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Motivating Teachers to Enact Free-Choice Project-Based Learning in Science and Technology (PBLSAT): Effects of a Professional Development Model

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Abstract We investigated the effects of a long-term, continuous professional development (CPD) model, designed to support teachers to enact Project-Based Learning (PBLSAT). How do novice PBLSAT teachers view their acquisition of PBLSAT skills and how do expert PBLSAT teachers, who enacted the program 5–7 years, perceive the program? Novice teachers evaluated that they acquired the relevant skills but also expressed worries about enacting the program, due to potential difficulties for teachers. Nonetheless, the teachers enacted the program and identified unforeseen benefits for themselves and their students. We suggest that the CPD model helps teachers develop a sense of personal ownership and customization for the program, through multi-staged support to integrate student free-choice PBL into the formal science curriculum.

Keywords Project-Based Learning (PBL) · Continuous Professional Development (CPD) · Professional development model · Novice and expert teachers · Ownership · Customization

Introduction

Educational researchers maintain that, although Project-Based Learning (PBL) is a constructivist teaching–learning strategy with significant educational potential, teachers need support to successfully implement this strategy in their classrooms (Marx et al. 1997; Thomas 2000). The purpose of this paper is to study the effectiveness of one sustained effort to provide this support. In this section, we present a historical background on PBL and its development, arguments in support of PBL, the particular type of PBL we adopted, and our model of professional

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development. In the other sections, we present two studies that examine the effectiveness of our model.

What is Project-Based Learning (PBL) and How Did it Develop?

PBL has been defined as a teaching–learning approach that guides students to learn the concepts of selected disciplines while using inquiry skills to develop research or design products (Blumenfeld et al. 1991; Thomas 2000). This educational approach has been recognized for many years throughout the world, from elementary schools to universities (Knoll 1997).

PBL first appeared in the late Renaissance in the architecture schools of Italy (1590–1765). The approach, which initially focused on the technological aspects of building machines, eventually incorporated scientific knowledge and became prominent as part of the syllabus of engineering schools in the United States (1765–1880; see Pannabecker 1995; Westerink n.d.). From 1880 to 1915, projects were integrated into public schools in America as part of the manual training movement. About that time, John Dewey and his group advocated projects as a means of learning by doing based on student self-interest and a constructivist approach. In 1918, Dewey's student Kilpatrick (1918) defined "The Project Method," which became popular in the progressive era. In parallel, the use of projects in education blossomed in Europe (Greoire and Laferriere 1998) and Russia (Kafkafy 1998). Between the 40's and 60's, there were two variations of this approach in Israel (Kafkafy 1998; Round 1995). During the 60's and 70's, the project approach lost popularity in the United States (Blumenfeld et al. 1991); but, since 1980, the approach has gained in popularity. Within the last two decades, a great deal of experience and knowledge about PBL has been reported (e.g., Knoll 1997; Koschmann 2001; Krajcik and Blumenfeld 2006; Krajcik et al. 1994; Mergendoller and Thomas n.d.; Thomas et al. 1999; Rosenfeld and Fallik 2002 Ruopp et al. 1993; Thomas 2000; Tinker 1997).

Throughout its history, learning through project work has been based on different educational models. Today, different variations of PBL exist. For example, one version of PBL, called PBS (project-based science), includes five basic components: (a) driving questions, (b) investigations, (c) artifacts, (d) collaboration, and (e) technological tools (Krajcik et al. 1994). Based on an extensive review of the existing literature, the basic criteria for PBL appear to be the following (Thomas 2000):

centrality: PBL projects are central, not peripheral to the curriculum;
driving question: PBL projects are focused on questions or problems that "drive" students to encounter (and struggle with) the central concepts and principles of a discipline;
constructive investigations: the central activities of the project must involve the construction of knowledge on the part of students;
autonomy: projects are student driven to some significant degree; and
realism: projects are realistic or authentic, not school-like projects.

Arguments in Support of Project-Based Learning

The PBL approach is well known for its benefits for students. Many studies have shown that students engaged in PBL perform better on achievement tests than do students in the control groups. This finding has been demonstrated for PBS (Blumenfeld et al. 1994; Ladewski et al. 1994; Marx et al. 1994; Marx et al. 1997; Marx et al. 2004; Rivet and Krajcik 2004; Schneider et al. 2002), design-based-science (DBS, Fortus et al. 2004) and for PBL in mathematics (Boaler 1999; Boaler 1997). In these studies, students demonstrated statistically-significant increased gains on both curriculum content and science process skills, many of which were aligned with local, state, and national standards.

Problem-based learning is considered a type of project-based learning; in this approach, students are challenged to solve a real-world problem (Hmelo-Silver 2004; Watson 2002). A meta-analysis of 43 articles investigated the effects of this approach on students' knowledge and skills (Dochy et al. 2003). The main finding was that "students in the experimental groups gained slightly less knowledge, but remember more of the acquired knowledge" (p. 533) than students in the comparison groups. Also, in a study of problem-based learning conducted at the Illinois Mathematics and Science Academy, an interdisciplinary course (Science, Society, and the Future) was given as an elective to senior high school students. A study of the students who took the course showed that they performed significantly better in the use of problem-solving skills and were more open to alternative ethical appeals than the comparison group (Stepien et al. 1993). In summary, the research literature shows that students who engage in PBL develop skills of independent learning (including problem-solving), learn to be more open minded, remember what they learn longer, and perform better on standard achievement tests than non-PBL students.

Project-Based Learning in Science and Technology and the Professional Development Model

A variation of the PBL approach—PBL in Science and Technology (PBLSAT)—was developed for middle school students in Israel during the years 1992–2005 by staff at the Weizmann Institue of Science in Rehovot, Israel (Breiner et al. 1999; Rosenfeld et al. 1997, 1999; Rosenfeld and Ben-Hur 2001; Rosenfeld and Fallik 2002). The Weizmann Institute of Science in Rehovot, Israel is a multidisciplinary research institution that includes the Department of Science Teaching. The department is composed of groups working in different science content areas, including the area of science and technology for junior high schools.

