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Engaging Teachers' Pedagogical Content Knowledge: Adopting a Nine-Step Problem-Based Learning Model

Karen C. Goodnough and Woei Hung

Abstract

Engaging primary and elementary students in meaningful, relevant science learning is challenging. PBL is an instructional approach that provides a means to foster meaningful science learning while enhancing teachers' pedagogical content knowledge (PCK). This paper reports on the experiences of a teacher inquiry group consisting of five teachers (K-5) and a university researcher as they adopted a nine-step problem design model to develop PBL experiences. The objectives of the study were to examine how various facets of teachers' pedagogical content knowledge are engaged as they design PBL modules; describe how teachers engage with a nine-step problem design model; and document teachers' perceptions of the strengths and limitations of the nine-step problem design model.

Keywords: pedagogical content knowledge, problem-based learning, science education

Introduction

Over the past few decades, problem-based learning (PBL) has gradually gained popularity in K-12 settings (Goodnough, 2006; Lambros, 2004; McGrath & Sands, 2004; Torp & Sage, 1998), across various levels and subject areas, such as science (Koszalka, Grabowski, & Kim, 2002), biology (Sungur & Tekkaya, 2006), and high school economics (Maxwell, Mergendoller, & Bellisimo, 2005). The adoption of PBL in K-6 settings has the potential to support the goals of scientific literacy (American Association for the Advancement of Science, 1998; Atlantic Provinces Education Foundation, 1998; Council of Ministers of Education, 1997; National Research Council, 1996), which generally include developing conceptual and theoretical knowledge, developing an understanding of the nature and methods of science, and engaging in and developing expertise in scientific inquiry and problem-solving (Hodson, 1998).

As more and more K-12 schools and educators adopt PBL, they will need to engage in new learning, such as gaining an understanding of the nature of PBL and how it should be

implemented, designing PBL problems, and using new strategies and techniques for facilitating PBL sessions (e.g., how to guide students during problem-solving and collaborative learning). In the context of science, research has shown that elementary and secondary teachers feel ill-equipped and ill-prepared to assume these tasks. This lack of preparation often translates into difficulty with teaching science, and as a result, teachers often adopt low-risk, conservative approaches to science instruction (Appleton & Kindt, 2002; Mulholland & Wallace, 2001; Tabachnick & Zeichner, 1999). For example, in a national survey of mathematics and science teachers (Fulp, 2002), 75% of 655 elementary teachers reported that they need considerable professional development to improve their science content knowledge. In addition to this perceived need, teachers reported being comfortable with using general pedagogical approaches in science, but less comfortable with “developing students’ conceptual understanding of science, making connections between science and other disciplines, and leading students using investigative strategies” (p. 19).

In terms of adopting PBL in the context of primary (K-3) and elementary (4-6) science education, designing effective problems is a critical, yet challenging task (Angeli, 2002). Teachers need to consider a range of factors, such as ensuring problems relate to the real world and engage and motivate students; creating problems that encourage students to develop higher-level thinking and group collaboration skills; designing problems that are open-ended and build on students’ prior knowledge; and ensuring problems target desired learning outcomes (Duch, 2001).

Over the last two decades, some researchers have provided guidelines for developing problems. For example, Barrows (1986) provided a taxonomy of PBL problems; Dolmans and Snellen-Balendong (1997) proposed seven principles for designing effective cases for PBL; Majoer, Schmidt, Snellen-Balendong, Moust, and Stalenhoef-Halling (1990) discussed construction of PBL problems; and Duch (2001) and Schmidt (1983) identified the characteristics of good PBL problems. These guidelines focus on the aspects of problems that need to be represented during design: problems need to be authentic, ill-structured, and contextualized; stimulate reasoning; enhance problem solving skills; promote self-directed learning; and enable students to engage their prior knowledge. These guidelines can help educators who adopt PBL develop an understanding of the necessary aspects or criteria for designing effective problems. However, these criteria are often not sufficient, for two reasons. First, many guidelines are usually discussed in a bullet-list fashion, and thus, the interconnections among various aspects of a problem are often not systematically discussed. Second, selecting and developing a PBL problem that meets these criteria, while effectively targeting intended learning outcomes, requires the adoption of a systematic design process. Developing a full understanding of what to consider when designing PBL problems will increase the likelihood that effective PBL problems are created, and consequently, optimal student learning is achieved. Undertaking such a design task without adopting a systematic process can be overwhelming and unproductive.

This paper reports on the experiences of a teacher inquiry group consisting of five teachers (K-Grade 5) and a university researcher as they developed PBL learning modules. Hung's nine-step PBL problem design process, based on his 3C3R model (Hung, 2006a, 2006b), was adopted during PBL development. The study was guided by the following research questions: 1) How will various facets of teachers' pedagogical content knowledge be engaged as they design PBL modules? 2) How will teachers engage with the nine-step design process? and 3) What are teachers' perceptions of the strengths and limitations of the nine-step PBL design model? Subsequently, the authors will discuss teachers' pedagogical content knowledge or PCK in the context of science education, the 3C3R problem design model, and the nine-step PBL design process.

Pedagogical Content Knowledge (PCK) and Science Teaching

Effective teaching involves having solid subject knowledge of a discipline, as well as an in-depth understanding of how to facilitate student learning within that discipline. Shulman (1986, 1987) developed the concept of pedagogical content knowledge (PCK) to show the importance of the integration of subject-matter knowledge and pedagogy in teaching. According to Shulman, PCK illustrates how the subject matter of a particular discipline is transformed for communication with learners. He refers to PCK as "the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject matter that makes it comprehensible for others" (1986, p. 9). According to Shulman, PCK illustrates how the subject matter of a particular discipline is transformed for communication with learners. It includes recognition of what makes specific topics difficult to learn, as well as the conceptions students bring to the learning of those concepts.

In this study, a PCK conceptual framework proposed by Magnusson, Krajcik, and Borko (1999) was used to examine how teachers engaged and enhanced their PCK as they designed PBL experiences. The framework consists of five distinct, yet interrelated, components for teaching science:

1. Orientations to teaching science. These are ways of viewing how science should be taught and how these views guide instructional decision-making. Many teachers' choices of instructional approaches reflect several distinct orientations (content emphasis, guided inquiry, process, problem-based). The reasons for adopting particular approaches are indicative of a teacher's orientation.
2. Knowledge of science curriculum. This includes beliefs about and understanding of curriculum goals and outcomes in particular courses and across grade levels. As well, this category involves an awareness of the curriculum resources available at various grade levels to support instruction.
3. Knowledge of students' understanding of science. This includes teachers' beliefs

about and insights into what prerequisite knowledge, abilities, and skills students need to learn particular topics, as well as an understanding of how students vary in their approaches to learning particular topics. A second area targeted in this category is teachers' knowledge of science concepts and ideas that are difficult for students to learn.

