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"What's So Terrible About Swallowing an Apple Seed?" Problem-Based Learning in Kindergarten

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Abstract Problem-Based Learning (PBL), an instructional approach originated in medical education, has gained increasing attention in K-12 science education because of its emphasis on self-directed learning and real-world problem-solving. Yet few studies have examined how PBL can be adapted for kindergarten. In this study, we examined how a veteran kindergarten teacher, who was experienced with PBL in her own learning, adapted PBL to teach students earth materials, a topic emphasized in the new state curriculum standards but students had difficulty understanding. The pre-post tests showed that students improved their content understanding. Analysis of the classroom discourse showed that PBL and the teacher's facilitation strategies provided opportunities for students to develop their questioning skills. In conclusion, we discuss the implications of this study for using PBL in kindergarten classrooms.

Keywords Problem-based learning · Kindergarten · Early childhood science education · Professional development

Introduction

A typical day in Ms. Martin, a veteran kindergarten teacher's classroom was as follows, a scenario familiar to many kindergarten teachers:

> Students wait for teacher direction. They want to know what the teacher wants and how to please her. The teacher follows the daily lesson plans in the district unit kit step-by-step. To implement the lesson plans in the unit, students are directed to go to activities in small groups. The students are focused on completing the task as quickly as possible with little discussion or conversation among them. Each lesson follows a similar format of teacher-selected tasks and students following directions until completion of the lesson for that day. The teacher concludes the lesson by telling the students what they learned today. When the students have questions about something, they ask the teacher to get an answer. When the teacher responds by asking them to try to find the answer themselves, the students do not know what to do next. They wait for teacher directions or just forget about the question and get back to the assignment.

When asked what she hoped to see in her classroom instead of the description above, Ms. Martin illustrated her ideal classroom scenario in which science was taught differently:

> Students are asking questions about the world around them. The teacher records their questions for the students and keeps them on a chart in the classroom. Using the framework of the GLCEs[1] and district goals, the teacher is able to select materials appropriate for young students to use, to find information

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[1] GLCEs stand for Grade Level Content Expectations in the new state curriculum standards. The state implemented new curriculum standards by the time Ms. Martin designed her PBL lesson.

about their questions, and to share with small groups, the whole class, and the teacher.

Ms. Martin was a participant in a multi-year professional development (PD) program that adopted Problem-Based Learning (PBL) as an overarching approach to improving K-12 science teachers' content knowledge and pedagogical content knowledge (McConnell et al. 2008). After having used PBL for 3 years in her own learning as a teacher and experiencing its effectiveness, Ms. Martin became interested in using PBL to achieve her ideal classroom scenario and improve her kindergarteners' learning. Her readings of PBL literature further convinced her to test PBL in her classroom.

PBL, a widespread instructional approach originated in medical education (Barrows and Tamblyn 1980), is rooted in a social constructivist view of learning, which argues that knowledge is socially constructed and that students learn best when the learning environment supports the knowledge construction process (Phillips 1995). In PBL, students confront an authentic, ill-structured problem and work in a small group to collaboratively analyze and solve the problem under the guidance of a facilitator. The important goals of PBL include helping students develop a solid knowledge base and effective problem-solving and collaborative skills, as well as becoming self-directed, motivated and lifelong learners (Hmelo-Silver 2004).

Drawing upon PBL literature (Savery 2006; Hmelo-Silver 2004; Mennin 2007; Barrows 1986), in this study, we define PBL to be an instructional approach that embodies four characteristics: problem-driven learning, structured discourse on problem analysis and problem-solving, student exploration of self-generated questions, and teachers as facilitators. These characteristics of PBL offer important affordances that can support young children's learning.

First, in PBL, learning is driven by an ill-structured, real-world problem. Such problems are often open-ended without a single correct answer and are situated in learners' familiar experiences. Dewey (1916) maintained that children learn in the psychological rather than the logical order and suggested to teach science through real-world problems that connect school learning with children's prior experiences. The importance of building on children's real-world experiences has been emphasized by other early childhood science education approaches such as "Inquiry Events" (Eshach 2003) and Reggio Emilia (Inan et al. 2010). Learning with ill-structured problems is important for young children because they are often presented with well-structured problems in school, such as solving puzzles or counting numbers (Eshach 2006). As Eshach (2006) pointed out, "Despite the fact that most problems in daily life are ill-defined, children at school are primarily given well-defined problems" (p. 34).

Second, PBL provides a discourse structure to engage young learners in discussing science (Hmelo-Silver 2004). The PBL discourse often starts with identifying a problem from a case scenario that can be presented in text or video. Then learners analyze the problem by identifying pertinent facts from the scenario. As they gain better understanding of the problem, they generate hypotheses to solve the problem. A critical part of the PBL discourse is to identify learning issues related to the problem that learners need to research in the self-study phase. Learning issues represent the knowledge deficiencies between what they know and what they need to know in order to solve the problem.

A sociocultural view of learning suggests that children's development is mediated by language and interaction (Vygotsky 1978). Early participation in science discourse can help children to acquire scientific language and enhance their readiness for science learning (Peterson and French 2008). Specifically, in the PBL discourse, students need to ask questions to generate learning issues. Questioning is an important inquiry skill for kindergarteners to develop that will benefit their science learning in later years (Glaubman et al. 1997; Samarapungavan et al. 2008).

Third, PBL enables student-centered exploration of scientific questions asked by students themselves. After students generate learning issues in the group discussion, they engage in self-directed research on the learning issues through different activities, such as reading books, and conducting experiments. Early childhood science educators generally agree that it is important to take into account children's interests in instruction (Eshach 2003; Inan et al. 2010). For example, in a Reggio Emilia-inspired preschool, the teachers attended to student interests by incorporating serendipitous events into instruction, such as finding a bug on the play ground, or a child's fear of thunderstorm (Inan et al. 2010). The PBL approach provides a structured way to align science teaching with student interests.