The PBLSAT program was adapted to the goals of new science and technology national curriculum, which stresses the development of learning, thinking, and research and design (R&D) skills. The PBLSAT focuses on the development of the following student skills: question asking, problem posing, or both; choosing a driving question; formulating a research question; writing a proposal; conducting peer evaluation; developing evaluation criteria; R&D methods; data collection and analysis, and drawing conclusions. While focusing on the development of these student skills, a teacher enacts the program by motivating students to develop projects of their choice, based on their own interests, within the context of a teacher-chosen curricular unit from the national syllabus on science and technology. Thus, the resulting student projects are not based on specially-designed curriculum units, but are chosen by the students, based on a wide variety of existing curricular units. Often, these projects involve out-of-school work by the students. In this way, the PBLSAT program can be considered as an example of "bridging the gap between formal and informal science learning" (Hofstein and Rosenfeld 1996, p. 87).

The Challenge of Continuous Professional Development (CPD)

To help students develop the PBLSAT skills, teachers themselves need to be well accomplished in their use. In this respect, inservice workshops may be useful to teachers. However, it is well known that many inservice workshops do not succeed because teachers do not enact in their classrooms what they studied in the workshop (Guskey 1986).

What are effective features of a CPD program? Research on CPD programs conducted in recent years (e.g., Kennedy 1998; Loucks-Horsley et al. 1998; Marx et al. 1998; Putnam and Borko 2000) indicated that they (a) are collaborative (both among the participating teachers and between the teachers and the CPD staff), (b) are long-term, (c) are connected with real classroom contexts and curriculum content, (d) integrate curriculum content with pedagogical issues, and (e) provide support for experimentation and risk taking. Our PBLSAT model was designed to take into account these principles. The model (a) involves collaboration between teachers (when they undertake their own projects and when they guide their own students) and between teachers and the CPD staff (during the teacher support frameworks); (b) includes three support frameworks (teacher as learner, teacher as teacher, teacher as innovator), as described below; (c) is connected with real classrooms and the central curriculum topics; (d) integrates these central topics with the PBLSAT skills through the teachers' mentoring; and (e) provides support for the teachers during their own PBLSAT projects and their enactment of PBLSAT with their students.

A similar model reported in the literature is called *Cycles of Collaboration, Enactment, Extended Effort, and Reflection* (CEER); it was used to develop the practice of teachers in their enactment of PBS (Marx et al. 1998). We have adopted their term, "enactment," (and not "implementation") to signify that this is a constructivist approach for the teachers, who need to adapt what they have learned to the unique conditions of their classrooms and schools (Krajcik et al. 1994).

Teacher Continuous Professional Development for Project-Based Learning in Science and Technology

While our model of CPD includes the elements of CEER, it explicitly focuses on a larger conceptual framework, as described below. Our major goal in designing this program was to give to the participating teachers the needed skills, support, and self-confidence to effectively enact PBLSAT in their schools.

The inservice workshops were part of a larger conceptual framework, named "The Evolving Model" of teacher development (Rosenfeld et al. 1997). This model includes two dimensions:

> **Focal areas of emphasis** (teacher as learner, teacher as teacher, teacher as innovator), along with a **common development sequence** for each focal area (from enthusiasm and confusion about goals and frustration about achieving those goals to the accomplishment of those goals). (Rosenfeld et al. 1997)

Based on this model, three kinds of teacher support frameworks were developed (Rosenfeld et al. 1999). The first one was designed for "The Teacher as Learner" and included basic workshops for novice PBLSAT teachers who have never experienced this approach (e.g., Rosenfeld and Ben-Hur 2001). The second support framework was designed for "The Teacher as Teacher and Innovator in the School" and included school support during the school year in which the teachers enacted the approach. The third support framework was designed for "Leading Teachers," that is, for expert teachers who had experience with the two first support frameworks for a long time (at least 5 years). Those teachers then guided other teachers in the other two support frameworks. (The third support framework is not the subject of this paper.)

Description of the First Support Framework

To apply the first support framework (The Teacher as Learner), a PBLSAT inservice workshop was designed. From 1992 to 2004, about 600 teachers participated in this workshop, which was characterized by the following components:

1. *Focus on PBL as an open-ended and structured process*. Each enactment of PBLSAT elicited many different student projects, all based on the same core concepts in science and technology taken from a curriculum unit that was chosen by the teacher. A student manual presented the PBLSAT process in an stepwise, but recursive, fashion; (Breiner et al. 1999), and a teachers manual provided more guidance in enacting this open-ended and structured approach in the classrooms (Rosenfeld and Fallik 2002).
2. *Focus on teachers as experiential learners in PBL*. The PBLSAT workshop gave teachers the direct experience of conducting their own project, from start to finish. We believe that, given this experience, they would be better able to guide their own students, while understanding their difficulties. This teacher-centered approach focused on such issues as PBLSAT skills development, as described above, including the teachers' free-choice of their own driving questions, based on a common curriculum topic.
3. *Focus on modeling the mentoring process in PBLSAT*. The staff of the workshop mentored the workshop teachers in the same way teachers were expected to mentor their own students (i.e., focusing on students both as individuals, as well as members of project groups, a tolerance for ambiguity, a balance between open-ended and structured learning, and an open-minded attitude towards identifying and dealing with project-related difficulties).

As an example, one PBLSAT workshop within the "Teacher as Learner" framework focused on the unit of "Senses and Sensors" (Piontkewitz et al. 2002). Teachers were guided to ask driving questions (Blumenfeld et al. 1991) that were new and appropriate for their own level, rather than the level of their students. The teachers were guided in self-selected teams to develop their driving questions into their own free-choice projects, based on the core concepts in science and technology in the Sense and Sensors curriculum unit. At the end of the workshop, teachers presented such projects as the following: "The After-Effect Phenomenon With Colors: Do All People See the Same Colors?", "How Can We Develop a Biological Alarm System to Continuously Monitor Blood-Sugar Levels in the Blood?" and "What Methods Can Be Used to Successfully Treat Motion Sickness?"

The PBLSAT workshops that were developed for the first support framework were either long term (56 h) or short term (21–28 h); toward the beginning of the PBLSAT program, the long-term format was standard. However, as time went on, the short-term format was adopted.

These workshops were conducted with teachers from many schools at the Weizmann Institute of Science or with teachers from a particular school on the grounds of that school. In all of these workshops, the PBLSAT approach was integrated with curriculum units taken from the Israeli science and technology syllabus. Thus, while these workshops differed in the amount of hours and in their location, they all focused on a central strategy (i.e., to focus on the development of teachers as learners of the PBLSAT skills by working on their own projects).

