An Examination of Teacher Understanding of Project Based Science as a Result of Participating in an Extended Professional Development Program: Implications for Implementation

Gale A. Mentzer  
Acumen Research and Evaluation, LLC

Charlene M. Czerniak  
The University of Toledo

Lisa Brooks  
Acumen Research and Evaluation, LLC

Project-based science (PBS) aligns with national standards that assert children should learn science by actively engaging in the practices of science. Understanding and implementing PBS requires a shift in teaching practices away from one that covers primarily content to one that prompts children to conduct investigations. A common challenge to PBS implementation is a misunderstanding of the elements of PBS. Identification of these misunderstandings as well as implementation challenges could inform professional development. This case study examined 24 teachers’ understanding and implementation of PBS during participation in a consecutive three-year, comprehensive professional development program. Results provide insight as to the process they followed in the transition to implementing PBS. Measures included classroom observations, reflective interviews, and attitudinal surveys. Results showed that teachers developed the knowledge, confidence, and understanding to implement PBS but in most cases it took at least two to three years for positive results to become evident. Teachers struggled to develop adequate driving questions that provided project-focused lessons. Other obstacles included teacher resistance to student-directed instruction, confusing inquiry-based instruction with hands-on activities, and inability to motivate students to work in collaborative teams. While challenging, over time the teachers developed the knowledge, desire, and skills to implement PBS.

Background

A Framework for K-12 Science Education (National Research Council, 2012) and the Next Generation Science Standards (http://www.nextgenscience.org) posited that children learn science by actively engaging in the practices of science. Thus, teachers are urged to implement inquiry-based instruction that blends core science ideas, crosscutting concepts and science and engineering practices (Vega, 2012). However, for many teachers this requires a shift in practices away from one that covers primarily content to one that has children conduct investigations or complete projects that may not have a predetermined “answer.” A common drawback to incorporating instruction that aims to model scientific inquiry is the confusion by teachers between scientific inquiry practices and discovery teaching wherein the teacher simply allows students to explore a phenomenon willy-nilly with no guidance or purpose (Holliday, 2004). Beyond inquiry practice, it is recommended that epistemic elements including understanding the types of questions inquiry can answer, the appropriate, acceptable methods for data/evidence collection, and meaningful interpretations of data be taught to improve student skill in conducting scientific inquiry (Sandoval & Reiser, 2004). Project-based science (PBS), and in a broader sense project-based learning, is a teaching approach that makes use of extensive student-directed scientific inquiry supported by appropriate teacher guidance/coaching, technology, and collaboration (Abd-El-Khalick, 2012; Buck Institute for Education, 2013; Krajcik & Czerniak, 2014; Marx, Blumenfeld, Krajcik, & Soloway, 1997; Ruopp, 1993; Tinker, 1996). Teacher-guided projects linked with local problems provide students with relevant applications of scientific theory and content (Marx et al., 1997). With PBS, students are coached to find solutions to real problems by asking and refining questions, designing and conducting investigations, gathering and analyzing information and data, making interpretations, drawing conclusions, and reporting findings. Collaboration is also considered essential and involves students building shared understandings of ideas and of the nature of the discipline as they engage in discourse with their classmates and adults outside the classroom (Krajcik, Blumenfeld, Marx, & Soloway, 1994). PBS encourages teachers to foster students’ understanding and reasoning and to diagnose students’ misconceptions (Blumenfeld, 1992; Tal, Krajcik, & Blumenfeld, 2006). Combining strong content knowledge with strong pedagogical knowledge of inquiry-
based instructional theory and strategies allows teachers to not only improve their own teaching but to motivate others to do so as well (Hofstein, Carmeli, & Shore, 2004; Mentzer, Czerniak, & Struble, 2014). Coupling content and pedagogy knowledge with the development of teacher leadership skills results in a more sophisticated approach to teaching inquiry (Schneider & Plasman, 2011).

However, the path of moving from more traditional, content-focused science instruction to PBS has many bumps and detours and evolves over time (Marx, Blumenfeld, Krajcik, Blunk, Crawford, Kelly, & Meyer, 1994; Scott, 1994). Common obstacles to embracing PBS as designed include teacher resistance to student-directed instruction (often perceived as giving up control of the class), confusing inquiry-based instruction with hands-on activities or discovery teaching, inability to motivate students to work in collaborative teams, familiarizing students with PBS and moving them to a point where they are comfortable conducting inquiry, the development of authentic assessments, and overcoming student resistance to employing critical thinking (Alozie, Eklund, Rogat, & Krajcik, 2010; Scott, 1994; Thomas, 2000). Other roadblocks include balancing PBS and classroom time and content, granting students sufficient autonomy, and melding required curriculum with PBS (Marx et al., 1994).