4. Knowledge of assessment. This includes teachers' beliefs about and understanding of which aspects of students' learning are important to assess within a learning episode or unit, as well as the methods of assessment that are appropriate for determining the learning that has occurred.
5. Knowledge of instructional strategies. This includes teachers' beliefs about and understanding of which instructional strategies may be used to teach in science, as well as specific strategies (topics and representations) that would be useful to adopt when teaching particular science topics.

Because PBL is a complex strategy, it requires science teachers to extend and utilize many facets of their PCK in a highly integrated manner. For example, teachers need to consider their beliefs about teaching science (orientations) and how the philosophical underpinnings of PBL align with these beliefs. Many PBL experiences are interdisciplinary; thus, teachers not only have to be able to interpret and apply curriculum outcomes to classroom practice, but they also need to integrate curriculum outcomes from several disciplines. PBL units and curricula are developed with the intent of improving student learning. When teachers design PBL problems, they need be cognizant of the prior knowledge and abilities students bring to the PBL context. If students have had very little experience with posing questions, conducting research, and functioning in collaborative learning environments, then teachers will need to provide appropriate scaffolding and guide students in using a range of new skills. Because PBL requires the use of a multilayered approach, teachers will need to incorporate a number of other teaching strategies or tactics (e.g., lectures and laboratory investigations). Furthermore, assessment approaches within PBL contexts are diverse, reflecting authentic, performance-based tools such as group products or self-rating scales. This study will provide insight into how facets of teachers' PCK are engaged as they design PBL experiences using a nine-step design model (Hung, 2006a).

A Conceptual Framework for Designing PBL Problems

When adopting PBL experiences, considerable attention needs to be given to several areas (e.g., learning outcomes to be targeted, complexity of the problem, student readiness to engage with PBL) during the PBL design process. To facilitate problem design that is systematic and attends to these areas, Hung proposed a design model and a corresponding nine-step process to apply the model.

The 3C3R PBL Problem Design Model

The 3C3R PBL problem design model (Hung, 2006a) consists of two classes of components: core components and processing components. Core components, which include content, context, and connection, support content and concept learning in a discipline, while processing components, which include researching, reasoning, and reflecting, support the development of cognitive processes such as problem solving skills. These components are aspects of a problem that need to be considered at each step in the design of a problem.

The core components are primarily concerned with the issues of appropriateness and sufficiency of content knowledge, contextualization, and integration. The content component aims to reconcile the issues of breadth versus depth of content acquisition by addressing the essence of sound content design of a PBL problem. The context component addresses the degree of contextualization of the problem that would in turn influence researching and reasoning processes. The connection component addresses the importance of helping students integrate knowledge learned throughout the curriculum. On the other hand, processing components are used to facilitate mindful and meaningful engagement in PBL by supporting learners' cognitive processes of problem solving skills and self-directed learning. For a complete discussion of the 3C3R model, please refer to Hung (2006a).

The Nine-Step PBL Problem Design Process

Based on the conceptual framework of the 3C3R model, Hung (2006b) further developed the nine-step design process to provide teachers and practitioners with a step-by-step process for systematically considering the critical components of a PBL problem. The process consists of the following: (Step 1) Set goals and objectives, (Step 2) Conduct content/task analysis, (Step 3) Analyze context specification, (Step 4) Select/generate PBL problem, (Step 5) Conduct PBL problem affordance analysis, (Step 6) Conduct *correspondence analysis*, (Step 7) Conduct calibration processes, (Step 8) Construct reflection component, (Step 9) Examine intersupporting relationships of 3C3R components. Next, each step in the problem design process will be described using an example from a grade six mathematics curriculum. Please note that the example has been substantially reduced and simplified and is therefore incomplete due to the length limitations of this journal.

Step 1: Set Goals and Objectives. Specifying the scope of the domain knowledge is the first necessary step in all instructional design methods (Gagné, Wager, Golas, & Keller, 2005; Jonassen, Tessmer, & Hannum, 1999), including PBL course/curriculum development (Drummond-Young & Mohide, 2001; Uyeda, Madden, Brigham, Luft, & Washburne, 2002). Learning goals and objectives help teachers or designers outline the breadth and depth of content and, consequently, provide a structure for aligning the scope of the problem

with curriculum standards or outcomes (Trafton & Midgett, 2001). When specifying learning goals and objectives, the designer should carefully consider three issues—domain knowledge, problem solving skills, and self-directed learning skills. The following example illustrates this:

Example

Instructional Goal: In authentic life contexts, sixth-grade students will apply knowledge of fractions, decimals, and percentages in solving genuine mathematical problems.

Domain knowledge objectives: Within a classroom setting, and given a real life simulated problem, sixth-grade students will identify, represent, analyze, and solve mathematical structures using fractions, decimals, and percentages in order to construct a hypothetical solution to a simulated problem.

Problem solving skills objectives: Based on the students' age and corresponding cognitive readiness, students will identify and define the problem and identify all necessary information to solve the problem.

Self-directed Learning Skills Objectives: Given that younger learners lack self-directed learning skills and experience with PBL, students will initiate group organization and allocate member responsibilities and generate learning issues.

Step 2: Conduct Content/Task Analysis. As Jonassen, Tessmer, and Hannum (1999) suggest, task/content analysis is critical regardless of what instructional method is employed. To conduct a content analysis for PBL curriculum, Sugrue's (1995) categorization of problem solving competence, which includes concepts, principles, and procedures, can help to identify critical content knowledge and skills that constitute the domain. Concepts are the core ideas within a domain. Principles are defined by Sugrue as "the rules that involve relationships among the concepts" (p. 29). Appendix A provides an example of key concepts, principles, and procedures that might be targeted in a grade six math unit.

Step 3: Analyze Context Specification. Situating learning processes in an authentic context is one of the key features of PBL (Barrows, 1994; Duch, 2001; Hmelo, 1998; Hmelo & Ferrari, 1997; Koschmann, Myers, Feltovich, & Barrows, 1994; Torp & Sage, 1998). Projected context is apparent when designing PBL problems for professional training or higher education curricula, for example, medical education or vocational education. The designer also needs to identify the factors that affect the professionals' practice in the field. K-12 curricula or university general education curricula, on the other hand, focus on providing general foundations of knowledge. Therefore, the applications of the content knowledge can be rather general.

