 51 East University Boulevard, Silver Spring, MD 20901, USA*
{mverona@mvhs1.mbhs.edu}
[b]*National Center for Supercomputing Applications, Champaign, IL 61820, USA*
{dcurtis@ncsa.uiuc.edu}
[c]*North East High School, North East, MD 21901, USA*
{dshaffer@nehs.org}

Abstract. High-school teachers' evaluations of RiverWeb Water Quality Simulator (WQS), a Web-based water quality management simulation, and the curriculum and pedagogy into which it is incorporated are described. Seven teachers participated in a two-day workshop, in which they took on the parts of students in using the WQS to explore the impacts of land use on water quality. As part of ongoing design and research collaboration, they participated in focus groups to consider the effectiveness of WQS activities. The teachers judged the RiverWeb WQS as potentially effective in fostering student engagement in sustained, inquiry-based activities focused on watershed processes that determine water quality. Teachers suggested improvements to the functionality and learner interface of the simulator, and requested that additional resources be added to help them scaffold student learning. Teacher feedback indicated that such supporting materials should be restricted to teachers and include pedagogy and content pages as well as links to external, online informational and data resources. These findings, together with data gathered from classroom observations with students, will be used to develop and embed content, pedagogy, and pedagogical content knowledge (PCK) support for teachers within the WQS environment.

1. Introduction

Targeted at 8th-12th grade formal science education, the RiverWeb Water Quality Simulator (WQS)[1] is part of an ongoing, collaborative design experiment [1, 2] to refine tools and strategies supporting inquiry into watershed dynamics, particularly physical, chemical, and biological processes determining water quality. The WQS builds on and extends the Maryland Virtual High School (MVHS) Core Models Project in which teachers collaborate to develop and implement computer modeling activities designed to promote core science concepts such as the interdependence of ecological systems. WQS prototyping is also linked into RiverWeb[SM] Program[2] from the National Center for Supercomputing Applications (NCSA) that leverages emerging modeling, simulation, visualization, interaction, and web technologies to develop digital river basins with which diverse learners can explore and study river basin processes in formal or informal settings.

Realizing the full potential of the WQS to promote inquiry is predicated on a rich classroom context that embraces varied, flexible interactions among students and teachers. Consistent with this viewpoint, WQS development depends on a persistent, iterative design partnership with K-12 teachers to carry out software prototyping, curriculum integration, and evaluation [3, 4]. This partnership is based on the following mutually supportive perspectives. Learning curriculum, i.e. "situated opportunities for the development of new practice," is characteristic of a community of practice. [5]. Knowledge of practice is "constructed in the context of use, intimately connected to the knower, and, although relevant to immediate situations, also inevitably a process of theorizing." Thus teachers at all professional levels play a critical role in "generating knowledge of practice by making their classrooms and schools

[1] www.mabelode.mbhs.edu/riverweb/

[2] theriverweb.org

sites for inquiry, connecting their work in schools to larger issues, and taking a critical perspective on the theory and research of others" [6]. In developing the WQS, we are investigating how creative application of information technology can engender situated opportunities for innovations in practice, and at the same time, spur and support ongoing teacher learning and professional development as part of the school day. From a practical standpoint, we subscribe to the view [7] that productivity in software development is enhanced by 1) understanding the user and context of use, 2) implementing a prototype to be iteratively refined with input from the users, and 3) assembling standardized components to increase effectiveness. The preliminary work reported here focuses on the first two principles. We briefly address the third point in discussing future directions.

The curriculum design principles that inform our work include context, standards based, inquiry, collaboration, learning tools, artifacts, and scaffolds [8]. In this paper we characterize data collected from our teacher workshop in terms of software and curriculum design, and consider how this same web-based learning environment can support teacher development by scaffolding pedagogical content knowledge (PCK). In partnership with cognitive researchers at the University of Maryland, we are also conducting field studies of student learning with the WQS, as reported in a related paper [9]. What we find from both sets of results will be applied not only to further iterative refinement of the WQS prototype, but also other "WebSims" [10] that focus on different segments of the science curriculum.

2. Project Background Timeline

Since the WQS project's inception in spring 1999, research, design and implementation activities by MVHS staff and teachers in partnership with researchers from NCSA have included development of

- Computer models of system relationships between land use and water quality within an "archetypal" (i.e. geographically unspecified) river basin and, based on these models, implementation of a web-based simulator within a client/server framework.
- A web interface to the simulator enabling learners to select locations (i.e. sub watersheds, each corresponding to a distinct land use), choose indicators, and view model output in the form of graphs.
- An interactive tour that introduces learners to key operations as well as the basic science behind the simulator.
- A digital notebook in which students can record their observations, explanations, and hypotheses as they investigate water quality relationships, and teachers may structure, scaffold, and assess student investigations.

