Exploring the Relationship between Teachers' Experience with Curriculum and Their Understanding of Implicit Unit Structures

Hsien-Ta Lin and Barry J. Fishman
The Center for Highly Interactive Computing, Curricula, and Classrooms (hi-ce)
University of Michigan, 610 E. University, 4023 SOE, Ann Arbor, MI 48109, U.S.A.
Email: htlin@umich.edu, fishman@umich.edu

This study investigates teachers' understanding of underlying unit structures including: the relationship between lessons and curriculum design principles; and the connections among lessons in a unit. We investigated: (1) teachers' understanding of curriculum design principles; and (2) the role of teachers' experiences with curriculum units in their understanding of underlying unit structures. Using clinical interviews, we identified patterns in teachers' understanding. We found that teachers do not understand design principles and the relationships between these principles and lessons well, although more experienced teachers seem to know more than less experienced peers. Teachers also have difficulty identifying connections among lessons and therefore the overall unit structures. Both of these findings are problematic for curriculum developers seeking implementation that is "true" to the intentions of the materials. This study helps to inform future design of curriculum units, professional development, and tools that help teachers understand unit structures.

Objectives

As researchers work towards the development and adoption of new curriculum materials in support of inquiry-oriented learning, one of the challenges is helping teachers learn to use these materials in ways that are "true" to designers' original intent. Teachers face many challenges in using innovative curriculum materials, including high content knowledge demands, contrasting beliefs, and constraints in local contexts. Teachers need sufficient subject matter knowledge and pedagogical content knowledge (L. S. Shulman, 1986) to interpret innovative ideas (Remillard, 2000; Schneider & Krajcik, 2002). In addition, teachers may need to reconcile differences between their existing beliefs about teaching and learning and those of new materials (Collopy, 2003; Lloyd, 1999; Richardson, 1990). Teachers' decisions about classroom practices also depend on their assessment of specific instructional settings and individual learners' needs (Squire, MaKinster, Barnett, Luehmann, & Barab, 2003; Talbert, McLaughlin, & Rowan, 1993).

Teachers also need access to underlying curriculum lesson structures to help make wise decisions regarding their adaptations. Traditional professional development efforts have supported teachers in learning to implement innovations, instead of assisting teachers in learning to innovate (Randi & Corno, 1997). Recently, educative curriculum materials have been used to provide situated supports for teachers in improving teaching knowledge (Ball & Cohen, 1996; Davis & Krajcik, 2005). In contrast to traditional curriculum guides, educative curriculum materials provide situated learning opportunities for teachers in addition to teaching strategies for promoting student learning (Davis & Krajcik, 2005). Curriculum materials situate teacher learning in the context of classrooms by being an integral part of teachers' daily work and can support teachers over an extended period (Putnam & Borko, 2000).

Educative curriculum materials have the potential to help teachers improve their content knowledge, pedagogical content knowledge, curricular knowledge, and to become aware of curriculum designers' pedagogical intentions (Davis & Krajcik, 2005). Approaches for providing content support may include providing a one or two-page summary of the mathematical content before each lesson (Collopy, 2003) or explanations for important concepts alongside of activities (Schneider & Krajcik, 2002). Educative curriculum materials can also provide support for pedagogical content knowledge by addressing students' ideas about an activity, such as their probable prior knowledge and experiences, probable responses and demonstration of understanding, and challenging concepts. For example, curriculum materials can suggest that teachers can refer to suggested levels of student understanding and evaluate students' explanation of their computer generated graphs in order to determine students' readiness for the next lesson (Schneider & Krajcik, 2002). Another strategy is to show cases of other teachers (video or dialogue scripts of classroom discussions) during an activity and give teachers ideas about what might happen in classrooms. (Davis, Smithey, & Petish, 2004; Fishman, 2003). In addition to content knowledge and pedagogical content knowledge, curriculum materials can also help teachers reflect on the relationship between the current lesson and other curriculum units with a list of learning objectives (Wang & Paine, 2003).

Some software tools also aim to help teachers organize and see the pictures of their plans. However, the focus of these tools is more on production rather than educative aspect of planning practice. The Project Integration Visualization Tool (PIViT; Marx, Blumenfeld, Krajcik, & Soloway, 1998) was designed to help teachers with routine planning for project-based science units. PIViT allows teachers to create two-dimensional graphical representations of projects for their classes. It also provided features such as a calendar, concept map, and libraries that support teacher planning. However, it did not address detailed connection between standards and lesson components. Another tool is the Web-based Inquiry Science Environment (WISE; Linn, Clark, & Slotta, 2003) that provides online support for teachers in learning to use and design online inquiry-based learning environment in their classrooms (Slotta, 2004). The teacher's Portal and Educator's Toolbox (PET) in WISE allows teachers to customize projects to fit their curriculum and to design new activities with existing web resources and teacher guidance. Features related to planning in the teacher's PET include a Project Library (access to projects, lesson plans, learning goals, and science standards), a Project Editor (tools to customize projects to suit a teacher's curriculum and to create new projects), and online communities. However, WISE does not provide a picture of curriculum design principles in teachers' plan.