Finally, the role of a PBL teacher is to facilitate and scaffold students' knowledge construction through analyzing, researching, and solving problems. Experience itself does not necessarily lead to learning. It is not uncommon that teachers use fun activities in science teaching that successfully entertain children, but do not lead to science learning (Gelman and Brenneman 2004). According to Dewey (1938/1953), children can have educative experiences that lead to further growth and learning, as well as "mis-educative experiences" that constrain their development. In Dewey's view, teachers play an important role in creating educative experiences for students. In PBL, the teacher cultivates educative experiences for children through guiding their discussion, providing resources, and designing conceptually meaningful activities. For example, not every question that children ask bears scientific importance or can be feasibly investigated. Thus, teacher guidance is important in helping children to select learning issues for study.

In recent years, PBL has gained increasing attention in K-12 and higher education classrooms, such as 7th grade geography (Simons and Klein 2007), 9th grade biology (Chin and Chia 2006), 9th grade chemistry (Tarhan et al. 2008), 12th grade biology (Goodnough and Cashion 2006), undergraduate chemistry (Overton and Bradley 2010), undergraduate physics (Sahin 2010), graduate psychology (Hays and Vincent 2004), graduate business administration courses (Capon and Kuhn 2004), and pre-service science teacher education (Senocak et al. 2007).

Nonetheless, few studies have examined how PBL can be adapted to kindergarten classrooms. Although researchers have suggested that PBL can be an effective instructional approach for kindergarteners based on theoretical assumptions (Eshach 2006), empirical research is much needed to understand how PBL can benefit young learners and what adaptations need to be made.

In addition, Ertmer and Simons (2006) argued that the fact that PBL has not been widely adopted in K-12 settings is partially due to the great challenges that teachers face in teaching with PBL, such as adjusting to a facilitating role. Thus, teachers need support in their initial and ongoing efforts to use PBL in their classrooms. Little is known, however, about what the support should be. Despite the widespread advocacy for the prospects of PBL for improving students' critical thinking and problem-solving skills, there are relatively few empirical studies that have systematically explored ways to support teachers in using PBL. While Ertmer and Simons (2006) acknowledged that "planning and assessment tasks are also critical to the success of PBL" (pp. 41–42), their discussion mainly focused on helping teachers to jump the implementation hurdle drawing upon lessons learned from literature.

In this study, we examined how one veteran kindergarten teacher, who was experienced in using PBL for her own learning, adapted PBL for her kindergarten classroom and how students developed learning from the PBL approach. The purpose of this study was twofold. First, we aimed to document how one PBL lesson was planned, implemented, and assessed in kindergarten. The second purpose was to identify how the teacher's efforts to teach PBL were supported by a PD program. Specifically, we asked the following research questions: (1) How did one veteran kindergarten teacher understand and perceive the effectiveness of PBL and what motivated her to teach kindergarteners with PBL? (2) How could PBL be adapted and implemented in a kindergarten classroom? (3) How did students develop learning from PBL and how could their learning be assessed? and (4) What new issues emerged from experimenting PBL with kindergarteners?

Method

Context

Ms. Martin's efforts to teach kindergarteners with PBL as a collaborative action research project were situated in and supported by a PD program for science teachers. The PD included a 2-week summer workshop and a school year action research project. In the summer, teachers worked in small groups to solve science content problems and pedagogical problems. The teachers studied content areas that were difficult for them to teach (e.g., weather, force and motion, ecology). They also designed a unit that they were about to teach in the next school year. In addition, the teachers selected a teaching problem from their classroom practice to study, and designed a research plan around that problem.

In the school year, the teachers conducted research on their self-selected problems, videotaping lessons and collecting student work. There were six teachers in Ms. Martin's study group who met for 3 h once a month, including two kindergarten teachers and four 5th-6th grade teachers. These teachers all came from different schools. In their monthly meetings, they took turns presenting their research, showing video clips of their teaching and student work. The group then used the PBL process to analyze the problem by identifying facts relevant to the problem, generating hypotheses that accounted for the problem, and developing learning issues for further study.

Thus, PBL was used in two senses in this study. First, Ms. Martin as a PD participant used the PBL process to study her own practice. Second, she designed a PBL lesson for her students to learn about earth materials. Clearly, her participation in the PD influenced her design and teaching of the PBL lesson.

Participants

The focus teacher for this study, Ms. Martin, was a female, White teacher with 12 years of teaching experience. She taught in a full-day kindergarten in a suburban district. There were 24 students in her class, about half boys and half girls. The majority of her students were Caucasians. She was a self-motivated teacher who was devoted to improving her teaching. She explained why she returned to the PD for the fourth time:

> I have had a terrific learning experience with my PBL participation. My teaching has changed as a result of

> information and data. I have expanded my peer group to different schools, grade levels, and districts. We have conversations about teaching and build friendship. We encourage each other and add "spice" to our year with PBL. I expect to continue to expand my knowledge of content and teaching while building a network with other educators.

Data Sources and Analysis

A rich set of data sources was collected from Ms. Martin throughout her 4 years' participation in the PD. First, we examined the data sources related to her PBL teaching in Year 4, including (1) the teacher's research plan developed in the summer workshop (June 2008), (2) classroom video of the PBL lesson, including two whole-class discussions and small group activities (December 2008), (3) student assessment data (four assessments in 2008–2009), (4) the teacher's study group meeting notes (January 2009), and (5) the teacher's final report that summarized her action research project at the end of the school year (May 2009).

In addition, we looked into the longitudinal data from Year 1 to Year 4 to understand the teacher's experience with PBL, including (6) summer workshop evaluation surveys, (7) end-of-year surveys, and (8) end-of-year interviews, all of which were collected by the external project evaluators with a major goal of assessing the effectiveness of the PD in improving teacher learning and changing classroom practice. In these surveys and interviews, teachers were asked to explain what PBL was and discuss the usefulness of PBL for their learning in content and pedagogy. Finally, we examined the teacher's final reports for her action research projects in 4 years to understand whether she improved her pedagogical content knowledge in teaching specific contents.