A computer science teacher and an environmental science teacher, with 20 years combined experience, spearheaded initial development and piloting. In July 2000, having evolved an initial prototype and pedagogic framework, we held a two-day workshop at Montgomery Blair High School for seven science teachers. These teachers taught earth science, environmental science, ecology, biology, and computer science to students ranging from 8th to 12th grades. Teachers took on the roles of students, working with the simulator in pairs, and following a peer-group learning strategy. Through observations of and depth interviews with the participants, we sought to understand instructional values that teachers place on WQS features and activities that can guide further development of educative curriculum materials [11] to support teachers in enacting the RiverWeb WQS in their classrooms.

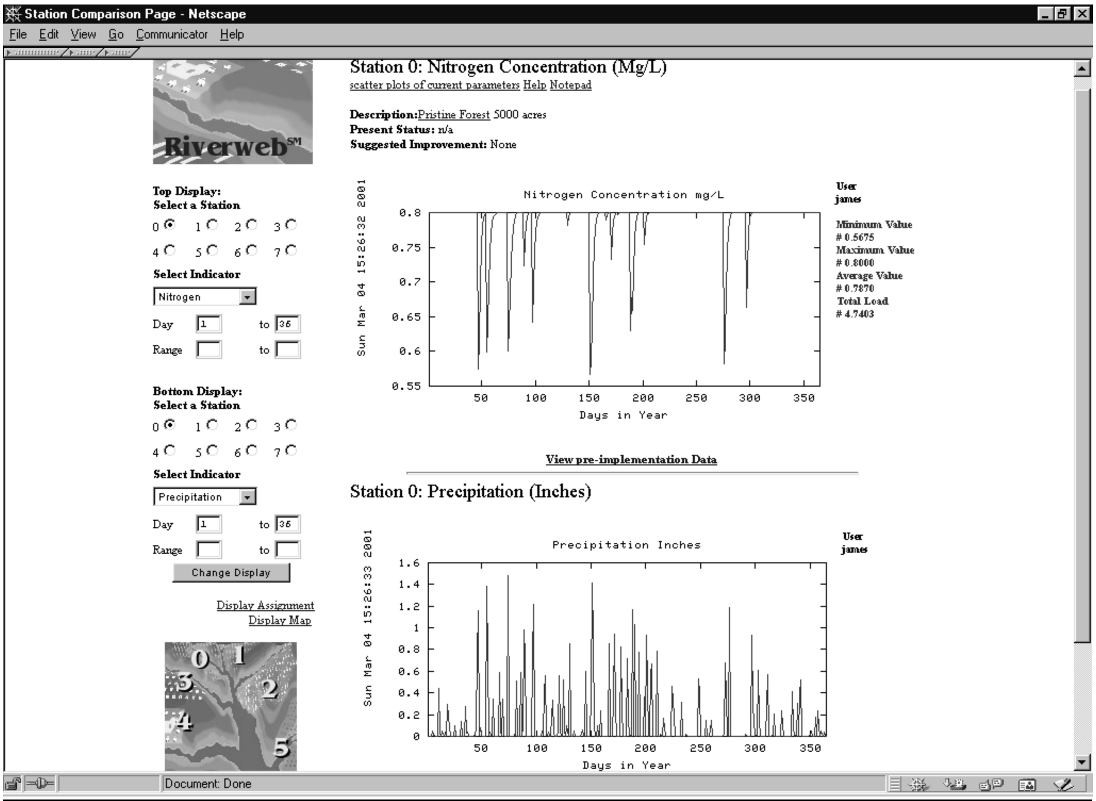

Figure 1 RiverWeb WQS interface illustrating graphs of nitrogen (top frame) and precipitation (bottom frame) time series in the pristine forest (Station 0).

3. RiverWeb WQS Core Functionality

Students enter the WQS through an interactive map that depicts the watershed and its subdivisions, each corresponding to a single land use and coverage. For example, station 0 monitors water quality in stream draining a pristine forest, while station 7, which represents an estuary, samples the common outflow, and therefore cumulative impacts on water quality across the entire watershed. Additional sub watersheds (stations 1-6) encompass lumbered, agricultural, suburban, industrial, wetland, and urban areas respectively. Upon selecting a location, the student is taken to a page in which to select further station locations and physical or chemical indicator, submit form requests to the server (via a “change display” button), then view simulation outputs as graphs. Thus students may compare how time series of two indicators vary within the same sub watershed, or how two different sub watersheds influence the variation of a single indicator. By modifying Day and Range inputs learners may change the scale of the x-and y-axis respectively. A miniature interactive map in the lower left corner permits selection of another sub watershed, whereupon graphs displaying default indicators (Nitrogen and Precipitation) are displayed.