However, one of the challenges identified in previous educative curriculum materials studies is that curriculum designers focused more on enhancing teachers' content knowledge and pedagogical content knowledge, and less on helping teachers understand the underlying unit structures (Remillard, 2005). Most educative curriculum materials provide adaptation suggestions at the level of elements (e.g., substitute an instructional strategy with another one in a lesson) and do not provide supports for teachers to observe the consequences of modification on the overall profile of design principles. However, teachers need to see both the big picture and the details of a unit in order to make coherent lesson plans (L. S. Shulman, 1986). Without understanding the intentions embedded in the curriculum materials, there is a danger that the essence of the reform might be lost in the adaptation and reduce "lethal mutations" (A. Brown & Campione, 1996; Spillane, Reiser, & Reimer, 2002).

The goal of this study is to investigate teachers' understanding of implicit unit structures to inform a design experiment (A. Brown, 1992) of an online planning tool that aims to help teachers see the unit structures in innovative curriculum materials (Lin & Fishman, 2004). We focus on teachers' understanding of two kinds of unit structures. The first is the relationship between individual lessons and curriculum design principles, which refer to both educational standards such as National Science Education Standards (National Research Council, 1996) and project-based science (PBS; Singer, Marx, Krajcik, & Chambers, 2000) concepts. For example, a single lesson in a chemistry unit may address one content standard on conservation of matter. The second type of lesson structure is the connection between two or more lessons. For example, a concept introduced in an earlier lesson is required for student understanding of another advanced concept in a later lesson. When teachers do not perceive these linkages, they may omit lessons that lay important foundations for later lessons.

Theoretical framework

From a socio-cultural perspective, learning is the process of understanding how to participate in the discourse and practices of a particular community (Lave & Wenger, 1991; Vygotsky, 1978). People understand a particular way of thinking by participating in social practices with more knowledgeable others and tools that provide scaffolding to mediate learning in one's zone of proximal development and gradually develop meanings of activities, internalize these supports, and become able to do tasks in the absence of others and tools (Bruner, 1990; Vygotsky, 1978). Authenticity is a critical element for active participation in which learners work in real-world contexts such as collaborative activities, modeling, and decision making that are necessary to support the negotiation and creation of meaning and understanding (J. S. Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Resnick, 1987).

In a community, artifacts have both physical existence (material elements), and embedded meanings and ways of thinking (conceptual elements) (Cole, 1996). In the process of creating and modifying artifacts, people use symbolic representations in a community to embed in these artifacts their ideas, meanings, and ways of thinking. Other people in the community can use these artifacts to extend their cognitive or physical capabilities and reach originally unreachable goals (Pea, 1993; G. Salomon, 1993). Internalization is a critical process in which people convert conceptual elements into mental functions (Vygotsky, 1978). As learners experience social interactions repeatedly, they gradually learn to make sense of these experiences on a higher and abstract level (Lave & Wenger, 1991).

A difference between experts and novices in a community is that experts can identify deeper and less apparent principles, organize their knowledge around important concepts and contextualize this knowledge to specific situations. In addition, experts can apply these concepts to shape their understanding of new situation by noticing patterns, relationships, or discrepancies that are not apparent to novices (Sabers & et al., 1991; Schwartz & Bransford, 1998). For example, expert and novice teachers often differ in the organization of plans and anticipated classroom interactions. Novice teachers tend to provide simple descriptions of isolated events and not to make inferences about the underlying structure of the instruction and student behavior (Clark & Yinger, 1987; Putnam & Borko, 2000). Since patterns or models in their repertoire of previous classroom interactions aided teachers' decision-making, expert teachers are able to predict student reactions and alternative conceptions in activities and see meaningful patterns in planning process

Based on this theoretical framework, curriculum materials can be regarded as social artifacts initially created by curriculum designers and later used by teachers (Putnam & Borko, 2000; G Salomon, 1993). Underlying curriculum unit structures are part of the conceptual elements of curriculum materials. From this perspective, teachers may internalize these implicit concepts when they use curriculum units. Teachers who have more experience with innovative curriculum units may be able to recognize the underlying unit structures better.

The research questions for this study are: (1) What are teachers' current understanding of PBS curriculum design principles and underlying unit structures? and (2) How are teachers' experiences with PBS curriculum units related to their understanding of design principles and underlying unit structures? Understanding differences in teacher understanding of these embedded curriculum concepts may provide guidance for the design of curriculum materials, professional development, or software tools that aim to help teachers use curriculum materials.

Methods

This study addresses the second phase of our design experiment (A. L. Brown, 1992; Collins, 1992) that explores the role of technologies in supporting teachers understand the underlying structures of curriculum units. In the first stage (Lin & Fishman, 2004), we interviewed middle school science teachers in order to understand their planning process, the factors they take into consideration during modification, and the resources they used.

This study is embedded in a systemic reform effort focused on the use of project-based science (PBS; Blumenfeld et al., 1991) science curricula in urban middle schools (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000). Project-based science focuses on student-designed inquiry that is organized by investigations to answer driving questions, includes collaboration among learners and others, the use of new technology, and the creation of authentic artifacts that represent student understanding. The five design principles for PBS curriculum units (Singer, Marx, Krajcik, & Chambers, 2000) are: (1) establish meaningful context; (2) engage in scientific inquiry; (3) collaborate to share/refine understandings; (4) utilize learning tools; and (5) create class/individual artifacts (see Table 1).