Step 4: Select/Generate PBL Problem. In the next step, the designer should explore and establish a pool of real-life problems within the specified context and then select one

problem that best matches and supports the results of the analysis in the first three steps. The selected PBL problem needs to be appealing to learners to keep them motivated (Hung, 2006a).

For example, the grade six mathematics PBL, a list of potential needs to be generated: 1) Plan a budget to treat your mother to a Mother's Day outing, 2) Plan a budget for "back to school" shopping, and 3) Devise a budget plan to start a school store to raise money for school activities. After considering the following factors related to the potential problems—simplicity (age-appropriateness), relevance (familiarity), and appeal (motivation)—problem one is adopted because it targets all of these factors. Problem two is a promising second, but since this project will be given to students in early May, the time frame was more conducive to the Mother's Day problem. The following problem was generated:

Mother's Day is about four weeks away. You and your sibling want to treat your mom to a special day. You and your grandparents are going to chip in \$50 to get you started. You each get \$25 a month total for doing your chores, and this income is available if you choose to buy your lunches. A hot lunch is \$.85 per day. The sales tax where you live is 7%, and the average gratuity for a waiter or waitress in your area is about one fifth of your total bill. Your grandparents would like to see your budget for this day.

Step 5: Conduct PBL Problem Affordance Analysis. The next step is to construct a comprehensive description of the problem space (Newell & Simon, 1972) for analyzing its problem affordance. This depiction is the preparation for the correspondence analysis in Step 6.

Example

Full Description:

- I. Understanding the problem:
 - A. Problem state: The children want to plan a special "Mother's Day Outing."
 - B. Goal state: Plan a budget for this outing for three people, listing all possible expenses, and considering the total funds available and criteria set by the grandparents.
- II. Problem solving processes:
 - A. Determine how much money will be available to use for this event.
 - B. Research unknown variables.

Domain knowledge needed for solving the problem:

Concepts used:

1. Concepts of income and expense
2. Concepts of decimals

Principles used:

1. Rule for finding a percentage of a number
 - * Turn the percent into a decimal (see below), and multiply it by the original amount.

Procedures used:

1. Adding, subtracting, multiplying, and dividing decimals, and fractions
2. Finding a percent of a number

Factual information used:

1. Sales tax rate is 7%
2. Average gratuity is 20%

Problem-solving skills analysis:

1. Identify the known variables given in the problem
2. Identify the unknown variables needed to solve the problem

Step 6: Conduct Correspondence Analysis. Correspondence analysis is an essential mechanism for ensuring the reliability and effectiveness of the PBL problem in the nine-step design process. This analysis detects whether the problem corresponds to the intended content coverage and the skill level of learners by examining: 1) whether the problem properly affords or supports the learning goals, 2) whether the key knowledge involved in solving the problem matches the intended content knowledge, 3) whether the contextual information in the problem is sufficient to situate the learning in an authentic context, or 4) whether the connection component of the problem is properly designed. An over-affording (the scope of the problem is excessively larger than the scope of the intended content) or under-affording (the opposite) PBL problem will need to be calibrated in the next step. Refer to Appendix B for an example of how this analysis is conducted.

Step 7: Conduct Calibration Processes. Based on the correspondence analyses from Step 6, the problem can be calibrated or modified as needed and transformed into the problem presentation. Content, context, researching, and reasoning are the four components involved in the calibration process to craft a problem that is well aligned to the intended content and learners' characteristics. The full description of the problem case is also transformed into a "problem" to be solved during this stage.

Example

The items that need to be revised to align with the learning objectives are as follows:

1. Represent the objective of having the students see equivalents. The facts were now reworded by using different language representing fractions (the gratuity used to say 20%; it was changed to one fifth)
2. Include the grandparent stipulation that the money needed to be "equally divided."

3. Add that transportation is free (another known variable)
4. Include the information that students needed to represent their budget both in fraction and percent form so they could visually see relationships between them
5. Make the total money equal to \$100, so that viewing percent/fraction/decimal relationships would be easier (based on 100, for that part of the problem at least)

Step 8: Construct Reflection Component. Student reflection is one of the major features of PBL (Barrows & Myers, 1993). Incorporating a reflection component for students as part of the problem-solving task can help cultivate learners' self-directed learning skills and habits. The design of the reflecting component should focus on 1) acquisition of all the necessary knowledge, 2) adequate depth of study, 3) effective and efficient research methods, 4) logical and effective reasoning processes, 5) conceptual integration of knowledge, and 6) effective problem solving strategies. The following provides an example of incorporating a reflective component:

Example

You will be grouped in pairs for this activity. Each of you needs to contribute to the project. When you and your partner meet during each class to put your ideas and research together, you should discuss the ideas that you feel strongly about, and back up your ideas with proof. Bring information (menus, flyers, calculations) to show that your ideas will work in the context of the problem. When you are considering different combinations of lunch, activities, and the gift, try using "if, then" statements to support your hypothesis generation.

Step 9: Examine Intersupporting Relationships of 3C3R Components. The last step of the 3C3R design process is an evaluation step. This step evaluates the problem by checking how the various components of the problem work together and are connected. The content, context, connection, researching, reasoning, and reflecting components in PBL problems are not independent of each other. Rather, they are complementary and mutually support each other. Therefore, when designing PBL problems, this supportiveness among the six components is critical to maximizing the effect of each component within the PBL problem as a whole. At this stage, the designer should revise the problem statement based on the result of this evaluation as needed.

Example

Table 1. *Evaluation results of inter-supportiveness of 3C3R components*

	Content	Context	Connection
RESEARCHING	The information that directs students' research information in solving this problem sufficiently supports the content knowledge specified in the learning goal and objectives.	The contextual information sufficiently supports students to research intended content knowledge.	Not applicable since this is a stand-alone PBL problem.
REASONING	The information that directs students' reasoning through the problem space sufficiently supports the students' content knowledge acquisition specified in the learning goals and objectives.	The contextual information sufficiently supports students to engage in the reasoning process specified in the objectives.	However, we may need to make sure the information in the problem is sufficient to activate the students' prior knowledge for taking on these researching and reasoning processes in solving this problem.
REFLECTING	The information in the reflection component of the problem sufficiently guides the students to engage in evaluating their own acquisition/processing of content knowledge	Not applicable since the projected context for this learning module is general.	