Students may also implement a best management practice (BMP) to investigate how it mitigates water quality through its effects on runoff and other indicators, both locally and at the common outflow. Additional links include access to a scatter plot to explore putative quantitative relationships between selected indicators, background information on land uses and BMP’s, and the digital notebook (see below).

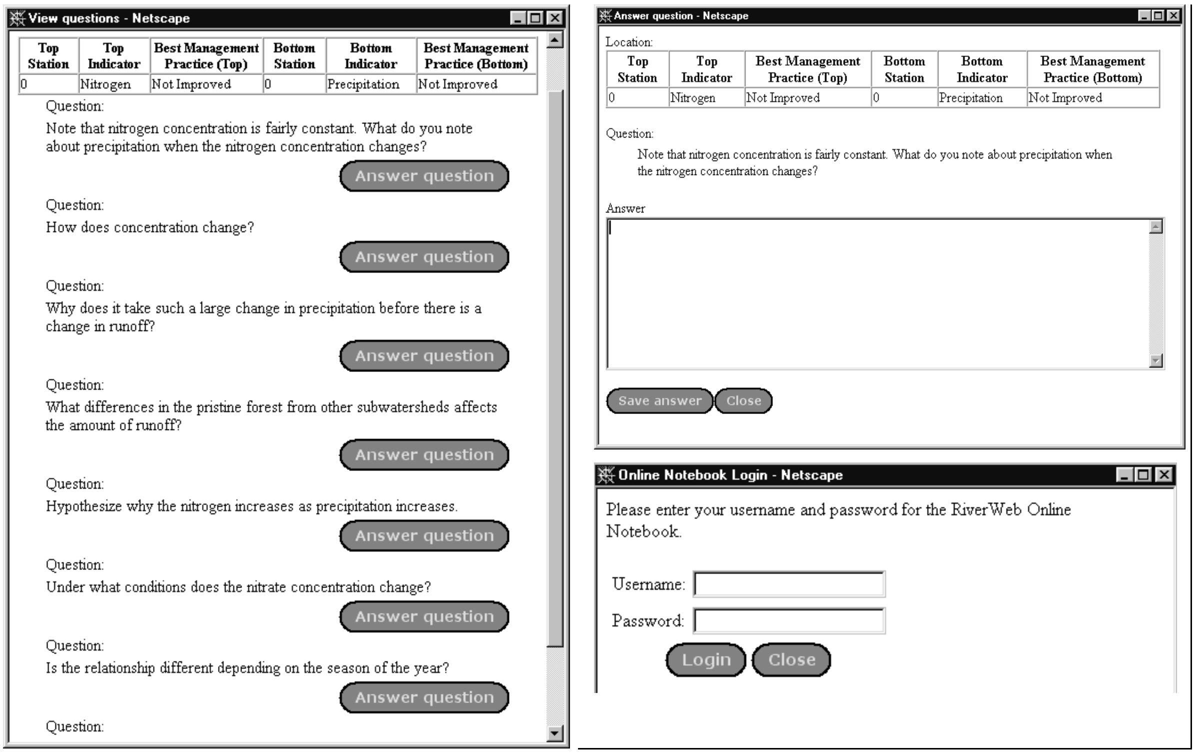

Figure 2 Digital Notebook, showing login and default questions keyed to selected indicators and locations.

4. Pedagogic Framework

Our approach to prototyping the WQS has been informed by design principles [8] related to social constructivist theory in which students construct understanding through collaborative problem solving, and share, build and exhibit this understanding through discourse and artifacts. In tandem with evolving the software, we have developed a pedagogic framework to integrate the WQS within an inquiry-driven curriculum unit. Our framework adapts the Jigsaw approach to team-based, cooperative learning [12, 1, 13] in order to structure multiple learning activities, while supporting individual accountability during group work. To introduce a study of water quality to the class, the teacher delineates a scenario in which the students, representing various stakeholders, must prepare to testify before a hypothetical state commission on land use and best practice management. After discussing a newspaper report on local non-point pollution, for instance, students are introduced to fundamental concepts underlying the simulator. First, students plot the path that rain falling on the school campus takes to mouth of the watershed, describing the kinds of impurities the water might pick up on its way. Next, the teacher guides the classes in articulating a simple hypothesis relating selected water quality indicators to precipitation at station 0, the pristine forest. Then students use the interactive tour to become familiar with the simulator interface and with key concepts related to time series. By scaffolding initial planning and goal setting, the tour helps the student concentrate on the current step [14], which is to examine time series graphs to determine how the indicators vary with precipitation. The scatter plot helps students to confirm relationships glimpsed in comparing two time series. In the class discussion that follows students provide evidence from the tour to support or refute their prior hypotheses and reconsider and refine their ideas, whereupon an initial concept map is drawn up by the class to represent collective notions of land use-water quality relationships. At this point the students are ready to begin their Jigsaw explorations.