To master PBS, teachers need long-term professional development and yet, while professional development is frequently offered to in-service teachers, the programs are not typically designed to link past experiences or advance teacher higher order thinking skills nor are they implemented long term (Schneider & Plasman, 2011). In a review of 361 research articles published between 1986 and 2010 about teachers’ pedagogical content knowledge learning, only five followed the teachers for at least a year (Schneider & Plasman, 2011). Findings from this review indicated that professional development that targets inquiry practices appeared to be more successful in the development of teachers’ pedagogical content knowledge than those that merely increase content knowledge alone. Therefore, PBS professional development that includes advanced content should facilitate teacher implementation of inquiry-based instruction. To provide long-term professional development that assists teachers in their implementation of inquiry-based instruction using PBS, it would be helpful to identify not only the challenges to comprehension and implementation, but to also gain a better understanding of the path a science teacher follows in the transition from more traditional teaching practices to the adoption of PBS.

It is the purpose of this study to examine the following research questions: (a) What elements of PBS are the most difficult for teachers to grasp, embrace, and implement? and (b) How much time does it take to realize the effects of professional development designed to move a teacher from traditional to inquiry-based instructional practice? To investigate these questions, data collected from teachers who participated for three continuous years in a National Science Foundation Math-Science Partnership project (LEADERS—Leadership for Educators: Academy for Driving Economic Revitalization in Science) designed to improve science education by making it relevant to students through the incorporation of PBS linked to the renewable energies industry and its environmental impacts were analyzed.

**LEADERS Program Overview**

LEADERS was a partnership that gathered and merged the expertise of four essential entities: K–12 school districts, higher education, the renewable energy industry, and informal science education sites in the economic revitalization of the Great Lakes Region. The partnership collaborated in the development of PBS curriculum relating to renewable energy.

**Professional development for teachers.** Teachers participated for three continuous years (cohort 1: 2010, 2011, 2012; cohort 2: 2012, 2013, 2014). The eight-week Summer Institutes (SI) focused on the three areas essential to effective teacher leadership: science content, pedagogy, and leadership. Specific professional development opportunities included workshops, graduate level science content courses and educational teacher leadership courses delivered during the SI and academic year follow-up. The SI plan of instruction included a balance between renewable energy advanced content, PBS and lesson development, and leadership courses. The PBS and leadership courses continued throughout the year as the teachers implemented PBS science in their classrooms and delivered professional development sessions for their district science teachers.

**Components of LEADERS support.** Advanced content courses were developed by blending the PBS course content with the science and engineering content courses. Lessons in the courses followed the 5 E Learning Cycle Model (Bybee & Landes, 1988). Each teacher developed a PBS unit for his/her classroom in the summer. During the fall, teachers focused on implementing the lessons in their own classrooms and collaborated on developing PBS activities linked to the economic development of the region to become proficient in implementing PBS. By using a lesson study approach
(Perry & Lewis, 2009), teachers managed to (a) plan a lesson; (b) observe one teacher teaching the lesson; (c) collect and analyze evidence of student learning within the lesson; (d) refine the lesson; and (e) reteach the lesson, if necessary. Working within their grade-level group, teachers provided critical feedback on the effectiveness of the lesson in achieving the student learning goal (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003) and were provided with ongoing professional development from a coach who worked with them during the school year.

The teachers shared their experiences implementing PBS to teach sustainable energy concepts through five PBS professional development workshops to district science teachers each year. They determined the science content for their workshops based upon state science standards and their district’s curriculum and taught through the utilization of the 5 E Learning Cycle Model. PBS professional development workshops aimed to contribute to the development of participants as leaders in the movement to transform science instruction within their districts to include PBS as an instructional strategy understood and implemented.

**Method**

**Participant Selection**

In 2010 and 2012, participants from partner school districts applied to the project and were selected through consultation with school district leaders and project directors. Selection was conducted by a committee using a rubric that was based on the following criteria: previous leadership roles within the district, state or national recognition (e.g., National Board Certification), participation in other teacher leader programs, strong science background, respect among peers, experience with adult learners, and commitment to the National Science Education Standards (National Research Council, 1996). Elements of strong science background included professional development in science, student participation in science fairs or other science activities/competitions, and extra coursework the teacher may have completed in science. Participants were divided into two cohorts of 12 each and came from three high-needs districts. The first district was predominantly rural and was made up of several smaller districts with one regional coordinating Board (public). The second two were high-needs urban districts (one public one parochial) as determined by percent living in poverty (both districts) and low student performance on standardized tests (public only). All districts enrolled slightly over 20,000 students in 2013–2014. The urban public district served a population that was over 50% minority and 80% economically disadvantaged; the urban parochial district enrolled approximately 28% minority students and included a mix of urban, suburban, and rural schools with approximately 20% economically disadvantaged; and the rural district served a population that was 90% white with approximately 40% of the students being economically disadvantaged. The participating school districts were proponents of PBS. Each cohort participated for three consecutive years. Demographics are shown in Table 1. Because the sample was small \((n = 12\text{ per cohort})\) the two groups were merged for analysis.