Please refer to Appendix C for the final version of the problem statement.

Methodology/Methods

Five primary/elementary teachers and a university researcher/facilitator (the first author of this paper) adopted Collaborative Inquiry (Bray, Lee, Smith, & Yorks, 2000), a participatory, action-based inquiry approach, as a means to develop PBL learning experiences. In this approach to research and adult learning, participants are colearners and coconstructors of knowledge, with relationships reflecting equity among participants; the inquiry

is self-directed rather than other-directed and participants share in the exploration and development of different forms of knowledge through sustained interaction (Reason, 1989, p. 4). The group engaged in planning, reflection, dialogue, action (implementing ideas in classrooms) and learning and capitalized on their varied knowledge and understandings to inform decision making. The study occurred over an eight-month period from November 2005 to June 2006. The outcomes reported in this paper focus on the design phase of the PBL process.

The group met for five individual planning days (5-6 hours) to explore the nature of PBL and to design PBL experiences using Hung's (2006a, 2006b) nine-step problem design process. The first author and group facilitator provided the teachers with articles written by the second author and a checklist, developed from the articles, to be used as a guide as teachers progressed through the steps. Before starting the design process, participants completed a variety of readings and engaged in a range of discussions about the nature of PBL. These discussions continued throughout the design process as group members developed new insights into the nature of PBL.

In this study, the PBL approach adopted reflected the following characteristics: The learning was driven by open-ended, ill-structured, authentic problems (Evenson & Hmelo, 2000; Gallagher, 1997; Wilkerson & Gijsselaers, 1996); students worked in groups (Barrows, 1996; Hmelo, 1998); learning was student directed and facilitated by the teacher (Barrows, 1986); an emphasis was placed on the development of content knowledge (van Gessel, Nendaz, Vermeulen, Junod, & Vu, 2003); and the development of communication, problem-solving, and decision-making skills (Johnson & Tinning, 2001) was promoted.

To view the design process from multiple perspectives and to gain insight into how teachers adopted the nine-step model, a variety of qualitative methods and sources were used, including:

1. *Participant observation.* For an eight-month period (November 2005 to June 2006), the group met for over 30 hours, on a variety of occasions, to plan the PBL experiences. Over a four-month period (September–December 2006), implementation of modules and ongoing and postimplementation debriefing/discussion occurred. All meetings were face-to-face or held synchronously using a web-based communication/collaboration tool called *lluminate Live*. All meetings were audiotaped and later transcribed. In total, 50 hours of audiotapes were transcribed.
2. *Electronic journal entries.* Teachers made reflective entries using an online course management system, provided to university faculty to support research and teaching, during the development and implementation of their PBL experiences. These entries fostered individual reflection about the ongoing process and allowed the facilitator to provide advice and feedback and to act as a sounding board.

3. *Documents and materials generated by the group.* These documents ranged from charts created by the collaborative inquiry group during planning sessions to lesson plans developed for the PBL units.
4. *Pre- and poststudy interviews.* Each interview was 30-60 minutes, allowing insight into the various aspects of teachers' changing beliefs and thoughts. All interviews were audiotaped and later transcribed.

Data analysis was ongoing throughout the study. This entailed reading and rereading the data from all data sources. During this process, the authors engaged in writing analytic memos and recording notes about developing insights and thoughts. Initial basic coding involved assigning labels to units of text from transcripts and journal text. The PCK categories and the steps in the design process guided data analysis, while strengths and limitations were identified across the data set. Crabtree and Miller (1992) refer to this as a template strategy; sets of codes are applied to the data, but may change as data analysis proceeds. A qualitative software program, *MAXqda2*, was used to organize and code data and to generate categories and themes. Ultimately, the author brought meaning to the analyzed data through interpretation, the process of making sense of the findings, offering explanations, and generating conclusions (Marshall & Rossman, 2006).

Context of the Study

This study was the result of an ongoing partnership between the Faculty of Education, Memorial University of Newfoundland, and a local school district. Teachers were recruited in the spring of the year by sending invitations to school principals. Teacher collaborators who volunteered to participate in the project were given a small honorarium to purchase science materials for their schools, while several teacher release days were funded through a Social Sciences and Humanities Research Council grant.¹ These days were used for planning the PBL modules, sharing ideas, and reflecting on the design process. One of the teachers taught in an urban community, while the other four were from schools located in rural communities. The structure of the teachers' schools ranged from K-12 to K-5; however, the teaching assignments were at the primary/elementary levels. All teachers taught all core subjects in the curriculum, with the exception of French, Music, and Physical Education.

Tina, an experienced teacher of 23 years, worked with a grade two class of 18 students (9 boys and 9 girls). Four children followed a program with modified learning outcomes,² while the other students were average or above average in terms of academic ability. Tina had completed a graduate degree in education, a Bachelor of Arts and a Bachelor of Special Education.

Anna had a BA, a Bachelor of Education, as well as a Master of Education, and had been teaching for 23 years. She implemented her PBL unit with a group of 22 grade four

students (8 boys and 14 girls). Five children followed programs with modified learning outcomes, and two of these children were labeled as behaviorally challenged.

Myra worked with a grade three class of 12 boys and 12 girls. She described her class as being weak academically, particularly in reading (50% were below grade level). One student was following a program with modified learning outcomes and one student had been diagnosed with dyslexia. Myra had taught for 15 years and had completed a BA, BEd, and Master of Arts degree. She had been involved in development of a new primary science program for the provincial Department of Education. It was there that she learned of the project and became interested in furthering her professional development in science education (Planning meeting).

Sharon, with 18 years experience, had completed graduate work in education, as well as a BA and BEd. She implemented her PBL module with a grade one class of 24 students (13 boys and 11 girls). The class was of mixed ability; four students followed a program with modified learning outcomes and one student had a hearing impairment.

Patsy worked with a grade four class of 18 students, having equal numbers of boys and girls. The class had several strong students; one student followed a program with modified learning outcomes, while another student had been diagnosed with a behavioral disorder. Patsy had completed a BA and BEd and been teaching for two years.

Anna and Patsy worked together to develop their PBL module on habitats (grade four), while Tina developed a PBL module on life cycles. Although Myra and Sharon taught different grade levels (grade three and grade one respectively), they developed a module that focused on the needs of living things. Many of their learning and assessment activities were similar, but differentiated for learners with varying abilities, interests, and motivation.