In Jigsaw #1, students are assigned to one of six possible "land use" working groups. Their goal is to determine what contribution their region is making to poor water quality at the common outflow area monitored by station 7. They initially investigate how one or two pairs of indicators are related within their land use area.

In Jigsaw #2, students recombine within a number of indicator groups. For instance, in one such group studying phosphates, student would investigate how that particular indicator enters the watershed, how it is affected by distinct land uses, and the severity of the threat to water quality that it poses. To conduct their research, students would pursue links to information within and beyond the WQS site, as directed by the teacher. This leads into a transition class discussion that focuses on the importance of runoff in causing high indicator levels and leads to a refined concept map that represents students' understanding of how reducing runoff could help improve water quality.

In Jigsaw #3, students then return to their working groups armed with background information about their assigned indicator and a basic understanding of how each region's land use influences the level of this indicator. For instance, the student who has worked with the phosphate group has discovered that fertilizers and detergents are sources of increased phosphate levels. Each member of the working group teaches fellow members about putative mediating factors behind an indicator's rising levels and the problems it poses to water quality. The team selects a mitigation strategy and implements it in simulation to determine its effects on target indicators.

At each stage of the group learning process students individually answer open-ended yet carefully tailored questions in the digital notebook helping them connect the graphs to previous knowledge. Using this same tool, each student records additional questions and ideas, thus building individual and group artifacts of learning. In the Jigsaw wrap-up activity, each group prepares a presentation for the "water quality commission" using text from the notebook and graph images downloaded from the simulator. The teacher leads the class in further refining the concept map such that it integrates the causal relationships between indicators of water quality and land use throughout the watershed.

5. Professional Development Perspective

The MVHS CoreModels Project[3] has developed modeling activities to support students in learning the skills and concepts needed to meet national and state standards. To promote adoption of effective teaching strategies the CoreModels professional development model employs hands-on training followed by classroom support and quarterly face-to-face meetings to foster sharing and collaboration among teachers. This model adopts the recommendations of Mundry and Loucks-Horsely [15] to provide opportunities for teachers to 1) engage in their own learning of science and mathematics through supplementary activities, 2) plan how they will enact new activities in their own classroom, and 3) reflect on the success and difficulties of such implementation with teachers and staff developers.

From previous work with Core Models, we also understood the importance of curriculum materials to support teachers in enacting modeling activities, and so developed guidelines to increase the effectiveness of such materials. The logistics of the lesson built into the student guide must work smoothly. The guide must provide very thoughtful scaffolding by posing questions and/or directions for exploration which, step by step, take students through the basic concepts and interpretations of model outputs (especially graphs). It must provide pathways to higher order thinking. Also, it should afford connections to real world applications and data; including wet lab results, related concepts (for instance system thinking) as well as other disciplines. And the guide should address mandated standards, such as Maryland Core Learning Goal Skills & Processes (for example, analyzing and summarizing data and using

[3] http://mvhs1.mbhs.edu/mvhsproj/cm.html

graphs to support arguments in written and oral communications). A real world scenario provides authenticity, and helps focus student activity towards achieving these goals.

Applying these guidelines, we have begun to develop a teacher guide to accompany the WQS. The guide will consist of a concise unit overview (with references to specific learning standards), lesson plans for two 90-minute periods or three 45-minute periods, a model answer key and appendices. The lesson plans will include best practices, teacher tips, and pre-activity suggestions, especially a wet lab. Day 1 plans should discuss critical logistics (such as effectively grouping students at computers), expectations, graph interpretation, and prerequisite knowledge. Day 2 plans should support connections to real world applications and systems themes. It should also stress the importance of interacting with or questioning students at the computer on graph interpretation and higher order thinking skills. The plans should focus on a post-activity discussion: critical concepts to review, real world extensions, systems themes, and assessment. The goal is to integrate this online guide with the teacher login to the simulator.