We focused on teachers' understanding of a ten-week seventh grade PBS curriculum unit called "What is the Water Like in Our River?" (Water). In this unit, students investigate watersheds, movement of water, and relationships in the surrounding landscape and aquatic ecosystem. Students investigate chemical and physical factors that affect water quality, and the relationship between water quality and biodiversity. Students also construct physical and dynamic models of watersheds to help integrate scientific concepts relating to aquatic ecosystems and answer to a question that they have selected related to water quality. Students use Model-It (Jackson, Stratford, Krajcik, & Soloway, 1996), dynamic modeling software, to construct cause and affect models of their aquatic ecosystem. Students plan, build, test and evaluate their model based on the concepts that they have learned about through investigations about their river. In addition, the use of a range of scientific probes provides opportunities for the students to collect and visualize real-time data in the field as they investigate the aquatic ecosystem.

Table 1 *The design principles of project-based science curricula*

Name	Description	Examples
Establish meaningful context	Meaningful, defined problem space that provides intellectual challenge for the learner.	Driving question and sub-questions Anchoring event
Engage in scientific inquiry	A set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena	Asking questions Data collection and analysis Communicating data
Collaborate to share/refine understandings	Interaction among students, teachers, and community members to share information and negotiate meaning	Small-group design meetings Think-pair-share learning strategy Group presentations
Utilize learning tools	Tools that support students in intellectually challenging task	Data collection Communication Modeling
Create class/individual artifacts	Representations of ideas or concepts that can be shared, critiqued, and revised to enhance learning	Concept maps Scientific models Lab reports

As discussed earlier, teachers' experience with innovative curriculum units seems to contribute to their understanding of underlying principles in curriculum units. In order to study the difference between novice and experienced teachers, we purposefully selected seven seventh grade science teachers who represent different levels of total teaching experience, years of science teaching, and years teaching the Water unit and other PBS units for participation in this study. Participating teachers' science teaching experiences range from three to 20 years. The times they have enacted Water range from zero to three. Details of teachers' teaching experiences are shown in Table 2. It is worth noting that the Water unit was usually the last unit in a school year and there were only about four weeks to finish the whole unit. Therefore, most teachers' previous experiences with the Water unit only include a small portion of the unit.

To address our research questions, we selected three constructs for measurement: (1) teachers' experiences with PBS design principles; (2) teachers' understanding of PBS design principles; and (3) teachers' understanding of the underlying unit structures of the Water unit. The relationship between research question, construct and method is shown in Table 3.

Table 2 *Teachers' teaching experiences*

Teacher	Times teaching Water	Times teaching other PBS units	Years teaching science	Years teaching 7th grade	Years of total teaching
A	2	5	3	3	3
B	3	9	20	15	24
C	3	7	7.5	4	7.5
D	1	4	4	2	4
E	0	4	4	2	4
F	0	3	4	4	4
G	0	2	20	25	40
Mean	1.3	4.9	8.9	7.9	12.4

Table 3 *The relationship between research question, construct and method*

Research question	Construct	Method
What are teachers' current understanding of PBS curriculum design principles and underlying unit structures?	Teachers' understanding of PBS design principles	interview
	Teachers' understanding of the underlying unit structures of the Water unit	clinical interview
How are teachers' experiences with PBS curriculum units related to their understanding of design principles and underlying unit structures?	Teachers' experiences with PBS design principles	interview, survey
	Teachers' understanding of PBS design principles	interview
	Teachers' understanding of the underlying unit structures of the Water unit	clinical interview

A teacher's experience with a PBS design principle is calculated as the sum of instances of the PBS design principle in their previously enacted Water and other PBS units. A teacher's understanding of PBS design principles refers to the number of identified key concepts and examples of the five PBS design principles. A teacher's understanding of the underlying unit structures of the Water unit refers to the number of identified: (1) relationships between lesson components and PBS design principles (lesson-PBS relationships) and (2) connections between lessons. Lesson components are parts that constitute a lesson. For example, a lesson on building computer models in the Water unit composes of the following components: Revisit the idea of modeling, Provide overview of the computer model, Identify variables, Make relationship between variables, and Review major concepts. There are 22 lessons and 100 lesson components in the Water unit.

To establish baseline data for the unit, we conducted a clinical interview (Ginsburg, 1997) with a designer of the Water unit. In the clinical interview, the curriculum designer described the underlying unit structures of the Water unit. After this clinical interview, we conducted clinical interviews with participating teachers before their enactment of the Water unit. We asked them to describe the meaning of each project-based science design principle. Next, we presented teachers with a hypothetical lesson plan that shows a list of Water lessons taught and omitted by a teacher. With the original Water unit curriculum materials at hand, teachers write down the code for PBS design principles they found in each of the omitted lesson components and explain why thought this was so. We chose the omitted lessons so that the instances of PBS design principles in these omitted lessons represent those in the Water unit. Teachers identified the underlying unit structures related to those omitted lessons using a think aloud protocol (Chi, 1997) during their analysis of the hypothetical lesson plan. We also asked teachers the times they have taught Water and other PBS units. The length of clinical interviews with teachers is one hour approximately. The procedure is shown in Table 4.