**Data and Instruments**

To explore the process of the development of PBS understanding, a triangulated, mixed methods research design was employed. Periodic classroom observations of the teachers teaching a PBS unit were conducted each fall and spring (PBS knowledge and practice). Observers visited each classroom at least twice a week over a three to four week period to gain a full picture of the PBS unit/lesson. Observations were qualitative but used a rubric protocol based upon the hallmarks of PBS instruction (Krajcik & Czerniak, 2014). These hallmarks included an evaluation of: (a) the driving question (does it relate to what scientists really do; does it provide room for students to design and conduct their own investigations?); (b) opportunities for scientific investigation; (c) opportunities to work with and make sense of data; (d) the use of technology to support student investigations; (e) opportunities for collaborations; and (f) relevance of final product to real-world outcome and driving question. In addition, observations allowed for an examination of student comfort with science and learning as reflected in their participation in the lessons. Granted, not every element would be observed during each visit; however, the spacing of the observations made the probability of viewing most of the elements higher. Interviews with teachers administered at the conclusion of the series of observations included questions about intentions and reflection on practice. These questions were standard for all observations but could include observation-specific questions to clarify what was observed and teacher intentions. Questions explored how well the teacher felt the lesson went, whether there was anything that he/she would change, what he/she thought the students learned from the lesson, how it fit into the PBS unit, and confidence teaching PBS.

Additional data included pretest/posttest measures of content gains from the Summer Institute courses (knowledge), the Science Teacher Efficacy Beliefs Instrument (STEBI) (Riggs & Enochs, 1990) and the Science Teacher Ideological Preference Scale (STIPS) (Gado, 2005; Jones & Harty, 1978) (attitudes). The STEBI
provided information about the teachers’ belief in the impact high-quality science teaching (i.e., PBS) can have on student learning and the extent to which the teachers also felt confident they could provide that type of instruction. The STEBI has a reliability coefficient of .73 (Riggs & Enochs, 1990) and has shown evidence of instrument validity (Boone, Townsend, & Starver, 2010).

The STIPS measured instructional practice preferences using two subscales: inquiry-based instructional strategies and non-inquiry-based strategies. Internal consistency reliability was established at .76 overall and .71 for the inquiry subscale and .70 for the non-inquiry subscale (Jones & Harty, 1978). Results of the STIPS can provide insight as to teacher willingness to use inquiry-based instructional strategies as opposed to more traditional, non-inquiry techniques. A stronger willingness to use inquiry-based strategies is a precursor to implementing PBS.

**Data Analysis**

The analysis provided an exploration of the process of development of the teachers’ PBS understanding during their participation in LEADERS. Qualitative data (observation notes and interviews) were examined for emerging themes based upon the PBS elements mentioned earlier (e.g., was there an opportunity for students to engage in scientific investigation; to make sense of data?). Analysis of case notes and teacher responses to post-observation questions used a phenomenological approach to uncover common experiences from participating in LEADERS (Patton, 2015). Three phases of coding were employed (Corbin & Strauss, 2015). Open coding examined responses for themes both anticipated (relevant to PBS and inquiry instruction body of research) and unanticipated. Open coding was reviewed to determine dominant themes and then axial coding mapped relationships between codes. Finally, selective coding was applied to describe the common experiences and relate responses to quantitative data.

Quantitative data included to complement qualitative results were analyzed using the Rasch Measurement Model (RMM) to convert the ordinal data collected on the rating scales to interval data (thereby reducing measurement error), to verify instrument sensitivity and construct validity, and to better identify the contribution the items on the instruments contributed to the overall assessment of the constructs (Wolfe & Chiu, 1998). A repeated measures analysis was then conducted with the resulting parametric data to examine change over time of teacher beliefs and preferences. Using RMM with the STIPS allowed for the identification of specific items the teachers had the most difficulty agreeing with.