All relevant data from the surveys, interviews, classroom video, assessments, and the teacher's artifacts were analyzed around the four research questions in an iterative process guided by the grounded theory approach (Glaser and Strauss 1967). Themes emerged from the data and were corroborated across different data sources. Such data triangulation helped to enhance the creditability of the findings. First, to understand how the teacher's understanding of PBL evolved through her participation in the PD, we analyzed the changes in her responses in the surveys and interviews in which she was asked to describe PBL. A pattern of progress in her understanding of PBL emerged across the years as she became increasingly able to articulate the characteristics of PBL. To understand how she perceived the effectiveness of PBL, we examined her responses in multiple interviews when she discussed the usefulness of PBL for her learning in content and pedagogy, which was corroborated by the final reports of her four action research projects. We also examined her research plan in Year 4 to understand why she used PBL for her kindergarteners.

Second, we analyzed the surveys, interviews, the classroom video of the PBL lesson, and her final report to understand how she designed and implemented the PBL lesson and facilitated student discussion, as well as identifying salient patterns in the classroom discourse. In particular, we examined student questioning in the PBL discourse and how the teacher's facilitation strategies enabled students' development of questioning skills.

Third, we analyzed the assessment data to determine student learning from PBL. We tracked the changes in the four assessments that measured students' understanding of the big ideas of the PBL lesson to determine their learning gains and retention. We examined the PD documents that supported the teacher's lesson and assessment design. Finally, we analyzed the notes from her study group meetings to understand what issues emerged from using PBL in kindergarten and what tentative consensuses that the teachers reached.

Results

In this section, we first describe how Ms. Martin developed her understanding of PBL through her participation in the PD and how she perceived the usefulness of PBL. Next, we describe how she designed and implemented a PBL lesson for her kindergarten students and how she assessed student learning to determine the effects of the lesson. Finally, we summarize the emerging issues regarding using PBL in kindergarten.

Encountering PBL in Her Own Learning

Ms. Martin had participated in the PD for four times. Each year, she worked with other teachers in a small group to solve science content problems and pedagogical problems using PBL in the summer PD workshops. In the school year, she met with other teachers once a month and used the PBL process to analyze her own and her colleagues' problems of practice. Through the intensive experience with PBL in various contexts for an extended period of time, her understanding of PBL evolved. At first, she only had a vague understanding of PBL. In Year 1, when asked to describe PBL, she stated:

> Um, I think I, I've been a little more general and I try to connect things they're most familiar with as far as talking in terms of, um, a problem-solving process and, um, familiar terms, stuff like that, talking about applying it to inquiry. (Year 1, end-of-year interview, May 2006)

Her response above reflected a limited understanding of PBL at that time. After 2 years' participation in the PD, Ms. Martin was better able to articulate the PBL process. In Year 3, her explanation of PBL was:

> PBL is a problem-solving process that is useful both personally and professionally. A problem or dilemma is identified, learning issues are examined, hypotheses are created and tested, and finally solutions—"big ideas" are determined (Year 3, summer workshop evaluation, 6/27/2007).

Her understanding of PBL was more refined with another year's experience. In Year 4, when asked "What do you know about problem-based learning?", she responded:

> Problem-based learning is a method that is used to solve problems. It can be used personally to learn about an issue, or it can be a model used to guide students in learning. A dilemma, or learning issue, is identified, then prior knowledge is accessed, facts are listed and hypotheses created, questions are asked about the hypotheses generated and answers are sought. Then information is shared and new questions and hypotheses are identified as the solutions are chosen (Year 4, application survey, 2/8/2008).

As shown in the responses above, a clear progress in her understanding of PBL was evident over the 4 years. In addition, Ms. Martin highly valued the effectiveness of PBL in her learning. In Year 2, she explained that she had used the PBL process for troubleshooting in her curriculum planning and instruction.

> I like the problem-based learning model, and I've applied to myself in personal ways. If I worked on this unit…, the whole PBL model helped me think of, so, what's the fact about my unit, what's my hypothesis, what's going to happen in my unit? …So it is a neat model in personal ways. I think it works well. I know it is based on medical model. It does work (Year 2, end-of-year interview, 4/25/2007).

In addition, learning with PBL changed her classroom practice towards inquiry-based student-centered instruction. When asked how her participation in the PD affected her classroom practice, she stated:

> I think that I tend to use PBL to learn about issues in all areas, such as even like math. I find it's just a different way to look at different issues that come up in the day or might come along as you're planning your teaching. I've looked at how I use small group work in my classroom in particular. I think about how I structure my group or what the task is. I have changed quite a bit. I'm allowing my students to do more inquiry. I'm not like so controlling of what I think that they should be doing and in what order. I let them have a little bit of inquiry going (Year 3, end-of-year interview, May 2008).

Ms. Martin also considered PBL an effective way to develop teachers' content knowledge, pedagogical knowledge, and pedagogical content knowledge. Each year, she reported that she gained a better understanding of the content she studied with PBL. She also expanded her pedagogical knowledge in various instructional strategies that she studied or her group members studied, such as use of small groups, assessment, rubric, and science talk. In addition, she enhanced her pedagogical content knowledge in teaching specific content areas—properties of objects in Year 1, life cycle of trees in Year 2, weather in Year 3, and earth materials in Year 4. An analysis of her teaching of trees using science talks in Year 2 was reported elsewhere (Zhang et al. 2010b). When asked whether PBL was an effective teacher learning approach, she responded:

> Yes. I develop greater meaning and retention when I learn in a personal way. I have greater retention and am more likely to apply and share with others when I learn that way. Like working in a group can accomplish more together. It helps me clarify my thinking and understanding when I share with others (Year 4, end-of-year interview, 4/9/2009).

Given her intensive engagement with PBL in her own learning and her enthusiasm about its effectiveness, it is not surprising that she became interested in teaching her kindergarten students with PBL.

Why PBL for Kindergarteners?

Ms. Martin was troubled by an observation that while her students were able to state some simple facts, they often had difficulty articulating big ideas of a science lesson. Thus, the problem that Ms. Martin chose to focus on in her action research in Year 4 was how to teach students big ideas, as she stated in her research plan.

> How can I increase students understanding of big ideas in science? This question originates as a result of the assessments given to the kindergarten students. When I assess students in my kindergarten class, they can state simple facts about the topic, but have more difficulty expressing the big ideas of the unit (Year 4, research plan, 7/1/2008).