Results and Discussion

The adoption of PBL in this study was new for all teacher collaborators. Outcomes related to the design of PBL problems, the engagement of various aspects of teachers' PCK, and teachers' perceptions of the strengths and limitations of the nine-step design model are highlighted subsequently.

The design of PBL problems

The primary goals of adopting the nine-step 3C3R PBL design model are to facilitate the development of problems that target specified outcomes and promote student understanding of content knowledge within a discipline, as well as the development of student problem-solving and self-directed learning skills. Furthermore, when designing a problem, consideration needs to be given to students' prior experience with learning through PBL and how the problem appropriately engages students in mindful learning of the intended content.

To provide insight into how the design process was adopted in this study and how teachers engaged with the model, the authors use an example developed by one of the teachers, Tina. Although Tina was the only one who adopted this problem for implementation, the actual design involved discussion and feedback from all group members during each step of the design process. It should be noted that all teachers followed a similar design process, as described in the subsequent example.

In Step 1, Tina selected learning goals and outcomes from the science curriculum she wished to target. For example, students were expected to: 1) observe and describe changes in the appearance and activity of an organism as it goes through its life cycle, 2) identify constant and changing traits in organisms as they grow and develop, 3) propose an answer to an initial question or problem and draw simple conclusions based on observations or research, 4) identify new questions that arise from what was learned, and 5) communicate procedures and results, using drawings, demonstrations, and written and oral descriptions. Outcomes from other subject areas such as language arts were also targeted (e. g., students will be expected to communicate information and ideas effectively and clearly and to respond personally and critically). Through collaborative concept mapping, Tina and the group developed maps that outlined the concepts, principles, facts, and procedures that would be targeted in their respective units (Step 2). This provided an opportunity to examine how ideas were connected and to examine the unifying ideas in the PBL modules. Figure 1 provides an example of a concept map created by Tina with support and feedback from the group.

In Step 3, she selected a context for the problem (where it would occur), considered the nature of the task that would be incorporated into the problem, identified resources that were available to her to support the problem, and considered the nature of professional work that would be represented in the problem. In Step 4, based on the information generated in Step three, Tina selected a real world problem for the PBL: "The problem will deal with gardening and what to do when there are caterpillars in your garden."

In Step 5, Tina drafted a description of the problem:

I have too many caterpillars in my garden. The caterpillars are starting to destroy the leaves on my flowers and plants. It is very difficult to have a garden on Bird Island because of the rocky, nutrient-deficient soil. With hard work, time, and money, I have managed to create a beautiful garden. How can I protect my plants from being destroyed by these insects?

This step also involved stating the goal of the problem (students will develop an understanding of life cycles and how a specific organism changes as it progresses through each stage of the life cycle), stating known variables (e. g., overabundance of caterpillars, poor soil), unknown variables (e.g., why is the soil poor? how are the larvae destroying the plant?), and identifying the content knowledge and research and reasoning skills that would be targeted in the problem.

Figure 1. A concept map outlining the content topics targeted in Tina's PBL module.

Next, Tina engaged in a correspondence analysis (Step 6). Intended outcomes, identified early in the process, were compared to the content and reasoning skills that would be targeted in the problem as written in Step 5. For example, one of the intended outcomes was for students to observe the life cycle of a butterfly. Tina examined the problem, as formulated and written in Step 5, to determine if it would address the outcome. After doing this assessment, she decided that the wording in the problem would need to be changed to target this outcome. After completing the overall assessment, Tina determined if modifications were needed to the problem (Step 7: calibration) as stated in Step 5. Based on this analysis, the group felt the problem statement over-afforded (the scope of the

problem is larger than the scope of the content) the problem. Tina's comments during a planning meeting reflect this:

The problem over-affords the intended content and more information needs to be included in the problem statement to support the researching and reasoning components. My goal was to have students develop an understanding of life cycles and how a specific organism changes as it progresses through each stage of the life cycle. Using the butterfly as an example, I wanted them to observe firsthand how this insect goes through metamorphosis.

However, I feel that the problem contains too much information (over-affordance of the intended content) because it has details about my garden and the soil in it. I don't think I need to focus on the quality of the soil or the difficulty of having a garden in this geographic area.

Subsequent revisions of the problem resulted in the following scenario:

Every summer, Mrs. Bartlett likes to sit in a chair and enjoy her beautiful garden where she has lots of plants and flowers with butterflies flying from one to another. However, before Mrs. Bartlett can enjoy her peaceful summers, she always has to fight with hungry caterpillars who love to eat the leaves of her plants in the spring. She noticed that these caterpillars always appear around the same time, eating the plants, and then disappear. Then they appear again the next spring, just like the butterflies who come to visit the flowers in the summer and then disappear. Mrs. Bartlett thought it would be wonderful if she could get rid of these caterpillars so that she would not have to work so hard to save the plants and the butterflies would have more flowers to visit in the summer.

You and your teammate are entomologists (bug experts) in training. Your team and other teams of entomologists are called in to help Mrs. Bartlett with her problem. These insects are devouring her plants and flowers. What can you and your team tell Mrs. Bartlett about caterpillars? What can your team do to help Mrs. Bartlett with her problem without destroying her garden? Mrs. Bartlett will choose the best solution to her problem from all the proposals.

These additions allowed a refocusing such that the content and research and reasoning skills were better integrated. Introducing butterflies into the statement directed the students' researching and reasoning toward the life cycle of caterpillars, as well as the growth and changes in appearances, the main focus of the content component (outcomes).

Further modification in Step 8 allowed Tina to ensure reflection components were embedded in the problem. While Tina had identified a range of formative and summative tools that would be used in the PBL module (journal writing, paper-and-pencil tasks,

student presentations, self-assessment, rubrics, etc.), the problem did not have a strong reflection component embedded in the problem statement. The final revised problem statement, which included a reflecting component, is presented in Appendix D.

Step 9, the final step, then allowed the group to view the problem from a holistic perspective, examining how all the components of the problem were connected. Throughout all steps in the design process, teachers examined and engaged various facets of their PCK. The development of their PCK is described subsequently.

Engaging teachers in development of PCK

During each step of the design process, teachers were engaged in considering their beliefs about and orientations to teaching science. Considerations related to their knowledge of curriculum, instruction, and assessment were prominent throughout the entire design process, as these elements were highly connected and integrated. The teacher collaborators joined the project to enhance their comfort level with the intended learning outcomes and to engage students in more “meaningful” teaching and learning in science. One teacher, Anna, had not been pleased with the types of professional development opportunities that were available through her school district and felt this project would meet many of her needs: “This project is exactly what I wanted at this time. I haven’t been really pleased with the type of professional development that I’ve gotten, so I was getting stagnant in my teaching” (Anna, final interview, June 2, 2006).