---

**Table 1**

<table>
<thead>
<tr>
<th>“Name”</th>
<th>Grade</th>
<th>District</th>
<th>Gender</th>
<th>Ethnicity</th>
<th>Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amanda</td>
<td>5, 6, 7, 8</td>
<td>Parochial</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Sheri</td>
<td>4</td>
<td>Urban public</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Claudia</td>
<td>2</td>
<td>Parochial</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Irene</td>
<td>9</td>
<td>Urban public</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Rhonda</td>
<td>6, 7, 8</td>
<td>Parochial</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Heidi</td>
<td>11, 12</td>
<td>Parochial</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Emily</td>
<td>6, 7, 8</td>
<td>Parochial</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Beverly</td>
<td>10, 11, 12</td>
<td>Urban public</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Travis</td>
<td>10, 11, 12</td>
<td>Urban public</td>
<td>M</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Lyne</td>
<td>5</td>
<td>Parochial</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Deborah</td>
<td>9</td>
<td>Urban public</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Mary</td>
<td>6</td>
<td>Urban public</td>
<td>F</td>
<td>Euro-American</td>
<td>1</td>
</tr>
<tr>
<td>Terri</td>
<td>5</td>
<td>Rural public</td>
<td>F</td>
<td>Euro-American</td>
<td>2</td>
</tr>
<tr>
<td>Jamie</td>
<td>9, 10</td>
<td>Rural public</td>
<td>M</td>
<td>Euro-American</td>
<td>2</td>
</tr>
<tr>
<td>Sam</td>
<td>9, 10, 11</td>
<td>Rural public</td>
<td>M</td>
<td>Euro-American</td>
<td>2</td>
</tr>
<tr>
<td>Sylvia</td>
<td>K-4</td>
<td>Rural public</td>
<td>F</td>
<td>Euro-American</td>
<td>2</td>
</tr>
<tr>
<td>Joan</td>
<td>2</td>
<td>Rural public</td>
<td>F</td>
<td>Euro-American</td>
<td>2</td>
</tr>
<tr>
<td>Jack</td>
<td>9, 10, 11, 12</td>
<td>Rural public</td>
<td>M</td>
<td>Euro-American</td>
<td>2</td>
</tr>
<tr>
<td>Stephen</td>
<td>9, 10, 11, 12</td>
<td>Rural public</td>
<td>M</td>
<td>Euro-American</td>
<td>2</td>
</tr>
<tr>
<td>Michael</td>
<td>9, 10</td>
<td>Rural public</td>
<td>M</td>
<td>Euro-American</td>
<td>2</td>
</tr>
<tr>
<td>Rose</td>
<td>7, 9, 11, 12</td>
<td>Rural public</td>
<td>F</td>
<td>Euro-American</td>
<td>2</td>
</tr>
<tr>
<td>Angela</td>
<td>K-6</td>
<td>Urban public</td>
<td>F</td>
<td>Euro-American</td>
<td>2</td>
</tr>
<tr>
<td>Tarinne</td>
<td>6, 7, 8</td>
<td>Urban public</td>
<td>F</td>
<td>African American</td>
<td>2</td>
</tr>
<tr>
<td>Missy</td>
<td>7, 8</td>
<td>Urban public</td>
<td>F</td>
<td>Euro-American</td>
<td>2</td>
</tr>
</tbody>
</table>
assisted with identification of practices that were the most difficult to adopt (inquiry) or dismiss (non-inquiry). Combined, it was expected the results would illuminate the process of transition from teaching in a more traditional manner to the implementation of inquiry instruction through PBS.

Findings

The data analysis was structured to answer both research questions and more specifically whether teachers had a solid foundation in content and PBS pedagogical content knowledge, the degree to which teachers were successful in implementing PBS, the elements of PBS that were the easiest and most difficult for teachers to grasp and implement, and the amount of support/time needed to see change in teacher practices.

Teacher Content Knowledge

Pretest/posttest comparisons were made for four of the seven courses that comprised the advanced content portion of the Summer Institutes: Earth Systems Science, Alternative Energy, Biofuels, and Earth Technologies. Instructors from the other three courses did not provide pre/posttest data (Chemical Aspects of Sustainable Energy, Climate Change, and Physical Principles). One-tailed dependent t-test analysis results (Table 2) show that in each of these courses, teachers realized statistically significant gains in content knowledge. The maximum score for each course varied (e.g., Earth Systems had a maximum score of 8 and Biofuels, 30). It can be concluded that, for these four courses, the teachers achieved high gains in content knowledge. The practical significance of this is that it indicates that the teachers added to their content knowledge base through participation in concentrated professional development presented by university scientists and engineers. Therefore, gaining advanced content knowledge was not an impediment to implementing PBS.

Self-Efficacy

An examination of the teachers’ scores over time on the STEBI subscales provided insight into whether and, if so, how their attitudes toward the effectiveness of high quality science instruction (Outcome Expectancy) and their own belief that they could provide such instruction (Personal Belief) changed as a result of participation in LEADERS. For both analyses, ordinal scores were converted to interval scores using RMM with an expected mean of 25. Table 3 shows the results of the repeated measures analysis on the two STEBI scales. There was no statistically significant change in the teachers’ belief that quality science instruction would improve student learning. In fact, their belief that they themselves could provide high quality science instruction did show a statistically significant improvement. A post hoc test (Tukey) showed that Years 1 and 2 were not statistically significantly different (p = .96) but that Year 3 scores were (with Year 1, p = .001; with Year 2, p = .007). This suggests that their belief in their ability to implement inquiry-based instruction such as PBS improved over time and that an extended professional development program may be more likely to provide teachers with the confidence to implement PBS. Had the program been less than three years, no change would have been detected. It was in the third year of participation/practice when teachers moved beyond their initial beliefs in their ability to provide quality instruction.

Of note are the large standard deviations. They indicate a large dispersion of scores among the respondents—some scored very high and some very low. In other words, there is fluctuation around the mean. However, it is interesting that for Outcome Expectancy the standard deviation gets smaller over time indicating that the teachers as a group are responding more consistently about their beliefs that high quality instruction can improve science learning. On the other hand, the standard deviation for Personal Beliefs makes a jump during Year 2 suggesting that some teachers doubted their ability to provide quality instruction during the second year while others became more confident.
the variability gap closed in the third year could imply that the teachers, through practice, were once again responding more closely to the group mean.