Given her extensive experience in PBL, she reasoned that PBL could be an effective approach to helping students move beyond memorizing simple facts and understand big ideas. She hypothesized that:

> If I use Problem-Based Learning throughout the year in different content areas as a teaching strategy, then the students will be able to recognize the big ideas, because the emphasis is on conceptual understanding rather than the memorization of facts and they have practiced analyzing their thinking (Year 4, research plan, 7/1/2008).

She designed a PBL lesson in the PD summer workshop and implemented it in the school year. Her lesson design was structured and supported by the PD. Next, we describe the important principles embedded in her design and teaching of the PBL lesson.

Identifying Big Ideas for a PBL Lesson

The PD provided substantial support to teachers in their unit development, which transformed Ms. Martin's lesson design and instructional planning, as she explained:

> One of the most significant improvements is how I do my instructional planning now. I used to blindly follow the kit or unit without much thought. Now, I use "Backward Design" and think about what I want the students to be able to do or understand. Then I look at the experiences the students can have to identify patterns that will help them build understanding and explanations. I am using informal assessments to guide my pacing and teaching (Year 3, end-of-year survey, 5/14/2008).

In particular, focusing on big ideas was one of the most important insights that Ms. Martin had gained from her participation in the PD. When asked what aspects of her teaching were improved as a result of her participation, she emphasized "Focusing on big ideas."

> Initially, before PBL [the PD], I don't think I was aware of big ideas in science at all! Now I am using big ideas in my planning, teaching, and assessments. Students are able to explain the big ideas and build meaning using them… Because I see the importance, I plan many experiences, so students can see patterns and understand big ideas (Year 4, end-of-year survey, 5/13/2009).

Ms. Martin decided to design a PBL lesson to teach students earth materials, a topic emphasized in the new state curriculum standards but she found students had difficulty understanding. To identify the big ideas for the PBL lesson, she started from the state curriculum standards. There were two expectations in the state standards regarding earth materials at the kindergarten level:

1. Earth materials that occur in nature include rocks, minerals, soils, water, and the gases of the atmosphere. Some earth materials have properties that sustain plant and animal life.
2. Students can identify earth materials (air, water, soil) that are used to grow plants.

Correspondingly, she defined her unit objectives to be that students should be able to identify simple earth materials, and understand that plants need water, air, and soil to grow. Specifically, in the PBL lesson, she focused on the second objective in the state curriculum standards. The big ideas for students to learn were that water, air, and soil are earth materials that are needed for growing plants.

Using a Story as an Anchor to Introduce the Problem

Ms. Martin reasoned that an age-appropriate way to introduce a problem to kindergarten students was to use an interesting story. At the beginning of the PBL lesson, she read a story book, *What's so terrible about swallowing an apple seed?* (Lerner and Goldhor 1996) to introduce the problem to the students, while they sat on the floor in a circle.

> Ok, we are going to hear a story today, *What's so terrible about swallowing an apple seed?* [Showing the picture to students] One day, Rosie and her big sister, Katie, were sitting on their favorite tree eating crispy apples. Crunch, crunch, crunch, Rosie; munch, munch, munch, Katie. Crunching and munching, and munching and crunching, Rosie and Katie ate their apples right down to their core. Suddenly, Rosie said, "I swallowed an apple seed. Oops, I swallowed another one," and she giggled. "Oh, no!" said Katie in her most worried voice, "Watch out!" "Why?" asked Rosie, "What's so terrible about swallowing an apple seed?" Katie thought fast. "Well," she said, trying to sound smart, "The apple seed is going to grow into a tree right inside your stomach. That's what's so terrible." "How can it grow into a tree inside my stomach?" asked Rosie. "It is easy," answered Katie, "It is nice and warm down there. It's just the right place for a seed to grow." [Paused from book reading] Let's see for a moment. Let's just talk for a second about what we know about what happened so far. This sheet says "What we know." Raise your hand if you can tell me what you know about what's happened here (Transcript of the PBL lesson video, 12/9/2008).

After reading the first few pages of the book, Ms. Martin stopped and asked the students to identify what was known from the story. During the discussion, the teacher recorded student ideas on two charts: "What we know" and "What we need to learn." After 5 min' discussion, the teacher continued to read a few more pages of the book, representing a typical PBL process of providing partial information, starting analysis, and then providing additional information.

> Let's read a little bit more, then we add to that. Rosie thought for a long time, "But trees need sunshine to grow. It's dark in my stomach." "Of course," said Katie, like most big sisters, she had an answer for everything, "It's dark in the ground too, when you plant seeds there, but when the branches of your apple tree get big enough, they will grow out of your ears and get all the sunshine they need." Ok, so, let's see what we can add to this now, what do we know now that we did not know before? (Transcript of the PBL lesson video, 12/9/2008).

Hung (2006) suggested that "The authenticity of a problem is largely determined by the contextual information in which the problem is situated" (p. 59). Apparently, the common experience of swallowing an apple seed and the vivid details of the story introduced a sense of authenticity and the students were intrigued by the story. In their discussion, they were concerned about Rosie's feelings and worried that she might get sick. They were also curious about how the branches would get out of her ears. Examples of student responses included: "Is she swallowing two seeds into her throat? It will be stuck, so, like not feel very good, it won't be really good for her," "How will the branches get out of her ears?" and "She might just cry, if she gets a tree growing in her stomach." Such empathetic and curious responses suggested that the students were engaged in the story. To further engage students, Ms. Martin presented a note from Rosie who asked the class for help.

> We are going to find out how we can help her, right? So we need to find out how we can help Rosie not cry. In fact, Rosie has sent us a note, boys and girls, to Ms. Martin's class. She said, "Dear class, what should I do? Help me. Write back. From Rosie." [Showing a note to the class] She is a little worried. She is going to cry. And she wants us to help her find out "Will eating an apple seed make her sick? Will an apple seed grow in her stomach? Can the branches grow out of her ear? Do seeds need sunlight to grow?" We are going to do some projects and see what we can find out. And on this paper, we write down what we learned, and we can send it to Rosie. So she won't be so worried, so scared about what her sister told her, ok? (Transcript of the PBL lesson video, 12/9/2008).