Table 4 *Procedure for data collection*

Event	interview of curriculum designers' interpretation of unit structures	interview of teachers' understanding
Participant	curriculum designer of the Water unit	7 teachers
Task	identify unit structures in the Water unit and explain the reason	describe PBS design principles (10 min)
		describe the Water unit (10 min)
		identify elements of unit structures in the omitted lesson components of the case (40 min)
Length	120 min	60 min
Data	notes of unit structures for the Water unit	voice recordings of the interviews, teachers' response on worksheets

We calculated the sum of instances of each PBS design principle in each teacher's previously enacted Water and other PBS units as the score of their experiences with these principles. We make three assumptions in estimating a teacher's experience with PBS design principles from enacting PBS units. The first assumption is that all PBS units have a similar structure of unit structures. The second one is that, in average, teachers encounter half of the unit structures in a PBS unit from their enactment. The third one is that teachers taught the same lesson components every time they enacted a unit before. In the interview, teachers indicated the overall amount of their teaching experiences (total, science, PBS units, and Water) in a survey in a professional development workshop administered in summer 2004.

We coded teachers' responses in the clinical interviews according to definitions of PBS design principles and calculated the percentages of identified elements of these principles. We also calculated the percentages of teachers' identified and extra lesson-PBS relationships and lesson connections from those identified by the curriculum designer. Teachers' scores represent their experience with PBS design principles, understanding of PBS design principles, and understanding of the underlying unit structures. Finally, we identified relationships among these constructs.

Findings

One of our findings is that a teacher's experience with PBS units contributes to her understanding of some of the PBS design principles and lesson-PBS relationships. Second, teachers know better about PBS design principles than lesson-PBS relationships and lesson connections. However, most teachers could not identify much of the lesson connections.

According to the curriculum designer's interpretation of what PBS design principles related to each lesson component and the numbers of instance of each PBS design principles, the two most frequently occurring design principles are "Engage in scientific inquiry" and "Collaborate to share/refine understandings." Figure 1 shows the percentage of PBS design principles present in each learning set. Learning set two and three include 45-60% and 25-35% of instances of each PBS design principle, respectively. The percentage of instances of "Establish meaningful context" is highest in learning set one.

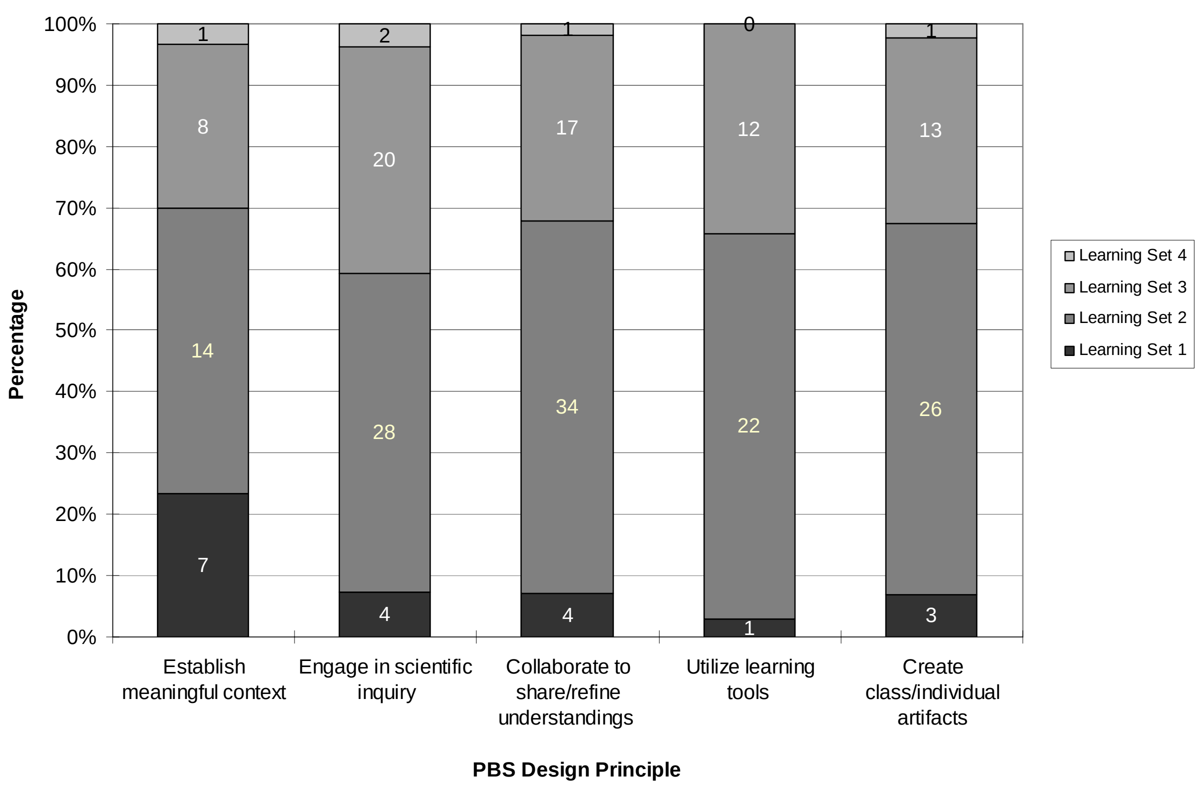

Figure 1. Number and percentage of PBS design principles in the Water unit.