The PBL approach aligned with teachers’ orientations and beliefs about teaching science—that learning in science should be student centered and foster critical and creative thinking skills. For example, when discussing the nature of PBL in an early planning meeting, teachers identified areas of student learning that could be targeted through PBL: helping students understand the role of science in the real world; developing inquiry skills, asking questions, making inferences, and drawing conclusions; evaluating sources of information; and enhancing presentation skills and written and oral communication. However, science had received little attention in the school curriculum. Thus, the teachers in the study welcomed the opportunity to renew the science curriculum, as well as recharge their knowledge of science pedagogy.

One major outcome of the design process was that teachers were engaged with developing their knowledge of curriculum. This was their first year in working with a new curriculum framework in science, so they were not familiar with the learning outcomes. The design process allowed them to become comfortable with interpreting the learning outcomes in science. For example, in Step 1 of the design process, teachers articulated the curriculum goals and outcomes (content knowledge, cognitive skills, and self-directed skills) they would be using in the PBL experience. Although these were provided by the Department of Education, the teachers had to make decisions about which learning outcomes would be targeted from science and other subjects, such as mathematics, social

studies, and language. The following brief excerpt from a planning meeting provides an example of some of the goals and outcomes addressed in one of the PBL units:

Scientific inquiry and collaborative problem-solving were targeted; there's going to be a lot of sharing and exploring within groups. I have planned the PBL carefully, so it should be motivating for them. After targeting our science outcomes, I then looked at how it [the PBL] meets other outcomes in the other curriculum areas. Language Arts are listed here and I thought they would be met through doing this PBL. In Math, they will be working with numbers and with number concepts, and they'll be collecting data. In Social Studies, they're going to be looking at their environment and how their environment changes over time, and they will probably be looking at how people interact within their environment, so those outcomes in Social Studies will be addressed too. (Anna, planning session, February 6, 2006)

Step 2 of the design process (identifying unifying ideas as well as concepts, principles, procedures, skills, and factual knowledge to be targeted) helped teachers develop an in-depth understanding of their own respective content knowledge (life cycles, habitats, living things). Having competency with the subject matter knowledge is absolutely necessary if teachers are to effectively integrate content and general pedagogy to enhance their PCK. As one teacher commented, "The development of these concept maps that focus on the content for our PBLs really makes us familiar with the science content" (Myra, planning session, February 6, 2006). Additionally, the teachers adopted an interdisciplinary approach by integrating outcomes from other curricular areas into the PBL design.

The design of PBL learning modules challenged teachers to consider very carefully the necessary knowledge, abilities, skills, and competencies (knowledge of students' understanding of science) students need to use or develop when engaged in a PBL experience. Early in the design process, teachers had several concerns, expressed in questions such as "How can we ensure all learners in the class will benefit from the approach? Will students be able to generate learning issues or questions about the problem? Will students like the approach? Will students who have modified learning programs be able to learn through PBL?" They also stressed the importance of finding out what students already know about a topic and the need to create PBL experiences for primary/elementary children that are fairly structured and teacher directed. This thinking about how a PBL should be structured is reflected in comments made by two of the teachers: "I teach grade two and they are not as independent in their thinking as you would hope they would be. So, while you hope and strive for independent thinking, you need to direct the learning" and "We structure more in K to 6 because of the nature of the children. They need a lot of structure and modeling. We should not take that modeling away now" (Sharon and Tina, planning session, March 20, 2006).

While reflecting on these questions and issues, throughout Step 1 (setting goals and objectives) of the design process, teachers collected and analyzed the necessary data for making informed decisions on the PBL module design. In this step, the teachers conducted a learner analysis, evaluating their targeted learners' levels of understanding in science, and assessing their cognitive capabilities to engage in the problem-solving process. This facilitated the process of selecting appropriate goals and objectives for their PBL module design.

In selecting assessment and learning activities (knowledge of assessment and instructional strategies), the teachers adopted strategies and approaches that would foster learning through inquiry and collaboration; thus, student learning within collaborative groups was a critical component of the PBL process. For example, Sharon, in a planning meeting, talked about her use of cooperative learning in the context of PBL. She commented, "I use cooperative learning, but PBL will demand that I use many more cooperative learning strategies, especially if we want students to assume their fair share of work and to complete tasks collaboratively" (May 18, 2006). The teachers raised concerns about how well students would function in groups, especially students following modified learning programs. These concerns are reflected in some of their comments about how to enhance group functioning:

I think it is important to foster ownership within the groups. They can develop shared resources such as a kit or folder and allow them to generate a name for their group. This is really important for fostering rapport within the groups. (Anna, journal entry, May 8, 2006)

Yes, another thing that would help I think is having regular group meetings. "Ok, it's time for a meeting." They will need to talk about what they have learned, what resources they found, and the groups could talk about their questions. They need to consider if they have answered their questions and what they are going to learn next. (Sharon, journal entry, May 21, 2006)

You also need students to assume different roles . . . a director to ensure everyone is paying attention, a recorder, etc. and these roles could alternate. (Patsy, journal entry, May 24, 2006)

And we need to constantly model what effective group work looks like and I think we need to get them to evaluate how well their groups work. (Tina, journal entry, May 10, 2006)

When planning the PBL learning experience, the teachers considered assessment and learning activities simultaneously, while ensuring they were targeting the learning outcomes. As Myra said, "It is only natural that these two be considered hand-in-hand." They recognized that within a PBL environment, they would need to adopt a range of instruc-

tional and assessment strategies, stretching their thinking and classroom practices. For example, within the PBL modules, teachers orchestrated field trips; utilized guest speakers, videos, and the resources of external agencies; and used mini-lectures, graphics organizers, stories, Internet resources, inquiry activities, demonstrations, student presentations, rubrics, and classroom observations.

The nine-step design model

The inquiry group identified three major strengths of the model: fostering comprehensiveness, offering a useful reflective heuristic, and catering to the learning needs of all students. However, the teachers perceived the model as being too long and time consuming to use, lacking clarity in terms of language, and needing to include the design of learning activities as part of the process. These perceived strengths and limitations were agreed upon by the entire group after completing the design process and engaging in discussion and reflection at the end of the project.