Description of the Second Support Framework

The second support framework focused on the "Teacher as Teacher in the Classroom." The length of this framework depended on the needs of the teacher teams, who were the focus on this effort; on average, each workshop lasted from 28 to 56 h. In this stage, the teachers more fully addressed the issues relating to classroom practice. For example, with the assistance of the PBLSAT mentors, teachers focused on the following components:

1. *Focus on guiding teachers to plan, organize, and enact PBL in their classrooms*. Teachers were guided to enact the PBLSAT process with a curriculum unit of their choice, to set-up a long-term classroom management plan, to involve other partners within and outside their school (e.g., other teachers in the school, as well as staff from local academic institutions and science-based industries), and to design appropriate criteria for evaluating student projects.
2. *Focus on teachers as mentors of students in PBL*. The second framework focused on helping teachers to guide, critique, and assist students in their PBLSAT work. For example, the PBLSAT staff assisted the teachers in identifying specific problems (e.g., relating to student weaknesses regarding science content and research skills, project management issues, or both) and in discussing possible solutions. In each case, the novice PBLSAT teachers were encouraged to decide what actions to take.

3. *Focus on helping teachers solve difficulties relating to their schools*. Teachers were encouraged to identify and address problems regarding such administrative issues as needed resources (e.g., the use of buildings, staff, equipment, financial support, etc.), needed classroom time for enacting PBLSAT and needed other support (e.g., from other teachers, school principals, and school supervisors).

To support the above work, the second support framework included a PBLSAT teachers' forum. Composed of the PBLSAT teachers and their academic mentors, this forum met regularly to discuss issues raised by the participating teachers relating to the three points mentioned above.

Rationale of the Two Studies

The purpose of the current research was to study the effectiveness of our CPD model for free-choice PBL in Science and Technology from the perspective of the participating novice and expert PBLSAT teachers. We conducted two studies. The first dealt with the first support framework with its novice teachers, while the second dealt with the expert teachers, who participated in both frameworks.

First Study: Novice Project-Based Learning in Science and Technology Teachers

In this study, we addressed two research questions:

1. How do novice teachers evaluate their knowledge of PBLSAT skills before and after the first support framework (PBLSAT workshop)?
2. What are the perceived benefits and difficulties of PBLSAT for students, teachers, and the school, according to the novice teachers?

Methodology

Population

Three groups of middle school science and technology teachers participated in the first support framework (The Teacher as Learner workshops); they were all short-term (21–28 h). Group 1 studied during the summer of 2000 and included 20 novice teachers; the central subject was Transport Systems. Group 2 studied during the summer of 2001 and included 24 novice teachers; the central subject was Materials. Group 3 studied during the summer of 2001 and included 21 novice teachers; the central subject was Senses and Sensors. In this workshop, the teachers engaged in the process of design and technological development, rather than in the process of scientific research. While the backgrounds of these teachers were similar, the groups differed regarding the teachers' prior classroom experience with (non-PBLSAT) projects: 25% for Group 1, 50% for Group 2 and 100% for Group 3. They also differed in terms of their prior experience with other workshops that dealt with some PBLSAT skills (e.g., peer evaluation). In total, 58 novice teachers completed questionnaires in the beginning and at the end of the workshops (seven teachers did not complete either the pre- or posttest and were dropped from the analysis).

Methods

The study employed a questionnaire, which had two parts: open-ended and close-ended responses.

(a) Close-ended responses. The close-ended part of the questionnaire tested the perceived level of mastery of the following PBLSAT skills by the teachers: question asking, choosing a driving question, formulating a research question, writing a proposal, peer evaluation, developing evaluation criteria, R&D methods, data collection and analysis, and drawing conclusions. We adopted this method from research on taste (Ulrich et al. 1997) and modified it for this study. For each skill, the teachers had to mark their perception on a 100 mm-long, nongraduated line. Above the left end of the line, the following caption was written: "I have not acquired this skill"; on the right end of the line, the caption was: "I have acquired this skill." The participating teachers were asked to reflect on their knowledge of PBLSAT research skills on two occasions: before they started the workshop and after the workshop. Measurements were recorded with a ruler in millimeters, starting on the far left side. We chose this method because it allowed the subjects to report their perceptions more precisely than by using a Likert-type scale, which allows for only 4–5 possibilities. In our case, there were more in-between possibilities from which to chose; in addition, the visual form of the data (i.e., the resulting radar graph) allowed the reader (a) to see a complex pattern of many variables at the same time and (b) to visually compare the pre- and posttest results for each variable (via the inner and outer lines).

It is important to note that the first and the second groups engaged in both science and technology projects, so their questionnaires included all 9 PBLSAT skills. Since Group 3 engaged only in technology (design) projects and did not deal with three of the PBLSAT skills (R&D methods, data collection and analysis, and drawing conclusions), these skills were omitted from the data analysis.

(b) Open-ended responses. The open-ended part of the questionnaire examined the perceived benefits and difficulties of PBLSAT as enacted by the novice teachers. The teachers who participated in the workshops were asked to answer the following open-ended question at the end of the workshop: "In your opinion, what are the benefits and difficulties of PBLSAT?"

The responses to this question were analyzed via four steps based on the "First-Order Theoretical Analysis" (Shkedi 2004, 2005). We modified this method for this study. The four steps included the following:

1. *Primary analysis*. The teachers' sentences were divided into two lists: benefits of PBLSAT and difficulties of PBLSAT. These two lists were further subdivided into categories of benefits and difficulties.
2. *Mapping and focusing analysis*. Based on an analysis of the teachers' sentences, we found that the sentences related to three new categories: PBLSAT benefits and difficulties as relating to (a) students, (b) teachers, and (c) the school. We

categorized each sentence into one of these three subcategories. These two steps are illustrated in the Appendix.

3. *Quantitative analysis*. The sentences in each category (benefits and difficulties of PBLSAT) and each subcategory (students, teachers, and the school) were counted and illustrated in a histogram.
4. *Descriptive analysis*: Based on the above, the second research question was answered descriptively.

Analysis and Discussion of Results

The following results are based on the three teacher groups that participated in the Teacher as Learner workshops:

Close-Ended Responses

The averages of each question, illustrated by the radar graphs, are produced by the Microsoft Excel 2000 software. In each graph, the inner line presents the novice teachers' self-evaluation regarding PBLSAT skills at the beginning of the workshop. Every skill has is own axis. The outer line presents the novice teachers' self-evaluation regarding the same skills at the end of the workshop. Sign rank (S), a nonparametric operation, was performed for statistical analysis (Siegel and Castellan 1988). The collected data included only teachers who answered both questionnaires; their number (n) is presented next to the respective skill in each graph.