Observations and interviews supported findings from the Personal Beliefs scale. A common theme was that teachers struggled early with implementation due to a na"ıve sense of what it entailed. For example, Lynne, in her second year of participation, admitted that getting through a PBS unit took much longer than anticipated. During the third year, she realized that her current class struggled with critical thinking when compared with her class the previous year. She concluded that PBS implementation may not necessarily be “one size fits all” as she originally thought but, as with any lesson, should be tailored to the needs of the specific group of students. Amanda reflected during the first year that students lacked teamwork skills and that ignoring that deficiency spelled disaster for PBS group work. Subsequent interviews showed that she taught collaborative skills prior to introducing a PBS unit. An interview with Terri during her third year of participation noted, “This year I started earlier with making concepts like Claims-Evidence-Reasoning (i.e., scientific argumentation) more explicit. As a result, this year’s students did a better job of truly collaborating and communicating with each other during this unit.”

In general, post observation interviews conducted in the first year included many comments about the mechanics of implementing PBS. Common themes included miscalculating the amount of time required, providing too much or too little guidance for the students, and the belief that a high-quality PBS lesson had been employed when in fact it was a collection of inquiry activities loosely bound together through content. These examples illustrate that when teachers do not fully understand what PBS entails, they often do not prepare adequately for it and as a result become frustrated. Later interviews had fewer comments about the mechanics of implementing PBS and more comments about the process of investigation, improved student learning, and ability to better engage students.

Teaching Preferences

To uncover change in teacher preferences for inquiry versus non-inquiry teaching practices, the STIPS was administered once per year for the three years of participation. Teachers responded to items on a five point rating scale indicating their level of agreement with specific teaching strategies (with three indicating a neutral position). The resulting rankings were then converted to interval scores with an expected mean of 50 using RMM to provide an overall score (sum) for each scale. These overall scores were then investigated for change over time using a repeated measures analysis. The sample for this analysis was only 18 as 6 of the teachers did not complete the survey during their final year. The results showed statistically significant gains in preference after three years on both scales suggesting that teachers became more opinionated about teaching practice (Table 4). Post hoc analysis on the inquiry scale showed that the difference between Year 1 and Year 3 contributed to the significant findings. Therefore, the increase in preference for inquiry teaching practices, just as with the STEBI, was gradual from year to year but significant over the three year period. Post hoc for the non-inquiry scale showed significant differences between Year 1 and 2 and Year 1 and 3, indicating an increase in preference for non-inquiry practices after the first year of participation that remained consistent between Years 2 and 3. This is contrary to what was expected but an examination of the teacher preferred non-inquiry items may provide some insight and is supported by findings from observations.

Examining items on both scales that the teachers found the easiest to agree with (strong preference) and the hardest (least preference) by year in the program illustrates the practices they embraced or avoided. First the inquiry scale will be examined.

During the first year, teachers found it hardest to agree with the idea that students should figure out on their own the important concepts of the lesson. Additionally, they found it hard to embrace the practice of allowing students to identify on their own the important questions and means of investigation for pursuing possible results when conducting lab work. Coming from an accountability system in which students are given standardized tests to determine knowledge, it is understandable that the teachers would initially be reluctant to allow students to make these determinations. Standardized testing negatively influences the implementation of inquiry-based science instruction (Aydeniz & Southerland, 2012). With science classes

### Table 4

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inquiry Preference</strong> (n = 18)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1</td>
<td>56.08</td>
<td>10.10</td>
</tr>
<tr>
<td>Year 2</td>
<td>63.17</td>
<td>5.95</td>
</tr>
<tr>
<td>Year 3</td>
<td>66.16</td>
<td>8.46</td>
</tr>
<tr>
<td><strong>Non-Inquiry Preference</strong> (n = 18)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 1</td>
<td>42.6</td>
<td>9.90</td>
</tr>
<tr>
<td>Year 2</td>
<td>51.84</td>
<td>6.30</td>
</tr>
<tr>
<td>Year 3</td>
<td>48.91</td>
<td>5.67</td>
</tr>
</tbody>
</table>

F = 6.20, p = .005

F = 6.78, p = .003

School Science and Mathematics
occupying a finite amount of time, teachers may also be tempted to make lab work as efficient as possible by enforcing a prescribed process for conducting an experiment. Observations during the first year of participation showed teachers frequently provided tightly constructed and closed-ended lessons under the guise of PBS. For example, Joan’s driving question during her first year was, “How do caterpillars develop into butterflies?” While there was some investigation (students studied the stages of development), it was not student designed, it did not solve a problem, nor was a project/product involved. Other first year driving questions were similarly prescriptive: “What is the pH of Crane Creek?” (Beverly) and “How can a rain gauge tell me about rainfall?” (Sheri). Beverly gave her class water testing kits to add test solutions to small amounts of water to measure pH, salinity, oxygen level, and heavy metals. While students were engaged in data collection and analysis, they were all following the same procedure, in the same order, with the same intended outcome.

Other early lesson observations noted a common theme of teachers requiring every student to do the same thing. Amanda gave her 7th-grade class a list of scientific terms and charged them to “explore the Internet” to locate definitions. Amanda, who noted earlier that students lacked skills for group work, did not facilitate group work during early observations. Students worked individually, albeit while sitting in a group.