Strengths of the model

One of the perceived strengths of the model, as identified by all teachers, is comprehensiveness. The model allowed the teachers to view the design of a PBL experience from a holistic perspective, taking into consideration how components such as the outcomes, assessment, and problem scenario within a PBL interact. Sharon commented, "It certainly forces you to think about the whole picture, how the outcomes fit with the content, context, and assessment" (final interview, December 11, 2006). Patsy shared these views: "Although the process was lengthy, I felt for the first time through that the process gave me a solid understanding of how to go about planning a PBL" (final interview, December 12, 2006). It is critical for teachers and instructional designers to develop a holistic view of the design of instruction. If the components of curriculum are disconnected (e.g., a mismatch between learning activities and assessment activities), it is likely that the students' literacy in a subject domain will not be well formed. A lack of cohesiveness may result in "compartmental knowledge" (Spiro, Coulson, Feltovich, & Anderson, 1988), which is one cause of students' difficulty in applying or transferring knowledge in solving real-life problems.

Teachers recognized another strength—the model provided an effective heuristic for reflection, thus "allowing one to revisit steps, make changes, and stay focused on the outcomes" (Patsy, final interview, December 12, 2006). For example, all teachers liked Step 1, starting with the goals and learning outcomes to be targeted. As Sharon commented, "Outcomes drive our teaching and learning, thus the PBL needs to as well" (journal entry, November 12, 2006). The nine-step design process guides teachers and designers through the PBL problem design process step-by-step, and more importantly, helps them target the intended design goals and objectives. Without a structured heuristic, designers or

teachers may stray from the intended learning goals in the curriculum design process.

A full depiction of the problem that enables the designer to conduct a comprehensive correspondence analysis between the scope of the problem and the intended learning goals and outcomes (see Steps 5 and 6) would, in all likelihood, improve the effectiveness of the PBL problem and module by ensuring the problem appropriately affords the intended learning goal (Hung, 2006a, 2006b). Furthermore, the last step of the design process (examine intersupporting relationships of 3C3R components) provides an integrity check of the PBL problem, as well as an explicit reflective tool for the teacher or the designer to refine and optimize the problem design. The importance of engaging in a thorough design process that allows for an integrity check of the problem statement and the overall PBL experience is echoed in the comments of the teachers:

The scaffolding chart really helped wrap my head around all aspects of the problems and how students would engage with the problem. (Patsy, final interview, December 11, 2006)

Well, the overall process certainly enhanced the design of the PBL. In the nine-step process, we had to check goals and outcomes against other parts of the problem and had to examine how everything overlapped or did not overlap. You really had to dig deep. And I think the plus of the process is that you are really focusing on those outcomes. (Sharon, group planning session, November 21, 2006)

I would like to see the process abbreviated. However, it's really a validation process so that the problem truly is engaging and appropriate for your students and supports goals and outcomes. Without the process, you might just create your scenario and have your learning outcomes and activities and not go through this validation process. (Anna, journal entry, October 27, 2006)

Another benefit reported by three of the teachers was that the model forced them to place a greater emphasis on the learning needs of all students in an attempt to make PBL feasible for all learners. This is another indication, as referenced earlier, that the nine-step design process enhanced the teachers' knowledge of students' understanding of science. Considering learners' needs is a critical element of the 3C3R model and the nine-step design process. It ensures the difficulty level of the problem is appropriate for the targeted learners in terms of their cognitive capabilities as well as their current and targeted abilities in the areas of problem-solving and self-directed learning. These considerations are important because overwhelming the learners with what is beyond their capability or boring them with less than challenging problems would do little to foster optimal learning.

Limitations of the model

While the teachers considered the model to be comprehensive, they suggested that the process could be streamlined and some of the steps could be combined. Their rationale centered on the need for creating a less time-intensive approach: “Teachers want the *Readers Digest* version of any new learning as they do not have the luxury of time that we had to work on this process,” “we need something practical,” and “it has to be easy and straightforward” (Anna, Tina, Myra, planning meeting, February 6, 2006). The language used in describing the steps in the design process and the wordiness of the model were identified by the teachers as drawbacks: “Terminology is often difficult to understand” (Patsy, journal entry, April 6, 2006). In addition to this global feedback about the design model, the teachers suggested that identification of learning activities be an explicit part of the model. As two of the teachers suggested: “The model does not indicate where to include learning activities” (Tina, planning meeting, November 21, 2006). “This is very important. When planning, we always look at our outcomes and think about learning activities to go with the outcomes together” (Myra, planning meeting, November 21, 2006).

Step 6 in the process, correspondence analysis, required the teachers to align the intended subject matter content with the subject matter content identified in Step 5—affordance analysis. As well, the teachers had to compare the learning outcomes to the research and reasoning components identified in Step 5. Step 6 presented the biggest challenge for the teachers in terms of time and its lack of user-friendliness. “This was a bit confusing and it required so much work it definitely needs to be streamlined” (Anna, interview, December 11, 2006). Overall, the teachers recommended that a modified version of the nine-step design model be developed that is “teacher-friendly” and “realistic,” considering the hectic nature of teachers’ daily lives. As Sharon commented, “I really see strengths in all the steps; however, I wish there was something a little more simplistic and less cumbersome” (planning meeting, September 22, 2006).

Implications/Conclusions

The adoption of the 3C3R nine-step design process in this study facilitated professional learning, assisting teachers in examining their own decision-making and practice as it relates to curriculum, instruction and assessment, and student learning. Furthermore, the study provides insight into the feasibility of the process for adoption by K-12 teachers. The teachers agreed that the 3C3R model and the nine-step PBL design process provided a systematic conceptual framework, as well as an operational step-by-step means to guide the design of PBL problems. While the nine-step design process fostered the systematic PBL problem design process, the teachers also expressed practical concerns, namely, lack of time and resources. These concerns warrant serious consideration. A well-designed,

effective PBL problem requires extensive preparation, analyses, and planning. To accomplish these tasks properly, Steps 5, 6, and 7 (problem affordance analysis, correspondence analysis, and the calibration process, respectively), in particular, need to be modified so they are less time consuming and less energy intensive. For in-service teachers to adopt the 3C3R model and utilize the nine-step design process, the time they have for devoting to designing a PBL module would need to be taken into account.

The design of PBL learning experiences, as with many other curriculum and instructional design methods and processes, involves a series of complex tasks and needs to be approached systematically when considering the learning needs of students, as well as its practicality for the teachers. Improving the 3C3R model and the nine-step design process for K-12 educators will pose several challenges, such as finding a balance between the number of steps and amount of analyses and tasks necessary to make a PBL problem effective and the limited time teachers have to devote to the design process. This will continue to be one of the priorities in the continuing research of the 3C3R PBL problem design model and the nine-step design process.