Recently, research on the role of educative curriculum materials in supporting teacher learning has provided a theoretical perspective with which to interpret our guidelines and structure our efforts. Support for three categories of teacher knowledge, described by Shulman [16] as content, pedagogical, and pedagogical content knowledge (PCK) need to be embedded into curriculum materials. Schneider et al [11] have made a series of suggestions on how best to do this. 1) Organize materials as units subdivided into learning sets, and further into lessons. 2) Support content knowledge at the beginning of each learning set. 3) To aid pedagogical understanding, include explanations of the flow and sequencing of lessons and connecting content ideas in the unit as a whole, in each learning set, and in each lesson. 4) Use short notes within a lesson to tie pedagogy to content (PCK). Schneider and collaborators found that teachers understood lesson specific PCK better than more isolated information on content or pedagogy. Researchers conjectured that teachers paid attention and used the notes directed at PCK owing to their need to incorporate curriculum materials expeditiously when planning specific lessons in the immediate future. Teachers may have considered lesson content less in terms of its own internal, logical structure, and more in terms of how students would think about a lesson, or the ideas students would bring to the classroom.

6. Research Questions

In order to evaluate how teachers view the WQS and its potential to support inquiry, we developed a number of questions informed by social constructivist theory and participatory design principles. (See section 3) 1) To what extent are the RiverWeb WQS and its component parts usable in supporting authentic science learning in the classroom? 2) How does the framework provided by the WQS enable the teacher to enact sustained inquiry in line with relevant standards? 3) Does the proposed pedagogy foster collaborative learning in practice? 4) How helpful to teachers and students is the built-in scaffolding and what additional teacher support is required? 5) How may such support be characterized in terms of content, pedagogy, and pedagogical content knowledge?

7. Methods

7.1 Participants

Seven secondary teachers (5 women and 2 men) participated in this study as part of a RiverWeb WQS workshop. Participants possessed 5 to 25 years of experience in teaching. Five of the teachers taught environmental science, biology, or earth science to high school students. One teacher taught computer science to high school students, and one taught environmental science to high achieving middle schools students. Data was collected throughout a two-day (12 hours total) workshop in July 2000. One teacher had previously used the initial prototype RiverWeb WQS in the classroom, while three others had been exposed to an hour introduction during a previous workshop.

7.2 Procedures

The workshop was structured to intersperse the activities outlined in section 3 with group discussion to elicit immediate reactions and suggestions from the teachers. Our main objective was to determine and interpret the instructional values that teachers placed on the functionality of the simulator itself, as well as the accompanying materials and proposed pedagogical framework. A secondary objective was to obtain an understanding of difficulties teachers might experience in interacting with the WQS as a learner as well as a teacher. After being introduced to our research agenda, teachers took the WQS tour. A moderated discussion followed, after which teachers paired up to predict how water quality at a chosen monitoring station would vary from the pristine watershed ideal. After the Jigsaw #1activity and another moderated discussion, the teachers regrouped in Jigsaw #2 to consider one indicator in depth. Day two began with a moderated discussion focusing on the concept maps participants had drawn the preceding afternoon. In Jigsaw #3, teachers returned to their initial pairings to report on indicators and determine priorities for best management practices. The day ended with the entire group debriefing on the workshop's activities, after which teachers completed a written survey and took part in small group interviews. The entire workshop was audio taped and videotaped, including pairs of teachers working at computers and all group discussions and interviews. Five of the teachers attended the entire proceedings and were interviewed in depth in two subgroups (2+3) at the end of the workshop. The remaining two teachers were unable to stay till the end of the workshop and were interviewed separately several days later.

7.3 Data Sources

Transcripts of in depth teacher interviews provided our main source of data. In addition, transcripts of large group discussions and of teacher pairs working at the computer provided contextual information. These transcripts were based on 15 hours of audio and video data. The findings presented in the next section are based on our analysis of a research assistant's transcription of the audio data. Short form surveys provided additional contextual information with which to evaluate the transcript data.

8. Findings

Our analysis of teacher perceptions focused on the following components: the functionality of the WQS as a web-mediated learning tool, its effectiveness in supporting inquiry, the value of the cooperative pedagogic framework (Jigsaw), the artifacts generated during WQS-based activities, and the scaffolding incorporated within preliminary WQS curriculum materials.

8.1 Functionality of the WQS as a Learning Tool

We will first consider teacher evaluations of WQS functionality: overall impression, particularly valuable features, and improvements desired. Overall, the teachers expressed their belief that the WQS would help students make connections between a range of indicators representing a comprehensive set of land uses, and commented favorably on the overall design of the interface. They found that WQS was easy to navigate, permitting comparison of chosen pairs of indicators. Graphs were clear. Participants liked trying different combinations of indicators, and appreciated the ability to review graphs computed from previous input requests.

The teachers especially favored the Day Range zoom-in tool, the scatter plot capability, and ability to compare time series before and after BMP implementation. They appreciated the ability to view, copy, and manipulate the data as a series of numerical values in addition to the graphical display. Although teachers pointed to the juxtaposition of two graphs as a positive feature, they wished that both graphs fit on one screen, instead of having to scroll up and down to view them together. There was some frustration distinguishing differences between before and after implementation BMP on the same graph, even though each line was color-coded. This problem was more pronounced on the scatter plot where the Day Range zoom-in tool was not available. One teacher was unsure whether problems she encountered understanding the graphs was due to inexperience with computers or relative unfamiliarity reading graphs. She expressed the need "to compare graphs in same chart – to put things together quickly to grasp the big picture."