During the second year, teachers continued to resist the practice of allowing students to develop their own investigations in the lab but by the third year, none of the items on the inquiry scale stood out as difficult to agree with suggesting that after three years of PBS support, teachers began to embrace inquiry teaching practices. For example, Claudia created a PBS lesson focusing on gravity. The driving question was “How can we use gravity to create an arcade game for the school fair?” Student groups learned then applied principles of gravity to a variety of student designed games. Other student-planned investigations included designing a wind turbine that conducted enough energy to power a string of lights (Angela), the investigation of a variety of natural resources as potential energy sources to be used to run a battery that would power a toy boat or car (Travis), and an investigation of the relationship between temperature and CO2 levels (Terri).

The inquiry item that was the easiest to agree with, consistently through the three years, was that instructional materials should encourage students to develop alternative ideas to concepts encountered. During Years 2 and 3, three items moved from moderately acceptable to easy to agree with by all respondents: (a) To learn science, students should be provided situations that exemplify concepts but which require them to figure them out themselves from examples; (b) learning scientific concepts should include alternative views, weaknesses of current explanations, and doubts about the validity of the conclusion; and (c) students must challenge the truth of currently held scientific concepts and principles by seeking alternative interpretations that they can formulate, justify, and substantiate. In other words, rather than providing students with one “correct” explanation, teachers were moving toward encouraging students to challenge currently held concepts and to develop their own explanations. Linking this with the teachers’ efforts to develop and implement PBS, the emergence of these items as easy to agree with after experience implementing PBS suggests that the teachers’ experiences had a positive effect on their preference to use inquiry based instruction—particularly those strategies that encourage the students to take charge of scientific investigations. Claudia provides an example of this. During her first year the class was charged with deciding “What should I wear today?” with weather as the underlying content. She taught the class as a whole how to use a rain gauge but there was no project and little data analysis other than recording the rainfall over the course of a few days. During her third year, Claudia, as part of the arcade game project, provided students with a variety of magnets. Students were encouraged to select several magnets and walk around the classroom touching objects. After 10 minutes they came back to their groups and discussed what they discovered and were then asked to decide if and how this new principle, magnetism, might be incorporated into their arcade game.

On the non-inquiry scale, in Year 1, the teachers had strong preferences for designing lab experiments in such a way that the correct results or answers would emerge only for those who followed directions and those directions should be specific as to what to observe, measure, and report. This correlates with the reluctance to allow students to experiment with lab work in the inquiry scale in Year 1 as well as the anecdotal examples. After a year in the program, the teachers did not as readily agree with those items but instead found it easy to agree with the idea that the nature of science should be illustrated through the study of its technological applications and achievements. This item may have been ambiguous to the teachers in that the goal of LEADERS was to teach science using relevant applications related to renewable energies. As such, the teachers were encouraged to include the application of
technology in their lessons. When reading the item, they may have glossed over the “nature of science” and read simply “science.” In fact, it could well be the high level of agreement with this item that caused the increase in the non-inquiry scale overall scores.

Teachers initially resisted the non-inquiry teaching practice of explicitly telling students important concepts contained within the content dealing with the topic. And, somewhat in conflict with inquiry scale findings, they had difficulty agreeing with the practice of designing lab investigations that follow specified directions and procedures designed to illustrate a concept. It was perhaps the “designed to illustrate a concept” portion of the item that they disagreed with considering their preference for explicit instructions Year 1. An interesting switch in teacher preferences occurred between Year 1 and subsequent years. The idea of including lab directions with specifics as to what to observe, measure, and report, initially embraced by teachers, became one of the hardest items to agree with in Years 2 and 3, suggesting that teachers recognized the value of student-driven lab work which was borne out by the examples noted earlier. It appears that by the third year, increased teacher preferences for inquiry-based instruction should improve the chances that PBS is implemented in the classroom.

**Elements of PBS**

One of the most challenging aspects of the observations was drawing conclusions due to the range in grade levels observed (grade 2 through 9). There were, however, some consistent themes regarding hallmarks of PBS that emerged regardless of grade level. Early lessons observed (Year 1) included elements of PBS but did not suggest a coherent lesson. Most frequently, teachers employed hands-on activities pieced together under the umbrella of a common topic. Additionally, teachers provided students with investigations rather than offering a driving question that motivated them to create their own investigations and there was seldom a final product or project. For example, Sam had this driving question: “How can society reduce our carbon footprint?” This is a bit broad, even for 9th graders. It could have been narrowed to how might the student, a family, the school, or the local government reduce their carbon footprint. This unit did not appear to be well structured and the lessons loosely related to the driving question. They included naming organic compounds, how organic compounds relate to nutrition, designing and testing a calorimeter, and how calories are used as energy use in living plants and animals. Understanding what constituted a good driving question—one that initiated and focused students on investigations—was difficult for teachers to grasp during their first year of participation. Sometimes the questions were overly vague or simple: “Can I make salsa?”—related to growing a garden with tomatoes and peppers (Sylvia); “What’s in a name? That which we call an organic compound?”—learning to differentiate between lipids, carbohydrates, and proteins (Jack) or too prescriptive or not associated with a problem: “How can a rain gauge tell me about rainfall?” (Joan). Driving questions improved the longer the teachers participated in LEADERS, although some were never quite able to grasp the concept. Later questions included: “How can we make our school earthquake safe?” (Rose); “How can our school be more sustainable?” (Sam); and “Can we build a machine that is propelled by wind?” (Amanda).