The results of the questionnaires show that teachers experienced a significant improvement in most PBLSAT skills as a result of the three PBLSAT workshops. For example, the data show that the teachers in Group 1 felt they had acquired some of the PBLSAT skills, to some degree, before they began the workshop (Fig. 1). Their self-evaluation of the same PBLSAT skills increased as a result of the workshop. As can be seen from Fig. 1, this difference is statistically significant for the skills of choosing a driving question ($p < 0.001$); question asking, R&D methods, formulating a research question, peer evaluation, and writing a proposal ($p < 0.01$); and drawing conclusions ($p < 0.05$).

The data of the second group (Fig. 2), like the first group, show that teachers evaluated themselves as having acquired the PBLSAT skills to some degree, prior to the workshop. The skill that received the highest preworkshop self-evaluation (inner line) was formulating a research question. PBLSAT skills that showed the lowest teachers' preworkshop self-evaluation were writing a proposal, peer evaluation, developing evaluation criteria, and R&D methods. We can also see that the outer line is more circular at the end of the workshop. This indicates that the teachers felt they acquired all of the PBLSAT skills at more or less the same level, in spite of the differences between them. Except for the question-asking skill, all the other skills were statistically significant (from $p < 0.05$ to $p < 0.01$).

Unlike the other two groups, the third group engaged only in technology (design) projects, so their questionnaires evaluated only 6 of the 9 PBLSAT skills (see

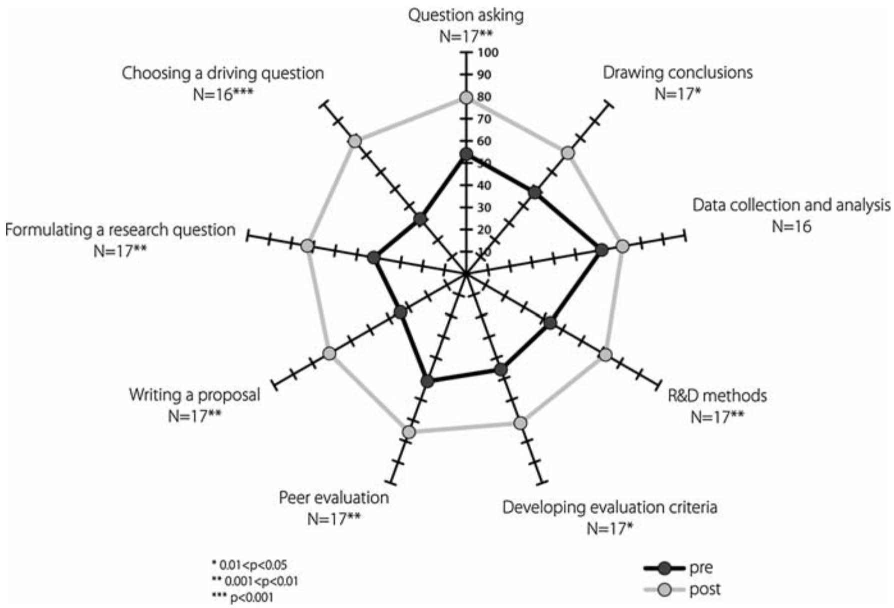

Fig. 1 Teacher's self evaluation of their acquired PBL skills before and after the first-group workshop

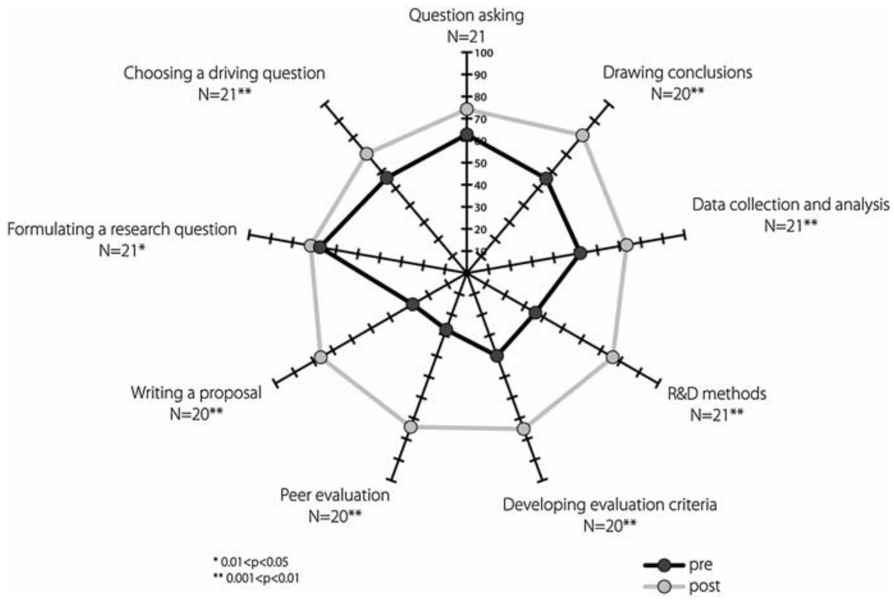

Fig. 2 Teacher's self evaluation of their acquired PBL skills before and after the second-group workshop

Fig. 3). Still, as in the other two groups, the teachers felt they had acquired the PBLSAT skills; the results are statistically significant for all skills (from $p < 0.05$ to 0.01), except for the skill of developing evaluation criteria.

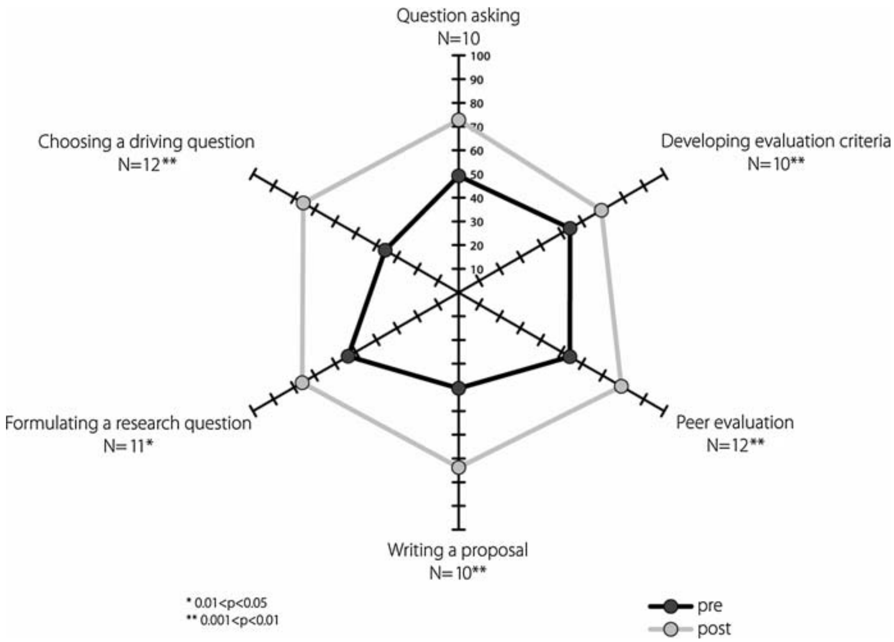

Fig. 3 Teacher's self evaluation of their acquired PBL skills before and after the third-group workshop