Teachers reported on some difficulties with the web interfaces to the notebook and tour. There were complaints about the notebook window disappearing behind the main page, loss of notebook entries when forgetting to click the Add/Save button and difficulties with tracking the questions related to stations and indicators.

Additional features the teachers requested to enhance the WQS included biological indicators (such as insects and fish), clearer differentiation between the different graphical displays, and a readout of the area corresponding to each land use. They wanted to be able to change that area and dynamically observe the effects on selected indicators in the selected sub watershed, as well as throughout the watershed, and to implement more than one best management practice for each land use. Teachers commented that they wanted students not just to observe the graph, and interpret its slope and amplitude, but also apply that information in answering questions about indicator trends and correlation. But they also expressed concern about information overload, suggesting that students work on no more than 2 indicators per group to avoid going off on a tangent. Lastly, teachers stated that they would like to see easier student access to essential background information about indicators, land uses, and their effects on water quality, as well as best management practices. Nevertheless, the teachers were unsure as to the quantity of information that should be made routinely accessible to students, or how much of this information should be provided at any given step during their explorations.

8.2 Standards and Context for Inquiry

During the workshop discussion teachers stressed the need to help students learn difficult concepts and practice skills related to standards. The WQS was designed to align with the Maryland Science Core Learning Goals 1 (skills) and 3 (biology) and the AAAS Benchmarks [17] in emphasizing the effect of the human presence on the earth, and common themes such as systems and dynamic change. We did not specifically discuss with teachers the extent to which WQS activities were standards based. In a short paper and pencil survey, however, workshop participants rated the WQS activities as successful in "helping students (and their teachers) meet standards at national, state, and district levels". Moreover, teachers believed that the WQS learning framework – the notebook, which structures student exploration via open-ended yet highly targeted sets of questions, links to resources, accompanying materials - could provide a rich context for sustained inquiry. .

T1: *It feels very open-ended because it- well, there's so many different possibilities and so many different ways you can compare it and things you can look at…*

T2: *Depending on what the teacher assigns, the kids can pursue different-different facets that they're interested in, and then take it a step further. And the kids can't, uh- often times when kids have activities, they know what the* *answer's going to be before they even read what's- what's coming up. They know what to expect.*

This view is born out by the field data with students reported in the accompanying paper [9]. The participants suggested that setting up a real world scenario provided an avenue for the class to develop an authentic, overall driving question that motivates, contexualizes, and structures subsequent activities, including a final report that incorporates artifacts gathered or created during the exploration. Why are so many fish dying downstream during summer months, and is our local creek part of the problem? The digital notebook could provide more specific sub questions that the class could develop together to deepen and extend their inquiry. Student debates on the feasibility and effectiveness of management practices (even without tying every option to the data) would extend the realism of the learning experience. Students' observations of BMP impacts currently incorporated in the simulator might serve as a starting point to open up discussion of alternative practices. Students could even take on distinct stakeholder roles in investigating the relative costs and benefits of management practices from the standpoints of farmers, suburban home owners, or developers, for example.

8.3 Collaboration

WQS activities are intended to foster collaboration in that groups of students work together to understand the influence of their particular land use on the overall watershed. Participants expressed concern about the large scope of exploration within the simulator. Realistically, small groups can explore but a limited range of conditions and related questions. Hence the importance of reconfiguring the class into expert teams, thus providing a structure for working groups to collect information about selected chemical and physical factors, as revealed by specific indicators. However, the teachers differed in prior use of cooperative learning strategies, as well as their specific employment of Jigsaw in the classroom. Two teachers had not used Jigsaw much or at all in their classroom. One of them commented that a lot of students do not like aspects of group work such as peers "coasting" on backs of others, or one student taking over, and that assessment may be difficult when students' work is interdependent. Both teachers felt, however, that the "open-endedness" of the activities supported through the WQS lends itself to cooperative learning, as distinct from more "straight laced" assignments like library research. The second teacher conjectured that the artifacts or products the students create during their explorations – graphs, notebook answers, concept maps etc. - lend themselves to non-traditional, performance-based assessments that could work in a group learning context.

All three teachers in a second interview group thought that the WQS could work well within the Jigsaw cooperative learning framework. But they also believed that sufficient classroom time (perhaps a week) and resources, particularly research materials, would be needed for the expert groups (in Jigsaw #2) to construct concept maps that represent their understanding of mediating causes.