Evidence of opportunities to collect and make sense of data as well as appropriate use of technology was present in all observed units; however, the connection between these elements of PBS and the driving question was not always apparent. About 45% of the teachers consistently struggled in their attempts to meld content with PBS. For example, the investigation of CO$_2$ levels with temperature was never apparent. The investigation of CO$_2$ levels with temperature was never linked to an overarching PBS unit (Terri). Similarly, in Beverly’s class, students selected an object in outer space, researched it on the internet, and created a PowerPoint presentation based on the research. The purpose of this, and how it related to a driving question, was not apparent. The work was student directed, however, and students learned some basic research techniques. With regards to student collaboration, all of the teachers allowed students to work in groups but as noted earlier several, during the first year, did not facilitate the group work or teach students how to work in teams. One difficulty with introducing PBS to children who have little if any experience working in groups is the tendency of one child to dominate. For example, in Claudia’s class small groups of students were asked to review their weather vane and discuss how it might be modified so that it would work better. One girl kept bringing in new materials and proposing to use them in the exact same way as the other materials that did not work (a straw, a pencil, a piece of paper rolled into a tube). Rather than modifying the design itself she simply wanted to change the materials. Other members, less outspoken, had better ideas for modifications but this student monopolized the problem-solving process. It is important that teachers understand that group work does not happen naturally and that student groups need coaching. Another group of students working on the weather vane redesign started out with good intentions and then started discussing that if it was red rather than brown it might look better (and presumably operate better).
A similar problem that teachers had early in their attempts to implement PBS was related to their interpretation of “student-directed.” Many thought that this meant “free rein” class time. For example, Claudia’s first year PBS lesson was the weather vane. To initiate building, she showed students pictures of windmills and then dumped a collection of potential building materials in the middle of the floor with instructions to “explore” them to assist in developing their designs. This resulted in a free-for-all, with children yelling, diving, grabbing, jumping, pulling, arguing, and, basically, general chaos. From an observation standpoint it was quite amusing but Claudia was demoralized and beside herself. It took both her aide and her about 10 minutes to restore order, and this event was certainly reflected in her assessment of her ability to provide high-quality instruction on the Personal Belief scale of the STEBI.

A typical early observation of student-directed inquiry often saw one or two students working diligently and the rest of the group discussing Facebook posts, after-school activities, friends, etc. With experience, however, the teachers became much better at facilitating group work as well as encouraging students to focus on their investigations. In fact, improvements were seen between fall and spring observations the first year. This early misunderstanding of what constitutes student directed science could contribute to teacher non-inquiry preferences. Post observation interviews gave insight as to how teachers’ grasp of PBS evolved. For example, Stephen noted, after two years in LEADERS, that his view of a teacher’s role in science education changed from presenting facts about science to guiding students to investigate important problems by also engaging them to design, develop, and evaluate artifacts or products as a set of activities.

Michael remarked that implementing “full-blown PBS” to students who are unfamiliar with it has drawbacks. “I would recommend it [a lesson that had elements of PBS] as a stepping stone to a full-fledged PBS unit.” And Jack recognized that he could not teach PBS all the time but did “reduce the day-to-day monotonous behavior and replaced it with PBS style lessons.” Earlier, Jack felt he was implementing PBS as designed. In his third year, he recognized that what he had been doing was “PBS style” or elements of inquiry but not necessarily project based.

Tarrine indicated that her view of science learning had changed because in her final year of participation she made connections between science content and students’ lives and communities. She felt that linking lab activities, textbooks, curriculum guides, and content standards within the lessons improved both the quality of the lesson and student learning. Stephen concurred. He described a success story of a student that became motivated to learn science and took control of her learning by investigating, inquiring, and conducting lab activities as part of a PBS unit:

She went from an F student to an A student and stopped being a discipline issue when she entered my science lab. The biggest thing for her was that she was guiding what she was learning; she felt more in control. I continually looked for new ways to interest her and she became a leader in the class; others started to enjoy coming to class and did the paperwork portion of the class because it was embedded within real investigations or engineering design challenges, not just defining vocabulary, watching teacher demonstrations and taking a test.

Stephen’s story epitomized how his view of science education changed:

It doesn’t involve just designing lessons that involve inquiry and hands-on experiences. It has to do with students playing a role in their own learning and finding the answers to their own questions. They have to be a part of the process . . . . Teachers need to engage students in the work that scientists and engineers do in order for students to gain an understanding of what science is. They need to look at the impacts of the environment and think about what happens “if I do this.” Students need to be involved in asking questions and researching their answers in a variety of ways . . . leading to more questions. Students are the most important part of the picture and must play a role in their own education. That will have the greatest impact on creating students who can effectively solve problems and work with others towards a common goal for learning.