Teachers' experiences in Water, other PBS units, science teaching, seventh grade teaching, and total years of teaching before this Water enactment are shown in Table 1. Overall, teachers have most experience with "Engage in scientific inquiry" and "Collaborate to share/refine understandings" and less experience with "Utilize learning tools" and "Establish meaningful context" (see Figure 2). Teachers A, B, C and D have taught the Water unit before. All four teachers taught lesson one of learning set one. Teachers A, B, and C taught most of the rest of learning set one and lesson one of learning set two. Teachers A and B also taught lesson two of learning set one. Only teacher A taught some other parts of learning set two and some of learning set three. The numbers of taught lesson components and those included in the case are teacher A (44, 16), teacher B (24, 11), teacher C (15, 6), teacher D (4, 0).

Teachers with more experience enacting PBS lessons seem to have a better understanding of PBS design principles. Overall, teachers' scores with respect to understanding of PBS design principles range from 51.7 to 81.7 (mean=67.1). The average score of the three teachers with more experience with PBS units (73.9) is 19 more than that of the other four teachers (62.1). Moreover, the scores of teachers' understandings of each PBS design principle ranges from 57.1 to 78.6 (mean=67.1; see Figure 3). This pattern of teachers' understanding of PBS design principles is similar to that of teachers' total experience of PBS design principles as shown in Figure 2.