Although the interesting story successfully introduced the problem and caught the students' attention, the teacher's role was still important in guiding student discussion of the problem. As Eshach (2006) noted, "Introducing problems alone, however, is not enough. Scaffolding is a necessary process that helps the child build cognitive abilities" (p. 53). Next, we describe how the teacher as a facilitator scaffolded student discussion and how she selected resources and designed activities to help students research the learning issues generated from the discussion.

Facilitating Student Discussion Without Evaluation

In guiding student discussion, Ms. Martin's facilitation strategies included (1) paraphrasing student ideas without evaluation and (2) acknowledging all student responses, but focusing on important ideas that were relevant to the big ideas of the PBL lesson.

Previous research has identified a common discourse pattern called *Initiation-Response-Evaluation* (IRE) in classroom discussion (Cazden 1986). That is, a teacher initiates a question, students respond, and the teacher evaluates the response to be right or wrong. The evaluation, however, often discourages students from engaging in meaningful discussion (Wells and Arauz 2006). Ms. Martin rarely evaluated student responses, even when the responses were obviously wrong or irrelevant. Instead, she paraphrased student ideas and recorded them on the chart. For example, when she asked the students to generate questions that they wanted to know, one student said he wanted to know how the branches would get out of her ears. Although this question was scientifically false, the teacher repeated the idea and recorded it as a learning issue on the chart without making an evaluation.

A side effect of using an interesting story to introduce the problem was that students may focus on irrelevant aspects of the story in discussion. The teacher's strategy was to acknowledge all students' ideas, but focus on important science ideas and elaborate on them. Next, we present an excerpt to illustrate the teacher's facilitation strategies. The following excerpt occurred after the students read books, viewed videos, and conducted experiments to research their learning issues.

1. T: Sofia, did you learn something, or if you have any question? Ok, a new question.
2. Sofia: [7s' pause] If she ate a whole apple, I don't really know if that apple will help this seed.
3. T: With the apple in her stomach?
4. Sofia: Yes.
5. T: Ok, so, you wonder if the apple in her stomach will help the seed grow. [Recording on the chart] Ok. Lily, you had a question too, didn't you?
6. Lily: Um, the, um, the, how does the seed, how does the seed grow inside her stomach?

7. T: Ok. How would a seed grow in her stomach? [Recording] How will a seed grow inside her stomach? Mike.
8. Mike: She could go to the doctor, so then the doctor could help her, could like get the seed out of her stomach.
9. T: Ok. So, one thing that we can tell her to do is she can go to her doctor.
10. Mike: Yeah.
11. T: So we learned, [recording] Rosie could go to the doctor. And I have a nurse come in later and maybe she can answer some of our questions for us, but Rosie goes to the doctor, he can tell her what to do. Anna.
12. Anna: I know some more stuff in medicine.
13. T: All right, she goes to the doctor, and we need to find out if medicine would help. [Recording] Does she need medicine? Andy.
14. Andy: How could a tree grow inside your stomach if there was no dirt down there?
15. T: Uh! What do we know? We know that plants need what?
16. Students: Water.
17. T: Andy said dirt. It's called soil. [Recording] Plants need soil, water. Can you have water in your stomach?
18. Students: Yes.
19. T: Plants need water, soil, and what is the other thing?
20. Students: Sun.
21. T: So, does she have these things in her stomach, soil, water, and sun?
22. Students: No!
…
23. T: Ok. So we know there is no soil and no sun, so if we know there is no soil and no sun, what could we tell Rosie?
24. Students: Don't worry about it.
25. T: Can we write to Rosie and tell her don't worry about it?
26. Students: It's not going to happen.
27. T: It's not going to happen, Rosie, you don't have soil, you don't have sun. You are going to be ok … But if you want to go to the doctor, you could (Transcript of the PBL lesson video, 12/10/2008).

In the excerpt above, the first several student responses were clearly irrelevant to the big ideas of the lesson that the teacher intended for the students to learn. Nonetheless, she acknowledged all ideas as valid responses and recorded them on the charts. Her typical follow-up move after a student's response was repeating or paraphrasing what the student said in a non-evaluative manner. In addition, wait time was evident in her facilitation. For example, she was patient in waiting for Sofia and Lily to figure out how to express their ideas.

Finally, in turn 14, Andy asked a question that was relevant to the lesson goals ("How could a tree grow inside your stomach if there was no dirt down there?"). The teacher then seized the opportunity and asked the students to review what they had learned about what plants need to grow. The subsequent discussion was centered on this topic, and the teacher repeated multiple times the concept that plants need water, soil and sun to grow. Interestingly, neither the teacher nor the students ever mentioned air as a necessary element that plants need in the discussion, which might explain the lack of air in student responses in the post-test.

The teacher's discourse strategies were influenced by her science teaching experiences in the previous years. For example, in her Year 2's action research project, she studied how science talks could be used to promote kindergarteners' discussion and learning of science (Zhang et al. 2010b). She found that although misconceptions frequently presented, students benefited from the science talks. Through that experience, she learned to be strategic with student misconceptions in discussion, using them in curriculum planning rather than correcting them on the spot, which might discourage students from participating in discussion and verbalizing their ideas.

It is important to note that student questioning was a salient characteristic of the PBL discourse. There were two whole-class discussions in the PBL lesson. The first discussion focused on developing learning issues, in which the students asked a variety of questions, such as "Why did she swallow that apple seed? Is that her mom? How will the branches get out of her ears? Does sunlight make seeds grow?" In some cases, the teacher helped the students to reframe their idea into a question, for example, from "She might just cry" to "How can we help her not to cry?" and from "You could get sick" to "Will eating an apple seed make you sick?" Through reframing a statement into a question, the teacher modeled how to ask questions. The students continued to ask questions in the second discussion when they applied what they had learned to solve the problem, as shown in the excerpt above.