We would like to address the issue of stability in using the nongraduated line measures. How can we know that the teachers related to the same points on the scales in the same way in both the pre- and posttests? One indication that this measure was stable comes from the three PBLSAT skills in Group 3 that were not reported above, because they were not taught in the inservice for these technology teachers (R&D methods, data collection and analysis, and drawing conclusions). The teachers gave higher scores for these skills before the inservice than afterwards; this is to be expected, because the skills were not part of the inservice. In all other cases, as reported above, the skill levels in the posttest were higher than those in the pretest. We believe that these results support the claim that these measures were stable (i.e., teachers related to them in the same reliable way) in both tests.

Open-Ended Responses. The following histogram (Fig. 4) shows that the teachers viewed the benefits and the difficulties for themselves and their students differently—many benefits and few difficulties for the learners of PBLSAT and few benefits and many difficulties for its teachers.

Specifically, the teachers identified many benefits of PBLSAT (95% of the benefit statements) for their students. Yochi, one of the teachers who participated in the workshop, wrote in her questionnaire that the student, as an active learner, chooses a topic out of a strong personal interest in the learning process. Another teacher, Merav, mentioned that this approach could cause the student to find more of a connection to the subject matter and, therefore, be more motivated to learn it. The teachers identified only a few difficulties for their students (30% of the difficulty statements). For example, Ronit wrote that the PBLSAT approach makes

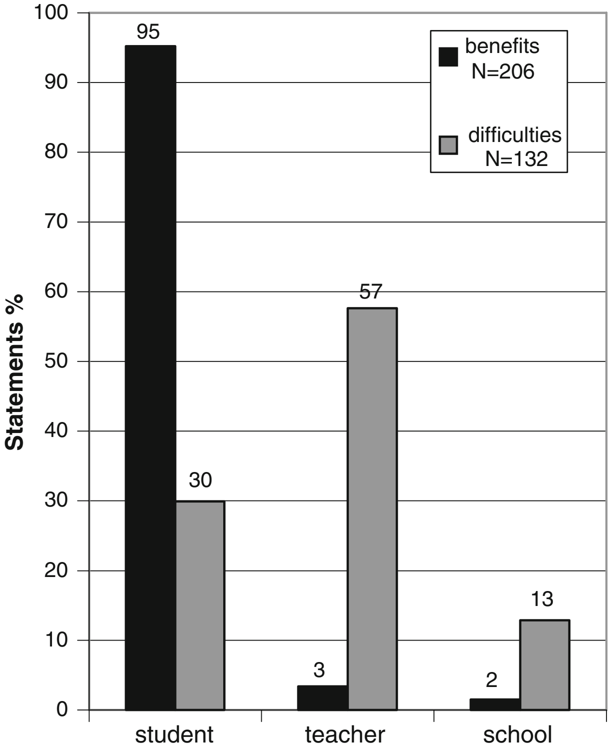

Fig. 4 Frequency of statements of novice PBLSAT teachers ($N = 58$) relating to the benefits and difficulties of PBLSAT. Percentages of statements are given

afterschool demands of the student and that the student does not always have the patience and the desire to invest more work than he needs to do at school. But the teachers found most of the difficulties for themselves as PBLSAT teachers (57% of the difficulty statements). For example, Hila wrote that applying the PBLSAT approach required a great deal of effort from the teacher—in the class, at home, and even during vacation—to succeed.

The teachers found only a few benefits for themselves (3% of the benefit statements) (e.g., creating teacher interest and a better teacher-student relationship). For example, Ahuva wrote that, as a result of the PBLSAT program, the students could better understand that in helping them, the teachers need to learn something new, and this strengthens the teacher-student relationship.

The teachers viewed more difficulties for the school system (13% of the difficulty statements) than benefits (2% of the benefit statements). Ela mentioned difficulties when she wrote that a successful application of the PBLSAT approach required the entire school system to prepare and organize itself, including the laboratories, an interdisciplinary staff, and a cooperative school administration.

On the other hand, Rivi wrote that a benefit for the school system was in marketing: PBLSAT as a learning process that leads children to produce products. These products allow the school to "sell" itself in a different way.

In summary, the results of the self-evaluations, before and after the workshops (Figs. 1–3), indicate that the teachers felt that they significantly improved their PBLSAT skills as a result of the workshops. The teachers of all the groups evaluated the skill of writing a proposal as the least familiar skill for them. Choosing a driving question and R&D methods were also evaluated as less-familiar skills in two of the three groups before the workshops had started.

The data also show that, although there were difference levels of the teachers' self-evaluation before the workshops (i.e., the inner line was jagged), the postworkshop results were all at a similar level (i.e., the outer line was rounder). In addition, the data show that the teachers received tools for applying PBLSAT in their schools, but this was not enough. The teachers estimated that in regard to these skills, there was still room for improvement (i.e., the outer line did not reach the maximum).

It is interesting to note that, while the 3 groups had different pretest scores, they had very similar posttest scores. We can explain the pretest differences as arising from different backgrounds (before the pretest) and the posttest similarities as arising from a common PBLSAT workshop (before the posttest). For example, in the pretest, Group 1 self-reported 30% ability on choosing a driving question, while Group 2 self-reported 60% on this skill. We connect this difference to the fact that only 25% of the teachers in Group 1 had experience guiding (non-PBLSAT) student projects, while twice as many (50%) of the Group 2 teachers had such a background. Likewise, in the pretest, Group 1 self-reported 50% on peer evaluation, while Group 2 self-reported 30% on this skill. We connect this difference to the percentage of teachers in each group who had participated in a different inservice that exposed them to the concept of peer evaluation (65% in Group 1 and 22% in Group 2). Nonetheless, the teachers in all of the groups self-reported similar scores for the PBLSAT skills after the workshop. This data suggests that, while the teachers came to the workshops with different initial backgrounds and skill levels, the workshop provided them all with a common language and similar ability levels regarding the PBLSAT skills.