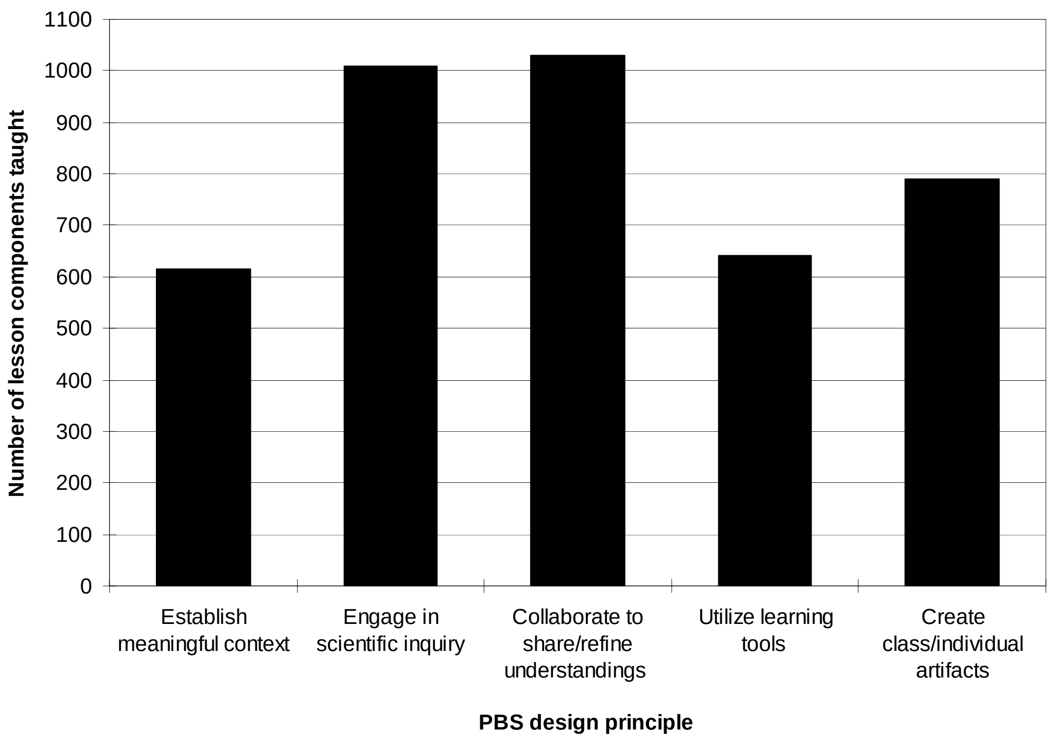

Figure 2. Teachers' experiences with PBS design principles

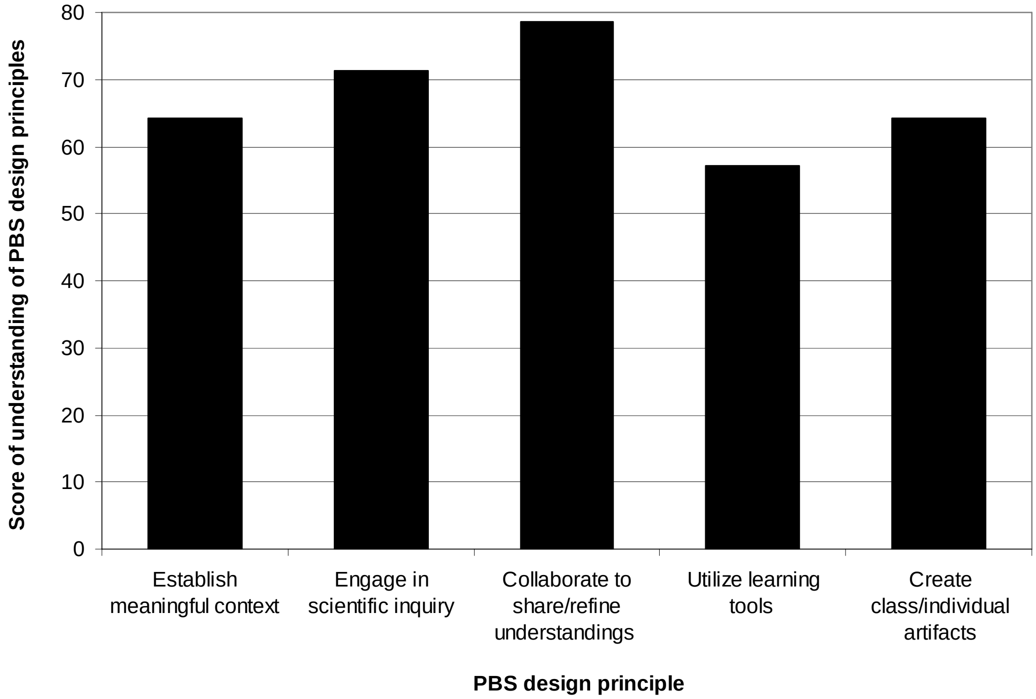

Figure 3. Teachers' scores with respect to understanding PBS design principles

Teachers with more experiences with the Water unit seem to have a better understanding of implicit relationships between lessons and PBS design principles. First, in the case analysis tasks, all teachers identified more lesson-PBS relationships in lessons they taught than in those that they did not, especially in those they taught more than once. Second, in the case analysis task, teachers who taught Water before pointed out 58.5 of designed lesson-PBS relationships than those who did not taught Water before (49.6). It is worth noting that teacher E, who did not teach Water before, pointed out very high score (83.6) of the relationships. In addition, among the three teachers who have taught Water before, the more Water experience a teacher has, the more designed relationships she could identify in taught lessons. In addition, teachers (both as a group and as individuals) identified more designer-identified relationships between lessons and two PBS design principles: "Engage in scientific inquiry" and "Collaborate to share/refine understandings". This result matches teachers' overall experience with these PBS design principles mentioned earlier in this section. Moreover, teachers who have more experiences in the Water unit could better apply their understanding of the lesson-PBS relationships in untaught lessons in this unit.

Third, all teachers pointed out extra lesson-PBS relationships that were not identified by the curriculum designer in the case analysis tasks. The average ratios of the number of extra relationships to that of designer-identified relationships are 1.68. In addition, the average ratios are the highest in lesson-PBS relationships related to "Establish meaningful context" (average ratio=2.0) among all PBS design principles in the case analysis tasks. The tendency of pointing out extra relationships does not seem to be related to teachers' experiences. It is worth noting that teacher E, who score high in identifying designer-identified lesson-PBS relationships, has the highest score in identifying extra lesson-PBS relationships.

Finally, none of the seven teachers could identify more than one-fourth of the 21 connections among lessons in Water unit, regardless of their experience level. Most teachers identified lesson connections less than three lessons apart. Two teachers mentioned that all lessons are connected, but they could not specify what lessons are related to others. Finally, only two teachers identified the connection of three lessons.

Discussion

In summary, there are three major findings in this study. Fist, teachers' understanding of PBS design principles is related to their total amount of experiences with PBS units. Second, teachers' understanding of lesson-PBS relationships is related to their experiences with Water unit. Third, teachers' understanding of between- or among-lesson connections is not related to their experiences.

Our results show that when teachers have more teaching experience with PBS units, they have a better understanding of PBS principles and can identify what elements of PBS theory are represented by individual lessons. The results are consistent with the socio-cultural perspective adopted by this study in that teachers construct their understanding of abstract learning principles embedded in innovative curriculum materials, at least in part, through using these curriculum artifacts in their teaching (Putnam & Borko, 2000).

However, there is a difference between understanding PBS design principles and underlying unit structures. Teaching experience with PBS units provides opportunities for understanding PBS design principles. In contrast, the ability to identify lesson-PBS relationships in a unit develops mainly through teaching that specific unit, and not from generalized experience with PBS units. Our results confirm that teachers did not particularly benefit from their total years of teaching experience or from teaching other PBS units designed with the same set of design principles.

Teachers have a better understanding of the relationship between lessons and some of the PBS design principles and not other PBS design principles. This may imply that being familiar with the lesson content may not be the only factor for teachers' performance in the case analysis tasks. One possible reason may be that teachers' definitions of the meaning of some PBS design principles are different from the designer's. For example, "Establish meaningful context" includes three elements: real-world context, defined problem space, and intellectual challenge for the learner. Most teachers mentioned "real-world context," but not the other two. Therefore, they could not see the relationship between this design principle and lessons not focusing on "real-world context."

Other factors certainly contribute to teachers' varying degree of understanding of underlying unit structures. In addition to the enactment of curriculum units, teachers also learn from professional development workshops, and from their communications with colleagues and researchers (Blumenfeld, Krajcik, Marx, & Soloway, 1994). Teachers may have better understanding of some underlying unit structures because of different topics emphasized in the professional development workshops they attended. For example, the focus of PD workshops might be on just telling teachers the meaning of inquiry-based teaching, on learning to use technologies, or on collaborative learning. Experienced teachers might have more professional development opportunities, and thus more interaction with curriculum designers. Moreover, teachers assign their own meanings to lessons based on their knowledge, beliefs, and local contexts (Grant, Peterson, & Shojgreen-Downer, 1996; Remillard, 2005). This could also explain why teachers in our study identified more relationships between lessons and design principles than those provided by the curriculum designer.