Two remaining teachers differed in their use of cooperative learning. One teacher often divided her class into groups, and assigned a task to each person in a given group. Not surprisingly, she thought that the Jigsaw strategy would work well with students exploring the WQS. The second teacher employs group learning approaches in her elective classes, but not so much in biology since she felt the very prescribed curriculum and assessments preclude the time it would take. She also doubted that the Jigsaw framework would work as well with her lower achieving students as with those in advanced classes.

8.4 Artifacts and Scaffolding

As mentioned above, teachers stressed the importance of group artifacts in assessing student learning. The assessment potentials of two types of artifacts were discussed during the workshop: concept maps and group reports incorporating notebook entries and graphs. Only concept maps were produced during the workshop, although one teacher implemented group reports with her summer students. All participants concurred that concept maps would help students articulate relationships between interrelated processes and assimilate understanding into their existing conceptual frameworks [18]. However, workshop transcripts showed that some of the participants lacked experience in concept mapping with their students. While transcripts from both in-depth interviews include discussion of the advantages of featuring complete concept maps in a comprehensive teacher guide two teachers expressed concern that their students would be unable to understand the key relationships inherent in the WQS well enough to map them.

One teacher suggested that in order to connect their observations in the simulator to the real world, students needed to see how land use impacts water quality and how such effects might be mitigated in the field. Several teachers mentioned the importance of wet labs in helping students understand physical, biological and chemical factors influencing water quality, even before they engage with the WQS. Students might grow algae and measuring dissolved oxygen, or create pollution filters and test their effects.

Participants emphasized the importance of scaffolding by the teacher in supporting student learning with the simulation. Though the notebook questions are designed to help students make their thinking visible, they also serve to scaffold student learning by prompting them to connect the data at hand to previous understanding, and to structuring student-student and student-teacher interactions. Some teachers felt that general questions would suffice since they would elicit specific responses for each pair of graphs. One teacher wondered if students could add their own questions, building upon the more general ones. Teachers agreed that it was critical that they be able to add to and replace the questions in the database, thereby customizing scaffolding of students' inquiry in step with their cognitive growth.

Scaffolding also requires access to background information that helps contextualize inquiry learning. Currently the WQS site points students to pages with limited information about selected indicator relationships, such as the connection between nitrogen load or sediment and runoff. Participants stressed the need to augment existing online resources. Information should be readily accessible on key topics such as indicators and BMP, perhaps through bookmarked web sites that include photographs and explanatory diagrams. However, teachers also felt that such links should not necessarily contain pre-digested information for students to answer questions. On the contrary links could (and, in the view of some of the teachers should) point to information that students would need to evaluate for themselves in order to support their hypotheses and answers to notebook questions. Further, some of the participants worried that that having all resources easily available would be "making it too easy for the students". They thought that teachers to be able control student access to resource links, making different resources accessible as students progressed through the WQS.

> *T1:* *[Y]ou have to, uh, look a little more deeply for those, and some of the students may not- it may not come to them what questions to ask to ferret that out. I mean, we're- when you start talking about mediating causes you're moving into higher-level thinking, which some are better at and some need some work with, uh.*

The same participants were also concerned that getting most students to infer mediating causes would require scaffolding (by the teacher) additional to any informational resources accessible via the WQS site.

> *T2:* *I think the potential is definitely there, but I think that's going to be something that's more teacher, uh, interaction or teacher guidance, scaffolding like we were talking about. A little bit more of that, for, uh, most students.*

In this and other comments, participants emphasized the importance of the teacher in catalyzing student learning. They requested that appropriate pedagogic content information be provided to support them. However, when interviewed separately, one of the above teachers responded that a comprehensive guide might be overkill. A web directory to useful resources might be helpful, but she would prefer a concise written document – a "little" teacher guide. A second participant echoed this view.

9. Future Directions

The workshop findings underscore the need to focus on developing additional materials to support teachers in enacting the WQS in their classrooms, in particular, resources that aid scaffolding of student learning. Teachers' content knowledge needs to go beyond that of their students, particularly knowledge of mediating causes that determine how land use effects water quality. For instance, it would be desirable to include explanations of how surface and subsurface flow combine to form stream flow, which in turn determines pollutant transport within the watershed. Strengthening teacher awareness and understanding of the WQS pedagogic framework, with specific guidance on implementing the Jigsaw strategy is also important, since the workshop participants who were uncomfortable with this strategy and other approaches to cooperative learning are representative of many others. But, as suggested by our experience with teacher use of CoreModels materials, by the research cited earlier [11], and by our findings from the WQS workshop, higher priority should be placed on supporting pedagogical content knowledge rather than assisting with content and/or pedagogy alone. One particular application for PCK would be in helping teachers guide students in building concept maps as an ongoing process, rather than a one or two session activity. Otherwise, teachers may not carry through with this activity, even when they seem to value it [11].