In sum, the PBL discourse structure with an emphasis on developing learning issues, the teacher's modeling, and the teacher's non-judgmental stance enabled the students to ask questions of interest to them and see how questions were formed. Such practices provided opportunities for the students to develop their questioning skill, an essential inquiry skill for science learning in later years.

Selecting Appropriate Resources and Activities for Students to Research Learning Issues

The teacher considered the most critical part of the PBL lesson to be the students doing research that was prepared for the kindergarten level and then applying the information they gained to form a solution and share with others. After generating several learning issues in the discussion (e.g., Do seeds need sunlight to grow?), the students engaged in a number of carefully designed activities to investigate the learning issues, including conducting experiments, reading books and taking notes, and watching interactive videos. These activities involved both group work and individual study.

Experiments

The students worked in small groups to plant apple seeds in a pot with soil, water, and light. They also placed seeds in a plastic bag with water, but kept the bag in a dark place. The students observed the seeds in the pot and bag to see if they grew. In addition, they cut up apples, took the seeds out to observe using hand lens, and ate the apples.

Informational Books

While the teacher used a storybook to introduce the problem and engage students, she had the students read several informational books that explained the science concepts. These books, selected from the school's library, were at early reading levels, so the students could read them independently. The students read *In The Garden* by Rose Lorenzo, *The Seed* by Joy Cowley, *Living Things Need Water* by Sharon Street, *What Does A Garden Need*? by Judy Nayer, *My Plant* by Paula Barrio, *How Flowers Grow* by Carrie Stuart, and *Making A Garden* by Tracey Reeder. These books explicitly explained that seeds need soil, water, sunlight, and air to grow. The students took notes on their notebook about what they learned.

Interactive Videos

In the computer lab, the students played two educational video games: *Magic School Bus*: *Explores the Rainforest* and *Explores the Human Body*. In addition, they watched two *Magic School Bus* videos that were available on the Discovery Education website: *Gets Planted* (about growing plants), and *For Lunch* (about human digestive systems).

Guest Visit

Finally, Ms. Martin arranged a health specialist from the school district to visit the class, who answered student questions such as what happened to the apple seed in the stomach and whether swallowing an apple seed could make kids sick.

Next, we describe whether these carefully prepared activities and resources helped the students to learn about the big ideas of the PBL lesson.

Assessing Student Learning

The development of Ms. Martin's assessment for the PBL lesson was structured and supported by the PD. During the summer workshop, teachers were guided to design an assessment to evaluate student learning and analyze the assessment to improve instruction. Specifically, teachers were asked to (1) develop one or two open-ended questions that targeted at the big ideas of a lesson, (2) identify an age-appropriate response that a student who had a thorough understanding of the big ideas might give, (3) identify the key components in the ideal response, and 4) tabulate student responses by the key components and misconceptions.

Guided by the design framework, Ms. Martin developed a question to assess student understanding of the big ideas of the earth materials lesson: What earth materials are used to grow plants? Next, she identified an age-appropriate ideal response for this question: The Earth has materials such as soil, air, and water that are needed for plants to grow, with soil, water, and air being the key components. The assessment was developed in her Year 3's participation in the PD and also applied to the PBL lesson that she taught in Year 4 because the big ideas were the same. She first assessed student learning with this question in Year 3 (2007–2008). In Year 4 (2008–2009), she administered the assessment immediately before and after the PBL lesson, and 4 months later to see whether the students retained their understanding of the big ideas. For each of the four assessment results, she examined whether student responses included any of the key components: soil, water, and air, as well as noting misconceptions in their responses.

The results were summarized in Table 1 and illustrated in Figs. 1 and 2. The pre-post tests showed that more students were able to include key components in their responses after the PBL lesson. In particular, there was a substantial increase in the number of students who included soil in their responses. In addition, the PBL students outperformed the students in the previous school year who were taught by regular instructional methods. In the previous year, 19 out of 22 students were able to give at least one correct response, and there were a total of 28 out of 66 possible correct answers given. In comparison, all of the 24 PBL students were able to give at least one correct response. There were a total of 65 out of 72 possible correct answers given. On the other hand, there was a substantial decrease in the number of students who presented

Table 1 Student assessment results

	2007–2008 Unit assessment (April 2008)	2008–2009 Pre-test before the PBL lesson (12/08/2008)	2008–2009 Post-test after the PBL lesson (12/12/2008)	2008–2009 Unit assessment (4/20/2009)
Key components in the ideal response				
Plants need water (rain, snow)	19	19	23	24
Plants need soil (dirt, ground)	4	8	23	24
Plants need air	6	5	3	18
Misconceptions				
The sun is an earth material	16	14	23	24
Seeds are earth materials	7	8	5	1
Roots, leaves, flower, or stem		3	2	
Bees		1		
A basket to keep them in		1		
Grass	2	1		
Snakes	1			
Hearts	1			
Worms	1			
Plant food				1