Summary, Conclusions, and Implications

Classroom observations, teachers’ reflective interviews, attitudinal surveys (STEBI and STIPS), and content gains illustrated the process of development of the knowledge, desire, and skills to implement PBS, but it took at least two years of participation in the project before evidence of a true understanding of PBS began to emerge and in some cases statistical evidence was not realized until the third
Teacher Extended PBS PD

Table 5
Summary of Findings

<table>
<thead>
<tr>
<th>Data</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher content knowledge</td>
<td>Significant gains every year</td>
</tr>
<tr>
<td>Teacher outcome expectancy</td>
<td>No change over three years; scores</td>
</tr>
<tr>
<td>Teacher personal beliefs</td>
<td>consistently high</td>
</tr>
<tr>
<td>Inquiry teaching preferences</td>
<td>Statistical improvements Year 3 over 1 and 2</td>
</tr>
<tr>
<td>Non-inquiry preferences</td>
<td>Statistical gains Year 3 over 1</td>
</tr>
<tr>
<td>Observations/Interviews</td>
<td>Statistical gains Years 2 and 3 over 1</td>
</tr>
<tr>
<td></td>
<td>Years 1 and 2: Not enough time allotted; driving questions weak, prescriptive lab work, inability to facilitate group work. Year 3: Stronger driving questions, more project-based units, more student initiated problem solving and lab work</td>
</tr>
</tbody>
</table>

Year 1 data confirmed the body of research noting common obstacles to implementing PBS including teacher resistance to student-directed instruction, confusing inquiry-based instruction with hands-on activities or discovery teaching, inability to motivate students to work in collaborative teams, and familiarizing students with PBS and moving them to a point where they are comfortable conducting inquiry. Teachers valued inquiry-based instruction from the onset but it took almost three years of professional development and practice before their confidence in delivering high-quality science instruction and their preference for inquiry-based instruction improved significantly. Attitudinal data confirmed what was observed in the classrooms—Year 1 teachers had disjointed lessons that were more of a collection of activities rather than a true scientific investigation. Years 2 and 3 observations showed greater understanding of the cohesion required of PBS.

Teachers also struggled the first year with giving students some autonomy over their learning and even understanding what that entailed. The absence of a project-focused unit and the degree of student generated learning appeared to be related. In Year 1 teachers continued to provide students with prescriptive lessons with only one path to the learning outcome or they engaged in discovery learning where students explored but for no purpose. Over time, teacher lessons and interview responses reflected an understanding that to learn science and scientific inquiry, students needed to have the opportunity to explore and investigate with a goal in mind. It was interesting that in Year 1 teachers felt they had a good understanding of PBS but as years progressed their comments included admissions that what they originally thought was PBS was not.

Overall, the most challenging aspect of implementing PBS for this sample was generating a driving question that motivated students to create their own investigations and that had connections between the course content and students’ lives. It is the driving question that differentiates PBS from hands-on activities or experiments. Teachers new to PBS often confuse PBS with hands-on activities and therefore comprehending what makes a good driving question may indeed be the threshold that must be crossed before a teacher can truly understand and implement a quality PBS unit. The value of the driving question is that it gives coherence and continuity to PBS by linking content with process of the project, the lesson, and other subject areas. In a PBS classroom, investigations and inquiry activities should play a role in answering the driving question; however, making students aware of these connections and understanding the reasons behind activities can be a challenge. PBS professional development should emphasize the mastery of developing driving questions.

PBS is one avenue to follow to align teaching with the Framework and the Standards. Initially, the teacher must develop the disposition toward changing practice. But to implement PBS as designed the teacher must also gain a clear understanding of the pedagogical technique and experience practice implementing it. Findings from this study suggest that brief PBS professional development sessions will not be successful but rather that PBS proficiency takes time—at least two years of instruction and support. PBS should be viewed as a practice of instruction rather than a strategy and district support of teachers over time is needed to realize its benefits.

Limitations and Implications for Future Research

These findings have implications with regards to science education and the degree of influence of extended (three years) teacher professional development. Most in-service teacher professional development programs do not have the resources to implement intensive, ongoing support. However, what this study suggests is that perhaps school districts and other providers of science teacher professional development consider the investment as positive results appear to take time to manifest. This study did not look at the long term effects of less intense PBS professional development. For example, might a six month program
yield similar results after a comparable amount of time of practice and implementation? In other words, does the professional development need to extend over three years or does it simply take that long for results to show? It is suggested that other types of science teacher professional development research consider, regardless of the length of the actual intervention, data collection continue for at least three years. The professional development described in this study was delivered to a small number of teachers with strong science and leadership backgrounds and so this group may indeed reflect the best that can be expected. Taking that into consideration, we can only wonder what might be needed with regards to PBS professional development so that successful findings can be generalized.

References