We also investigated how the novice teachers perceived the benefits and difficulties of PBLSAT for students, teachers, and the school (Fig. 4). The results show that the participating teachers estimated many more benefits for the students than for the teachers and the school system. We attribute this finding to the fact that, in the workshops, the teachers could personally experience the benefits of PBLSAT as learners. They did not personally experience the teacher's role in this process and were, therefore, more worried about the difficulties that awaited them as teachers. How did the teachers respond to this dilemma? With this question in mind, we turn to our second study.

Second Study: Expert Project-Based Learning in Science and Technology Teachers

Teachers in the first study participated as PBLSAT learners. The purpose of the second study was to examine expert PBLSAT teachers' retrospective perception about their participation as PBLSAT teachers. This study addressed the following research question:

How do expert PBLSAT teachers evaluate the value of the two support frameworks (PBLSAT workshop and school support)?

Methodology

Population

The study focused on seven expert PBLSAT teachers. We define *expert teachers* as those who took part in the PBLSAT workshops (from 21 to 56 h) and implemented the program in their schools for 5–7 years. The seven teachers were chosen from three middle schools we will call Aviv, Rishonim, and Ben-Zvi. These teachers participated in PBLSAT workshops that were included as part of long-term CPD programs (i.e., 2–3 years) for middle school science and technology teachers. Each teacher had at least a BA degree in one or more of the sciences, as well as a teaching credential. At the time of the research, the teachers had been teaching from between 6–27 years. In addition, several teachers also had backgrounds as nature guides in environmental education programs.

Methods

Interviews were conducted with the seven teachers. These interviews were open ended and indepth (Patton 2002); the questions were about the two PBLSAT support frameworks for teacher professional development: the basic workshop (described in our first study) and the teacher support for their PBLSAT enactment. Specifically, the questions included the following:

- What can you tell me about your experience in the PBLSAT CPD program—from the moment you were introduced at the first workshop and during your enactment of it in your school to the present time?
- What did you learn?
- What effect, if any, did this CPD program have on you, your colleagues, and your school?
- In this process, what difficulties did you experience, and how did you deal with them?
- Did your academic advisors from the Weizmann Institute of Science influence your work; and if so, how?

The interviews were transcribed and analyzed using content analysis, according to two predefined categories (Patton 2002): (a) the teachers' experience of the PBLSAT workshops and (b) their experience of the school support. We chose these two categories because they relate to our study's research question. Thus, after the interviews were transcribed, each teacher's comments were categorized into these two predefined categories.

Reliability Check

To check the validity of the second study, we asked three teachers (one from each participating school) who participated in this study to read the completed study and check it for accuracy in reflecting their PBLSAT experience. All three teachers expressed satisfaction with the study's validity. For example, after reading the study, one teacher said: “Immediately, I could see myself in this article … I agree with what was written in this paper.” The responses of the other two teachers were similar.

Analysis and Discussion

We will now present the perspective of the participating PBLSAT teachers, first regarding (a) the PBLSAT workshops and later regarding (b) school support.

The Teachers’ Experience of the PBLSAT Workshops

Three themes emerged when analyzing the teacher interviews regarding the PBLSAT workshop: (a) the value of the teacher as learner, (b) the value of a teacher-centered approach, and (c) the value of teacher teamwork.

(a) The value of the teacher as learner. The teachers spoke about the process of conducting a project. As Irit said,

> As teachers, we engaged in a project at the Weizmann Institute of Science. We experienced the same process that the students did: question-asking, finding knowledge resources, conducting the scientific experiment, and so on.

Furthermore, the teachers explicitly valued this process. For example, they felt that they experienced student difficulties, by making mistakes and solving-problems regarding their own projects. This behavior, i.e., facing unexpected difficulties and solving problems, is the basis of the PBL approach. Irit said,

> This approach helped me to understand all of the students’ difficulties. If I had difficulties, the student would have more and [my duty] is to try to help him. Not to just say “Go and look for the written sources yourself”. I had to guide the student to find these sources, whether in libraries or on web sites.

Dalia also talked about the same process of working on a project as a learner. She said that she could understand the unique approach as a result of making mistakes and then correcting them:

> I think that it’s obvious that doing projects is complicated and difficult for teachers. … Whoever has not gone through a long-term inservice, like we did, cannot understand the importance of projects. It’s important to experience mistakes and difficulties, to try to do things that don’t work…

Moreover, the inservice workshop emphasized to Irit the importance of acquiring not only knowledge, but also the necessary skills to help learners to acquire this knowledge. Irit explained how the workshop helped her and her two colleagues to develop collaborative learning skills:

> The best preparation [for working with students] was our experience. In other words, as teachers, we also had to do a project. We went through all of the stages, like our students, from asking questions to locating sources of information to conducting experiments and so forth. We had to do all of this as

> a group, and the three of us each pulled in a different direction. We identified each of our strong points, in different areas, and only then were we able to divide the work so that everyone could contribute their strong points. When there were disagreements, because we were three, it was easy to make a decision, since there was always a majority. Difficulties were settled in this way; and, slowly, everyone in the staff learned how to express themselves and to compromise.

Finally, Irit remarked that "Today I can read different types of disciplinary knowledge … from scientific magazines or science books, and so forth. But I could not have developed those skills without the inservice."

In summary, during the PBLSAT workshop, the teachers valued doing their own projects since this provided them with the opportunities to (a) experience difficulties and solving problems that their students would later face and (b) acquire learning and research skills that are applicable to many scientific disciplines.

(b) The value of a teacher-centered approach. The teachers felt that the workshop was teacher-centered, as opposed to program centered. They felt they were respected as teachers and as individuals. All of the seven teachers felt that the workshop staff supported them intellectually in acquiring knowledge and skills, as well as emotionally in dealing with project difficulties.

Ofra, from Ben-Zvi school, said, "We received one-hundred percent support [from the staff] … in answering our questions … [The staff] came to our school, especially in the first years, while we had lots of difficulties. We received a lot of support from the Weizmann Institute staff." In regard to the emotional support that the teachers received, Dalia**,** from Aviv school, compared the Weizmann Institute of Science inservice workshop to other previous workshops that she had taken. (We should note that Dalia participated in a 3-year CPD program at the sponsoring academic institution. Part of this course was the PBLSAT workshop, so it is possible that she did not make a separation between the entire program and the PBLSAT workshop.) She said:

> I think that, generally, the approach we received [from the staff] was unusual, because they related to us as people who think on their own. In previous workshops, the workshop leaders gave us the feeling that "You are only teachers" or, in the best case, "You are simply stupid people."
> Most of the workshop staff … gave us the opportunity to express our opinions and ideas and not just to be thinking human beings who keep quiet. I think this is the main thing that I got from this course. This was a new experience for us.