Finally, teachers did not have enough information about the overall structure of the unit. There was not much information on the lesson-PBS relationships and lesson connections in curriculum materials. Our observation of teachers' case analysis tasks shows that teachers sometimes assign a set of design principles to a group of lessons and therefore produce a larger number of relationships other than what were intended by the curriculum designer. This result suggests that teachers are not able to distinguish different roles of lessons. The lack of overview information may also explain why teachers could not easily identify connections among a series of lessons.

The results of this study indicate potential areas of focus for future curriculum design and professional development efforts. Several strategies could be used to help teachers understand underlying unit structures of a unit. One approach is to demonstrate detailed underlying unit structures to teachers and support them in analyzing and reflecting on these underlying unit structures for preparing teachers for learning in their subsequent classroom enactments (Bransford & Schwartz, 1999; J. Shulman, 1992). Second, curriculum and professional development designers need to provide different types of support for teachers with varying experiences and understanding of the underlying principles and structure of a unit. For example, teachers with less experience with a science education content standard might benefit more from learning activities that make relationships between this standard and lessons explicit. Third, professional development designers should focus more on some of the underlying design principles than others in order to help teachers develop a more balanced understanding. Finally, more studies are needed to identify other factors (e.g., teachers' knowledge, beliefs, and reflection practice) that contribute to teachers' understanding of underlying unit structures.

We are engaged in the design of the Planning, Enactment, and Reflection Tool (PERT) to support teachers' enactment of standards-based PBS curriculum units. The results from this study help focus the design of PERT by providing as much information as possible about unit structures to teachers, essentially making the implicit explicit (Lin & Fishman, 2004). Therefore, we integrate four components in PERT: (1) Goals and constraints; (2) Lessons; (3) Profiles; and (4) Connections. In "Goals and constraints", teachers could set the number of target class periods for enacting current unit and other constraints applied in their local contexts. In the "Lessons" module, teachers could see the structure of current unit and standards (National Research Council, 1996) related to each lesson. The "Profiles" component demonstrates overall numbers and percentages of important elements of a curriculum unit based on a teacher's current lesson selection. The "Connections" component shows the big picture of lesson connections in a curriculum unit. We will explore the role of PERT in teachers' modification of curriculum materials in the next phase of our design experiment.

References

Ball, D. L., & Cohen, D. K. (1996). Reform by the Book: What Is--Or Might Be--the Role of Curriculum Materials in Teacher Learning and Instructional Reform? *Educational Researcher, 25*(9), 6-8, 14.

Blumenfeld, P., Fishman, B. J., Krajcik, J., Marx, R. W., & Soloway, E. (2000). Creating usable innovations in systemic reform: scaling up technology-embedded project-based science in urban schools. *Educational Psychologist, 35*(3), 149-164.

Blumenfeld, P., Krajcik, J. S., Marx, R. W., & Soloway, E. (1994). Lessons learned: How collaboration helped middle grade science teachers learn project-based Instruction. *Elementary School Journal, 94*(5), 539-551.

Blumenfeld, P., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning. *Educational Psychologist, 26*(3-4), 369-398.

Bransford, J. D., & Schwartz, D. (1999). Rethinking transfer: A simple proposal with multiple implications. In A. I.-N. P. D. Pearson (Ed.), *Review of research in education* (Vol. 24, pp. 61-100). Washington, DC: American Educational Research Association.

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

Brown, A., & Campione, J. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble & R. Glaser (Eds.), *Innovations in learning: New environments for education* (pp. 289-325). Mahwah, NJ: Erlbaum.

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.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated Cognition and the Culture of Learning. *Educational Researcher, 18*(1), 32-42.

Bruner, J. (1990). *Acts of meaning*. Cambridge, MA: Harvard University Press.

Chi, M. T. (1997). Quantifying qualitative analyses of verbal data: A practical guide. . *The Journal of the Learning Sciences, 6*(3), 271-315.

Clark, C. M., & Yinger, R. J. (1987). Teacher planning. In J. Calderhead (Ed.), *Exploring teachers' thinking* (pp. 84-103). London: Cassell.

Cole, M. (1996). *Cultural Psychology: A Once and Future Discipline*. Cambridge, MA: Harvard University Press.

Collins, A. (1992). Toward a design science of education. In E. Scanlon & T. O'Shea (Eds.), *New directions in educational technology* (pp. 15-22). New York: Springer-Verlag.

Collopy, R. (2003). Curriculum materials as a professional development tool: How a mathematics textbook affected two teachers' learning. *Elementary School Journal, 103*(3), 287-311.

Davis, E. A., & Krajcik, J. S. (2005). Designing Educative Curriculum Materials to Promote Teacher Learning. *Educational Researcher, 34*(3), 3-14.

Davis, E. A., Smithey, J., & Petish, D. (2004). Designing an online learning environment for new elementary science teachers: Supports for learning to teach. In Y. B. Kafai, W. A. Sandoval, N. Enyedy, A. S. Nixon & F. Herrera (Eds.), *Proceedings of the 6th International Conference of the Learning Sciences, ICLS2004*. Mahwah, NJ: Lawrence Erlbaum Assoc.