Since all the workshop teachers volunteered to field-test the WQS in their classroom during the next school year, we are now exploring with them how to support all three types of knowledge development within an online learning system. Indexed web pages or "content assistants" to support content learning could be made readily accessible for both teachers and students via installation of appropriate links to internal or external information. We are also considering ways of enabling teachers to layer what information is visible to students and when. Supporting pedagogic knowledge in a manner compelling to teachers who do not normally read such information poses a greater challenge. Our first priority, however, is to investigate, in a continuing design experiment with participating teachers, how to embed PCK support in an online learning system, since there is ample evidence that teachers will readily take advantage of it [11]. We plan to integrate this system within a web-based, collaborative materials development environment (CMDE) [10] able to engage numerous, geographically dispersed teachers in using tested components to design and develop WebSims such as the WQS, and to promote their cooperative development and sharing of PCK resources and strategies.

10. Acknowledgements

The RiverWeb WQS Project is funded by grants from the National Science Foundation (NSF) awarded to the first author. The authors thank the anonymous reviewers for their comments. We also thank Roger Azevedo, University of Maryland, for his insights and, assistance in collecting data. Also, we appreciate the contributions of several University of Maryland undergraduates and graduate students, as well as Maryland secondary science teachers that participated in our work. Moreover, we are grateful for continuing encouragement and support from Lisa Bievenue, National Center for Supercomputing Applications.

References

[1] Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences*, 2(2), 141-178.

[2] Collins (1992). Toward a Design Science of Education. In E. Scanlon and T. O'Shea (Eds.), *New directions in educational technology*. New York: Springer-Verlag.

[3] Garaway, G.B. (1995). Participatory Evaluation. *Studies in Educational Evaluation*, Vol.21, pp.85-102. Pergamon.

[4] Conlon, T. & Pain, H. (1996) Persistent Collaboration: a Methodology for Applied AIED. *Journal of Artificial Intelligence and Education*. Vol 7, No 3/4, pp.219-252

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

[6] Cochran-Smith, M. & Lytle, S.L. (1999). Relationships of knowledge and practice: Teacher learning communities. In A. Iran-Nejad & P. D. Pearson (eds), *Review of research in education*, pp. 249-305. Washington, DC, American Educational Research Association.

[7] Fisher, D. (1991) *Myths and Methods: A guide to software productivity*. New York,. Prentice-Hall

[8] Singer, J., Marx, R., Krajick, J., & Chambers, J. (2000). Constructing extended inquiry projects: Curriculum materials for science education reform. *Educational Psychologist*, 35(3), 165-178.

[9] Azevedo, R., Verona, M.E., & Cromley, J.G. (2001, May). Fostering students' collaborative problem solving with RiverWeb. Paper to the presented at the 10th World Conference on Artificial intelligence in Education,

[10] Verona, M.E. (2001). WebSims: Creating an Online Science Lab. In L. Vandervert & L. Shavinina (Eds). *Provocative and do-able futures for cybereducation: Leadership for the cutting edge*. New York: Liebert, Inc.

[11] Schneider, R.M., Krajcik, J., & Marx, R. (2000). The Role of Educative Curriculum Materials in Reforming Science Education. In B. Fishman & S. O'Connor-Divelbiss (Eds.), *Proceedings of the Fourth International Conference of the Learning Sciences* pp. 54-61. Mahwah, NJ: Erlbaum.

[12] Aranson, E. (1978). *The jigsaw classroom*. Beverly Hills, CA: Sage Publications.

[13] Slavin, R. (1980) Cooperative Learning. *Review of Educational Research*, 50(2), pp. 315-342.

[14] McGee, S., Howard, B., & Hong, N. (1998, April). Cognitive apprenticeship, activity structures, and scientific inquiry. Paper presented at the American Educational Research Association Annual Meeting. San Diego, CA.

[15] Mundry, S. & Loucks-Horsley, S. (1999). Designing Professional Development for Science and Mathematics Teachers: Decision Points and Dilemmas. *National Institute for Science Education Brief*, 3 (1), pp. 1-7.

[16] Shulman, L.S. (1987). Knowledge and teaching foundations of the new reform. *Harvard Education Review*, 57 (1), pp. 1-22.

[17] American Association for the Advancement of Science (1993). *Benchmarks for science literacy. Project 2061*. New York: Oxford University Press.

[18] Novak, J. (1990). Concept Mapping: A Useful Tool for Science Education. *Journal of Research in Science Teaching* 27(10), pp. 937-949.