Another example of how the PBLSAT workshop influenced teachers on a person level was Ruth, who was a teacher from the Aviv school. The school had a tradition of PBL. During the 1st year that the PBL approach was implemented in the school, Ruth refused to take part. According to her science coordinator, Ruth initially felt more comfortable teaching from the science book and less comfortable engaging in the unpredictable process of PBL. Reluctantly, she participated in a long-term PBLSAT workshop. The workshop apparently touched her on a personal level. She later said, "The workshop … taught me to become curious, something that was new for me." According to her science coordinator, as a result of the workshop, Ruth started to become more involved with student projects. In fact, when she took over the role of science coordinator, she actively promoted the PBLSAT program with her staff.

(c) The value of teacher teamwork. During the workshops, the teachers undertook their projects in teams. Since the PBL process was long and complicated, the teachers learned to study and work together. For some teachers, this was a new experience. The first steps were difficult. The following quote relates to the teamwork, which was developed between three teachers from the Aviv school. Before the workshop, these three teachers worked without interacting with each other. One of these teachers, Irit, describes what happened:

> [During the project work] … it took time until we could identify the strengths of each teacher in the group. The moment we did, every teacher could contribute her strengths. The disagreements were solved because we were three and we decided by majority. Slowly, we learned how to communicate with each other in spite of our differences and our tendency to see things in certain ways or to pull in certain directions. We learned how to compromise on certain topics. … From this point of view, the PBLSAT process helped the three of us forge a common feeling of belonging, and this created the conditions for excellent work.

According to the science coordinator from the Aviv school, when these three teachers returned to their school, they continued to work together as a team. Thus, it appears that the importance of teacher teamwork—a product of the PBLSAT workshops—became even more evident when the participating teachers returned to their schools.

The Teachers' Experience of School Support

Part of the CPD program occurred inside the schools. After the teachers completed the PBLSAT workshops, they started to apply this approach in their schools. During this time, the PBLSAT staff often guided the teachers. They received support, like Dalia from the Aviv school, who explained that the staff "… did not throw us into the water and then say, 'Now swim!'"

Three themes emerged when analyzing the teacher interviews regarding school support: (a) the value of student support, (b) the value of teacher support, and (c) the value of supporting the novice PBLSAT teachers.

(a) The value of student support. The PBLSAT developers directly helped the teachers to guide their students in the process. A significant channel for student support in the Aviv school was the beginning of "mentoring days," in which the teachers and the PBLSAT staff guided the students in their project work. This guidance occurred in small groups. The staff provided students with just-in-time guidance to design and carry out their projects. Deborah, a teacher at Aviv remembers, "Many people really helped me. I remember that we got a lot of help from the Weizmann Institute of Science in special mentoring days. They helped us guide the students in their experiments and their other research work." A variation

of mentoring days was used, as well, at the Ben-Zvi school. The teachers arrived at the school on their “free” days (i.e., days they were not obligated to work) and provided the students with concentrated guidance on their projects.

(b) The value of teacher support. According to the participating teachers, the PBLSAT staff was a reliable and available source of support for the teacher. They advised the teachers repeatedly; and, in this way, strengthened the teachers’ self-confidence. For example, Oshrat, the science and technology coordinator of Rishonim school said:

> Our mentor [a PBLSAT staff member] brought us to the point where we felt a great deal of self-confidence. He led us from an outside perspective, which was very helpful. In other words, it is much easier to give advice from the outside than to give advice as someone who is part of the teaching staff.

Ayelet, who taught in Ben-Zvi, reported that her self-confidence and courage resulted, in part, from “tools” to bring out the potential of her students, which she learned and used in the PBLSAT program:

> I can divide the years into two parts: before the PBLSAT workshop and after it. This is the truth. The previous years were years of dreaming; maybe we will do something innovative one day, maybe the kids will discover their potential, somehow, and I will be able to do things that I want to do. But I did not have the tools. I had no idea how to do such big things. When the workshop came to an end, I felt that I could do it. Now I have the courage… I understand that I always could do it but I missed a few tools. Also, as a result of the workshop, my self-confidence increased. We now understand … that we have, in our hand, kids that can do much more than they did [previously].

One more aspect that helped teachers to apply the PBLSAT approach was the cooperation and the learning together between the developers and the teachers. Dalia from Aviv school said that this cooperation resulted, at least in part, because the teachers and developers codeveloped the PBLSAT program:

> Because our teachers [the staff of the PBLSAT program] in the Weizmann Institute of Science did not know exactly what to do, like us, we participated with them in a common learning process. That process helped us avoid getting stuck in a preplanned pattern, but to create a new path in a new direction. [The staff] gave us full legitimacy to ask for help. They gave us the legitimacy to try something new and then to regret it, to try something new and to continue, in spite of the unclear purpose—because a clear path did not yet exist.

It is important to note that the PBLSAT staff continued to support the teachers in their schools for few years. This support decreased over time, as the teachers’ self-confidence and independence increased.

(c) The value of supporting the novice PBLSAT teacher. In the years following each PBLSAT workshop, science and technology teachers who were inexperienced with the program joined the school staffs. The new teachers received help from their colleagues who had taken the workshop. Deborah started to teach at Aviv and then transferred to Rishonim, where she had to apply the PBL approach in her 1st

teaching year. She reported that she received a great deal of help from teachers in the school.

Deborah received assistance from the other teachers during each stage in the PBLSAT process. Before each stage, her colleagues explained the enactment to her. For example, before the "question-asking" stage, her colleagues assisted Deborah to guide her students to ask questions. After each stage, she was given assistance in how to give feedback to the students; for example, after a question-asking activity, her colleagues helped Deborah to evaluate student questions and give the students valuable feedback.

During this implementation of the PBLSAT process, Deborah and her colleagues participated in a long-term teacher workshop that included guidance for enacting PBLSAT in schools. Deborah joined this workshop after the participants took the basic PBLSAT workshop; in other words, Deborah did not experience the PBLSAT process herself, as did her colleagues.

It is interesting to note that Deborah felt that she had received more support from her colleagues in the school, than from the teacher workshop. Here is how she put it:

> My training within the framework of the workshop … contributed to me much less than did the practical work I performed with the other teachers in my school. The teachers were very experienced [in enacting PBLSAT]. I think that I learned the most from them.