Fishman, B. (2003). Linking on-line video and curriculum to leverage community knowledge. In J. Brophy (Ed.), *Advances in research on teaching: Using video in teacher education* (Vol. 10, pp. 201-234). New York: Elsevier.
Ginsburg, H. P. (1997). *Entering the child's mind: the clinical interview in psychological research and practice*. Cambridge: Cambridge University Press.
Grant, S. G., Peterson, P. L., & Shojgreen-Downer, A. (1996). Learning to teach mathematics in the context of systemic reform. *American Educational Research Journal, 33*(2), 509-541.
Jackson, S. L., Stratford, S. J., Krajcik, J. S., & Soloway, E. (1996). *Model-It: A Case Study of Learner-Centered Software Design for Supporting Model Building*. U.S.; Michigan.
Lave, J., & Wenger, E. (1991). *Situated learning : legitimate peripheral participation*. Cambridge England: New York.
Lin, H. T., & Fishman, B. J. (2004). Supporting the scaling of innovations: Guiding teacher adaptation of materials by making implicit structures explicit. In Y. B. Kafai, W. A. Sandoval, N. Enyedy, A. S. Nixon & F. Herrera (Eds.), *Proceedings of the 6th International Conference of the Learning Sciences* (pp. 617). Mahwah, NJ: Lawrence Erlbaum.
Linn, M. C., Clark, D., & Slotta, J. D. (2003). WISE Design for Knowledge Integration. *Science Education, 87*(4), 517-538.
Lloyd, G. M. (1999). Two teachers' conceptions of a reform-oriented curriculum: Implications for mathematics teacher development. *Journal of Mathematics Teacher Education, 2*(3), 227-252.
Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., & Soloway, E. (1998). New technologies for teacher professional development. *Teaching and Teacher Education, 14*(1), 33-52.
National Research Council. (1996). *National Science Education Standards : observe, interact, change, learn.* Washington, DC: National Academy Press.
Pea, R. (1993). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognition: Psychological and educational considerations* (pp. 47-87). Cambridge, MA: Cambridge University Press.
Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*(1), 4-15.
Randi, H., & Corno, L. (1997). Teachers as innovators. In B. J. Biddle, T. L. Good & I. F. Goodson (Eds.), *International handbook of teachers and teaching* (Vol. II, pp. 1163-1221). Dordrecht, The Netherlands.: Kluwer.
Remillard, J. T. (2000). Can curriculum materials support teachers' learning? Two fourth-grade teachers' use of a new mathematics text. *The Elementary School Journal, 100*(4), 331-350.
Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research, 75*(2), 211-246.
Resnick, L. B. (1987). Learning in school and out. *Educational Researcher*(16), 13-20.
Richardson, V. (1990). Significant and worthwhile change in teaching practice. *Educational Researcher, 19*(7), 10-18.
Sabers, D. S., & et al. (1991). Differences among Teachers in a Task Characterized by Simultaneity, Multidimensionality, and Immediacy. *American Educational Research Journal, 28*(1), 63-88.
Salomon, G. (1993). *Distributed cognitions : psychological and educational considerations*. Cambridge England: New York NY.

Salomon, G. (1993). No distribution without individuals' cognition: A dynamic interactional view. In G. Salomon (Ed.), *Distributed cognition: Psychological and educational considerations* (pp. 111-138). Cambridge, MA: Cambridge University Press.
Schneider, R. M., & Krajcik, J. (2002). Supporting science teacher learning: The role of educative curriculum materials. *Journal of Science Teacher Education, 13*(3), 221-245.
Schwartz, D. L., & Bransford, J. D. (1998). A Time for Telling. *Cognition and Instruction, 16*(4), 475-522.
Shulman, J. (1992). *Case methods in teacher education.* New York: Teachers College Press.
Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.
Singer, J., Marx, R. W., Krajcik, J., & Chambers, C. J. (2000). Constructing extended inquiry projects: Curriculum materials for science education reform. *Educational Psychologist, 35*(3), 165-178.
Slotta, J. D. (2004). Web-based inquiry science environment (WISE): Scaffolding teachers to adopt inquiry and technology. In M. C. Linn, E. A. Davis & P. Bell (Eds.), *Internet environments for science education*. Hillsdale, NJ: Erlbaum.
Spillane, J. P., Reiser, B. J., & Reimer, T. (2002). Policy implementation and cognition: Reframing and refocusing implementation research. *Review of Educational Research, 72*(3), 387-431.
Squire, K. D., MaKinster, J. G., Barnett, M., Luehmann, A. L., & Barab, S. L. (2003). Designed curriculum and local culture: Acknowledging the primacy of classroom culture. *Science Education, 87*(4), 468-489.
Talbert, J. E., McLaughlin, M. W., & Rowan, B. (1993). Understanding Context Effects on Secondary School Teaching. *Teachers College Record, 95*(1), 45-68.
Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge: Harvard University Press.
Wang, J., & Paine, L. (2003). Learning to teach with mandated curriculum and public examination of teaching as contexts. *Teaching and Teacher Education, 19*, 75-94.

Acknowledgements

This work was supported by National Science Foundation grant REC-9876150, the W.K. Kellogg Foundation, the Fulbright Foundation, and the Hewlett-Packard Corporation. We also thank Andrew Godsberg, Beth Kubitskey, Stein Brunvand, Jay Fogleman, and Anna Switzer as well as the teachers and administrators for their support in conducting this research. The opinions expressed in this work are those of the authors and do not necessarily reflect the views of the funding agencies or the University of Michigan.