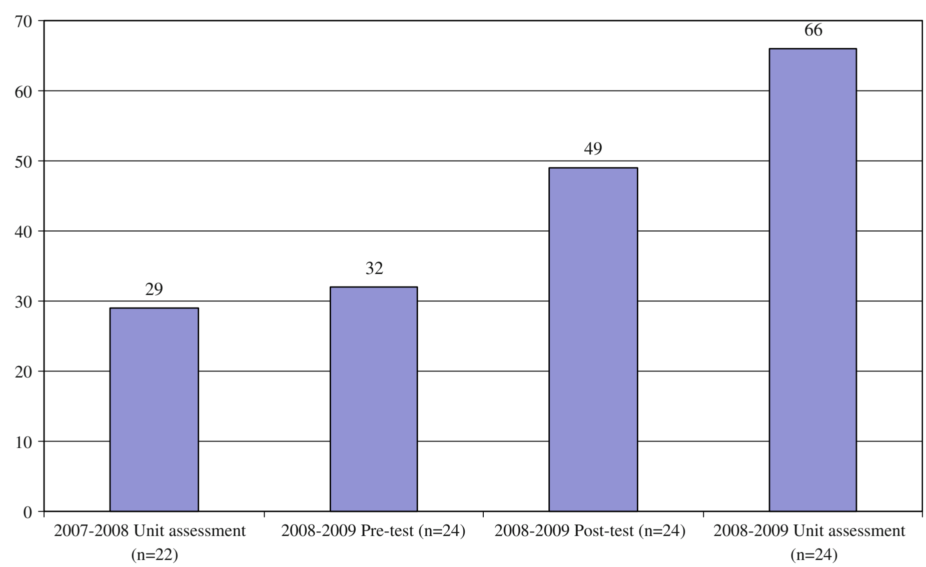


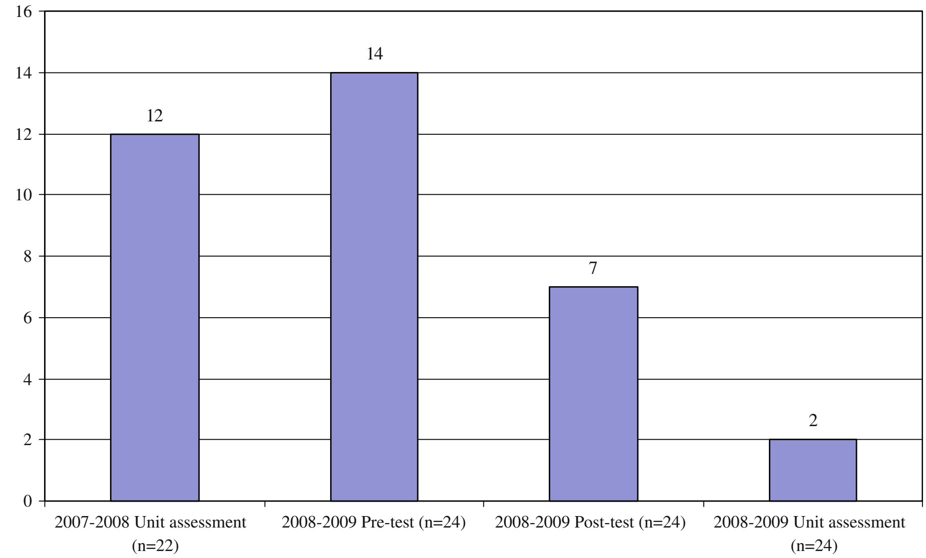
Fig. 1 Total number of correct responses in the four assessments

misconceptions in their responses after the PBL lesson, if excluding the misconception of treating the sun as an earth material, which seemed to reflect an issue in the assessment question rather than student understanding, as explained later. These results suggested that PBL was an effective approach for helping kindergarteners to learn about important science concepts and retain their understanding in an extended period.

In addition, the PD provided a structure to help teachers use the assessment results to improve their instruction and assessment. Specifically, teachers were asked to reflect on: What patterns do you notice in student responses? What ideas do the majority of students understand? What ideas appear to be confusing to students? Are there any clues to why they are confused? Do you have enough information to judge student understanding? If not, how might you alter the assessment task so that it will tell you what you need to know? What are your initial thoughts about how to teach the ideas that are confusing to students? What are the implications for your unit?

Guided by the reflection framework on student assessment, Ms. Martin noticed that the majority of students in each assessment understood that plants need water and sun to grow, but they confused the sun with an earth material.

Fig. 2 Total number of student misconceptions in the four assessments. The misconception that the sun is an earth material was excluded in the calculation because many students interpreted the question "What earth materials are used to grow plants?" as "what do plants need to grow?" In that case, it was not a misconception that plants need the sun to grow



When she first saw this confusion in the April 2008 assessment, she reasoned that students did not understand the concept of earth materials. But when she saw the confusion again in the pre-test before the PBL lesson, she started to speculate that the assessment question might be confusing to the students because they had learned about what plants need to grow right before learning about earth materials, so they might have interpreted the question "What earth materials are used to grow plants?" as "What do plants need to grow?" After seeing the confusion of identifying the sun as an earth material consistently in the four assessments, she was convinced that the students focused on plants rather than earth materials when they responded to the assessment question. To address the misconception, she planned to stress the idea that the sun is not an earth material using an activity of sorting earth materials and non-earth materials. She also saw a need to include more lessons on what are earth materials.

In addition, she noticed that the majority of students in the pre-post tests did not identify air as a necessary element for growing plants. She reasoned that this confusion was caused by the fact that air is invisible to students and concluded that students needed to do further experiments with plants without air. When she compared the assessment results of 12/12/2008 to 4/20/2009, she noticed that the students retained the big ideas in 4 months. She found it interesting that even more students were able to include the key components in their responses 4 months after the PBL lesson. She reasoned that the students did not memorize the facts, but had understood the big ideas and continued to build their understanding even after the lesson ended.

In sum, the assessment results helped the teacher to gain insights into student learning derived from the PBL lesson—ideas that they understood, that were still confusing, and sources of confusion, which further helped her to improve her instruction and assessment.

Reflecting on the PBL Lesson and Emerging Issues

The PBL lesson was largely a successful experience for the teacher, which encouraged her to continue to incorporate PBL in her lessons. As she reflected on the actions that she intended to take in her future teaching, she stated:

> I will look at units and lessons to plan more PBL. A change in my teaching is seeing the impact of identifying the big ideas of the unit. I use the Backward Design to identify the target goals and objectives and look at lesson cycles to decide where PBL might work. I plan to continue using Problem-Based Learning and inquiry in science lessons to help students understand big ideas and move beyond memorization of facts (Year 4, final report, 5/7/2009).

Meanwhile, new issues arose from the experiment of using PBL in kindergarten. At one of the monthly meetings, Ms. Martin shared the PBL lesson video and student assessment data with her study group, along with her reflection on the experience, which sparked a rich discussion among the group. The teachers raised many thoughtful questions about the PBL design and implementation at the kindergarten level.

> What criteria of PBL [should be used] at different developmental levels? If I do it too much, will they lose motivation? Is it too soon to do it again? Can you overdo the PBL use in the classroom? Can the PBL process be used in other subjects to solve problems? Is there more value in using a real problem or is it ok to role-play? Is the value different for different age

> groups? What is the value of role-playing (different characters) in science? At what point does it have to be seemingly real? How do you take the objectives and turn them into something that the kids will have ownership of? What gets kids to buy in? How can we make the questions to which children can relate? (Year 4, study group meeting notes, 1/21/2009).