Notes

1. The project was funded by SSHRC, the Social Sciences and Humanities Research Council, a Canadian federal granting agency that promotes and supports university-based research and training in the social sciences and humanities.

2. Students who follow modified learning programs have the learning outcomes, assessment activities, and learning experiences for courses modified from the regular curriculum, based on their unique learning needs as identified by a set of diagnostic tests and tools.

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Appendix A

Conduct Content/Task Analysis
Step 2 of the Nine-Step Design Model

Appendix B

Step 6 – Conduct Correspondence Analysis (Partial)

DOMAIN KNOWLEDGE (FROM STEP 2 →) (FROM STEP 5 ↓)		CONCEPTS				
		DECIMALS (D)	FRACTIONS (F)	PERCENTS (%)	REAL LIFE MATHEMATICAL SITUATIONS	EQUIVALENT RELATIONSHIPS BETWEEN D, F & %
CORE CONCEPTS	Concept of income & expense	☺			☺	
	Concept of Decimals	☺			☺	☺
	Concept of Percentages (A percentage is a ratio compared to 100.)			☺		☺
	Concept of Fractions		☺			☺
	Budgeting money and time	☺			☺	
	Concept of handling money	☺			☺	
	Relationships between fractions, decimals, and percentages	☺	☺	☺		☺
	Concept of marketing math (discounts)			☺	☺	
	Greater than, less than, and equal to (for comparing combinations)				☺	

Legend: ☺ Addressed in the problem.

DOMAIN KNOWLEDGE (FROM STEP 2 →) (FROM STEP 5 ↓)		PRINCIPLES			PROCEDURES		PREREQUISITES	BEYOND SCOPE OF OBJECTIVES
		EVALUATE MATHEMATICAL EXPRESSION USING APPROPRIATE RULES	SOLVING MULTI-STEP PROBLEMS	CONVERSION RULES FOR F, D & %	CONVERT F TO D, D TO F, F TO %, D TO %	SOLVE USING THE 4 MATHEMATICAL OPERATIONS		
CORE CONCEPTS	Concept of income & expense					☺		☺
	Concept of Decimals			☺	☺		☺	
	Concept of Percentages (A percentage is a ratio compared to 100.)			☺	☺		☺	
	Concept of Fractions			☺			☺	
	Budgeting money and time		☺			☺		
	Concept of handling money					☺		
	Relationships between fractions, decimals, and percentages			☺	☺			
	Concept of marketing math (discounts)		☺			☺		
	Greater than, less than, and equal to (for comparing combinations)		☺					

Appendix C

Final Draft of Problem Presentation

Problem: Mother's Day is about four weeks away. You and your "sibling" want to treat your mom to a special day. You decide to take her out to lunch, buy her a gift, and have a fun activity to do together after lunch. Your grandparents are going to chip in \$50 to get you started, and they stipulated that the money be divided equally between the food, the gift, and the activity. You each get \$25 a month for doing your chores, and this income is available if you choose to buy your lunches. A hot lunch is \$.85 per day. On the other hand, you may choose to pack a lunch instead for free. The sales tax where you live is 7%, and the average gratuity for a waiter or waitress in your area is about one fifth of your total bill.

Transportation will be provided and paid for by your mother. Also, your grandmother is available to take you food shopping if needed.

Your grandparents would like to see your budget for this day. It should show income and expenses. They'd like to see what fraction of your money will go towards lunch and an activity, and what percent of your budget will be used on the gift. Included in the budget should be at least one graph or chart, showing the distribution of money in fraction and percent form.

You need to brainstorm and come up with a list of questions to answer. This will help you during your planning. Keep evaluating your options by revisiting your list of questions to make sure you stay focused! Here are two questions to help you get started: How much money do you have? Can this amount be altered by your actions?

You will be grouped in pairs for this activity. Each of you needs to contribute to the project or your solution will suffer (and your grade). When you and your "sibling" meet during each class to put your ideas and research together, you should discuss the ideas that you feel strongly about, and back up your ideas with proof. Bring information (menus, flyers, calculations) to show that your ideas will work in the context of the problem. When you are considering different combinations of lunch, activity, and gift, try using "if, then" statements to support your hypothesis generation.

I will meet with each group individually to check your progress, and discuss any problems you are having. Be ready to share your working budget and itinerary each time we meet, and be able to explain why you are choosing the food, gift, and activity under consideration. You should also have one or two back-up plans ready as well.

Well, you have a lot of information and a lot of choices in front of you. Keep your information organized, be flexible with your options, stay in your budget, and you'll end up planning a super outing for your mom!

Appendix D

The Final Revised Problem Statement (Tina)

Every summer, Mrs. Bartlett likes to sit in a chair and enjoy her beautiful garden where she has lots of plants and flowers with butterflies flying from one to another. However, before Mrs. Bartlett can enjoy her peaceful summers, she always has to fight with hungry caterpillars who love to eat the leaves of her plants in the spring. She noticed that these caterpillars always appear around the same time, eating the plants, and then disappear. Then they appear again the next spring, just like the butterflies who come to visit the flowers in the summer and then disappear. Mrs. Bartlett thought it would be wonderful if she could get rid of these caterpillars so that she would not have to work so hard to save the plants and the butterflies would have more flowers to visit in the summer.

You and your teammate are entomologists (bug experts) in training. Your team and other teams of entomologists are called in to help Mrs. Bartlett with her problem. These insects are devouring her plants and flowers. What can your team tell Mrs. Bartlett about caterpillars? What can your team do to help Mrs. Bartlett with her problem without destroying her garden? Mrs. Bartlett will choose the best solution to her problem from all the proposals.

In order to produce an effective and trustworthy solution proposal, your team should use scientific methods, such as continuous, consistent observation and keep a journal of your research plan, how the plan has been carried out, and whether any revisions to your research plan are needed after a period of doing your research. Mrs. Bartlett will also pay your team a visit and interview you on the progress of your research. So, your team will need to prepare to answer Mrs. Bartlett's questions concerning her problem with caterpillars destroying the plants. And finally, in order for Mrs. Bartlett to select the best solution to her problem, each team will give a presentation of its research and solution to her problem.

Mrs. Bartlett is anxious to find a good solution to keep her plants healthy and attract butterflies to her garden since spring is coming and the caterpillars are about to come out. So, get started and help Mrs. Bartlett!