In particular, Ms. Martin was interested in two questions: How can I organize the resources needed for PBL? How can I help students integrate their thinking from one unit or subject matter to others? (Year 4, final report, 5/7/2009).

Through discussion and research into the learning issues, the group reached tentative consensus on some issues, as shown in the hypotheses they developed in the meeting.

> If I pose a problem at the beginning of the lesson, then students are more motivated and engaged because they know why they are doing work; If we do PBL on a regular basis with students, then they will do the process on their own because they will have ownership and the skills; If students see a value/purpose/audience to problems, then they engage because they have ownership (Year 4, study group meeting notes, 1/21/2009).

Nonetheless, many issues still remained open and unanswered, given the lack of relevant literature on PBL at the kindergarten level. Thus, future research should shed some light into these issues to better understand the use of PBL in kindergarten.

Discussion

In this study we reported a veteran kindergarten teacher's collaborative action research project, in which she designed, taught, and assessed a PBL lesson in her kindergarten class. She made important adaptations to PBL for kindergarten students. Assessment showed that there was an improvement in student understanding of the big ideas of the lesson. The successful experience encouraged the teacher to continue to incorporate PBL in her future teaching.

The teacher's efforts to teach PBL were supported by the PD. First, the teacher gained a thorough understanding of PBL through her multi-year participation in the PD. She found PBL an effective approach for teacher learning, which motivated her to test the idea of teaching kindergarteners with PBL. The PD also provided structures and frameworks to support her lesson design and assessment, which the teacher found useful. Thus, an important implication was that teachers need to experience PBL themselves to develop an adequate understanding of this approach before they can use it in their classrooms. In addition, the PD support that we described in this study can be applied to help other teachers to design their PBL lessons and assessment and overcome the challenges in PBL teaching (Ertmer and Simons 2006).

Because of the great variety of domains, contexts, goals, and forms in which PBL has been adopted, various PBL implementations and practices exist in literature (Maudsely 1999; Lloyed-Jones et al. 1998). In particular, Charlin et al. (1998) suggested that PBL can have "many faces" in multiple dimensions: the selection, presentation, format and purpose of a problem, learning objectives, nature of task, PBL processes, resources, instructor's role, and outcome assessment. Meanwhile, they identified three core principles of PBL: learning is driven by a problem, it is an overarching educational approach, and it is student-centered.

The three core principles of PBL manifested themselves in the PBL lesson in this study. An interesting story was used as an anchor to introduce the problem and drive student learning. PBL as an overarching approach guided the entire process of lesson design, implementation, assessment, and subsequent curriculum planning. Students played an active role in developing and researching their own learning issues and applying information to solve the problem. On the other hand, the PBL lesson was unique in its problem selection and presentation, learning goals, processes, resources, and assessment, which represented one possible "face" of PBL in kindergarten.

The adaptations that the teacher made in her PBL lesson are worth discussion because age-appropriate practice is essential at the kindergarten level. First, she used a story to introduce a problem to students, adding a unique option for problem design to existing PBL literature. A problem is typically introduced to learners with a scenario of a patient's symptoms in medical education (Hmelo-Silver and Barrows 2008), or a messy classroom scenario in teacher education (Zhang et al. 2010a). In secondary science education, a problem can be presented as a challenge to students (e.g., to design a balloon and a travel plan for traveling around the world via balloon) (Simons and Klein 2007), or ask students to play certain roles (e.g., genetics counselors who advise patients with a genetic disease) (Goodnough and Cashion 2006). Yet little is known about how to design problems for kindergarteners. This study suggested that storybooks can be useful resources for introducing problems and engaging students. On the other hand, stories might present misconceptions. Thus, appropriate informational books that address the science concepts should also be provided to students.

Another notable adaptation was that the teacher did not focus on hypothesis generation in discussing the problem, presumably for two reasons. First, the story problem that she adopted in the PBL lesson was different from the diagnosis-solution problems common in clinical practice, which require a hypothesis (diagnosis) to account for a patient's symptoms. Instead, the students' task was to determine what Rosie needed to do based on what they learned, a type of decision-making problem (Jonassen and Hung 2008). Thus, hypothesis generation did not readily apply in this story problem. Second, developing hypotheses to articulate the causes and effects in a scientific phenomenon can be too advanced for kindergarteners. Our prior research showed that, even for teachers themselves, generating a hypothesis to account for a pedagogical problem was rather difficult (Zhang et al., in press). Thus, future research should examine in what kinds of problems and to what extent hypothesis generation should be emphasized at the kindergarten level.

In addition, Ms. Martin considered learning to focus on big ideas to be one of the most critical insights she gained from the PD. Consequently, the importance of big ideas was emphasized throughout her PBL lesson design, implementation, and assessment. Ertmer and Simons (2006) reminded us that although developing content learning is one of the key goals of PBL, "it is relatively easy for both teachers and students to lose sight of this goal and to focus, instead, on the interesting activities that need to be completed" (p. 48). In fact, even as an experienced teacher, Ms. Martin reported that she often found herself losing sight of the big ideas that she intended for her students to learn prior to her participation in the PD. Thus, the approaches that she used in this study to identify, teach, and assess the big ideas for her PBL lesson have important implications for other teachers who are interested in PBL teaching.

The limitation of this study was that we only examined the implementation and outcome of one PBL lesson in one kindergarten classroom. Thus, we were unable to gauge how students improved their questioning skills and other higher order cognitive skills such as reasoning and problem-solving. In addition, many issues that the teachers raised in their group meetings regarding PBL teaching remained unanswered. Nonetheless, this study found that the PBL lesson improved students' content understanding based on the pre-post test results and comparisons to the previous students, and student learning was retained according to the assessment 4 months after the PBL lesson. In addition, the PBL discourse and the teacher's facilitation strategies provided opportunities for students to develop their questioning skills. Future research should continue to investigate the conditions for effective use of PBL in kindergarten classrooms and how PBL can support both content learning and development of higher order cognitive skills.

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