In this way, Deborah and other novice PBLSAT teachers learned from their more experienced colleagues in a just-in-time fashion. In this way, teachers who had taken the PBLSAT workshop provided valuable CPD for the novice PBLSAT teachers.

To summarize the second study, we will address our research question: "How do expert PBLSAT teachers evaluate the value of the two support workshops (PBLSAT workshop and school support)?"

It is clear that the expert PBLSAT teachers perceived that they had undergone a very significant CPD experience, even when they were asked to reflect on this experience 5–7 years later. As a result of the PBLSAT workshop, they valued the experience of (a) doing their own science and technology projects, (b) facing similar difficulties that their students would face in project work, and (c) improving their learning and research skills. They also valued the workshop's teacher-centered approach (as opposed to a curriculum-centered approach). This perception is based on the fact that the PBLSAT approach was designed to be student-centered. Thus, during the teacher-as-learner phase, the workshops focused on explicitly giving the teachers a personal experience of PBLSAT. Finally, the teachers valued their experiences in teamwork, both in their own individual projects, as well as in the school implementation.

As a result of the school support, the teachers valued just-in-time student guidance, especially in the mentoring days. They also valued teacher support, which strengthened their self-confidence and helped to give them the courage to take risks associated with implementation. Finally, some of the novice PBLSAT teachers valued their CPD gained "just-in-time" from their more experienced PBLSAT colleagues.

Up to now, we have described the second study. The following sections will summarize and discuss the first and the second studies together.

Summary and Conclusions

The PBL approach is well known for its potential and effectiveness for the learners (Berger 1996; Boaler 1999; Dochy et al. 2003; Fortus et al. 2004; Polman 1999; Schneider et al. 2002). Research suggests that the enactment of this complex approach in classrooms and schools is dependent upon an effective program of CPD for teachers (e.g., Marx et al. 1997; Thomas 2000). The purpose of our research was to study the effectiveness of our CPD model. We studied two of the model's three support frameworks: Teacher as Learner and the Teacher as Teacher PBLSAT workshops. Table 1 summarizes the salient findings of these studies, comparing the cognitive and affective effects for the teachers for each of the two frameworks of our model.

In the first support framework, the middle school science and technology teachers acquired PBLSAT skills by engaging in their own research and development projects. The teachers reported that the workshop helped them significantly improved these PBLSAT skills. Although the teachers were convinced about the significant value of the PBLSAT approach and could see the many benefits for their students (Fig. 4), they were very concerned about the future PBLSAT difficulties they might face as teachers. Despite these concerns, the PBLSAT teachers—or at least those who later became expert PBLSAT teachers—did not become discouraged. They continued to apply the PBLSAT approach. According to another study (Fallik et al. 2003) the teachers met the various challenges and managed to

Table 1 Summary of the cognitive and affective effects of two support frameworks of the PBLSAT professional development model

	Cognitive and practical effects	Affective effects
In-service workshop (first support framework: "the teacher as learner")	Teachers acquired PBLSAT skills	(1) Increased self-confidence (as PBLSAT learners) (2) Excitement of perceived PBLSAT benefits for the learner (3) Worry about perceived PBLSAT difficulties for the teacher
School support (second support framework: "the teacher as teacher in the classroom")	(1) Teachers enacted PBLSAT in their classrooms. (2) Teachers appreciated support given to students in the program. (3) Teachers employed (and created) solutions to PBLSAT difficulties.	(1) Increased self-confidence (as PBLSAT teachers) (2) Development of teacher ownership for PBLSAT

overcome them with a variety of creative solutions. These results and a more detailed analysis of the perceived PBLSAT difficulties (Fallik et al. 2003; Fallik 2004) show that the model presented the teachers with the relevant difficulties of PBLSAT, while still inspiring them to enact this approach in their schools.

Based on these findings, it seems to us that the most salient effect of our model is that it helps the teachers develop a sense of personal ownership for the PBLSAT approach. We suggest that this effect relates to several aspects of our model: (a) an emphasis on the personal and professional development of each teacher, (b) increased opportunities and support for developing their own customization of the program, and (c) increased opportunities and support for applying the approach within the formal curriculum guidelines. Below we discuss these aspects of our model in light of other research on the professional development of teachers.

Personal and Professional Development

The teachers in our two studies reported that they developed personally and professionally as a result of the two PBLSAT support frameworks. They also reported that this ongoing support motivated them to enact the PBLSAT approach in their classrooms. This was true not only for new teachers, but also for experienced teachers who had taught for many years. They all reported that they experienced a new and special kind of learning experience that they had not experienced in the past. In Israel, college students do not usually conduct scientific research or design projects on topics based on their own “free choice” and personal interest; this experience usually begins with the M.A. or M.Sc. degree. Thus, many teachers had this experience for the first time in the PBLSAT workshops. These teachers reported that their CPD experience was based both on their personal interests and their exposure to new science and technology topics in a process that gave them guidance and self-confidence.

We believe that these positive outcomes were based on two other features of our CPD model: (a) It was based on the teachers’ motivation for self-development, and (b) it engaged in a relatively long, constructivist and learner-centered process for the teachers. Many other studies of successful professional development programs have also underlined these connections (e.g., Bennett et al. 2002; Berger 1996; Blumenfeld et al. 1994; Darling-Hammond 1998; Gitlin and Margonis 1995; Guskey 1986; Krajcik et al. 1994; Polman 1999; Sarason 1996; Sparks 1983).

For example, while it is very common for teachers to participate in CPD programs for the purpose of learning and applying new education pedagogies, in many cases, teachers do not enact these programs in their classes. According to research by Sparks (1983), a central reason for this phenomenon is that many teachers are not likely to enact a program that has been given to them in a recipe-like manner, without any challenge for them to be personally involved in the program. This was not the case in the complex, intensive and free-choice PBLSAT workshops. Our two studies demonstrated that the PBLSAT support frameworks gave the teachers opportunities for continuous self-development in a learner-centered, constructivist manner. After the first workshop, the PBLSAT approach did not end; the second framework served as the springboard for teachers to apply this approach in their classrooms and schools. The teachers moved from being traditional teachers in traditional settings to constructivist teachers in traditional settings. They were supported to create their own solutions to problems that arose in real time. This process helped them develop a sense of ownership for the PBLSAT program. Prior research has shown that, for teachers to adopt new constructivist practices, they need to engage in a long process of change (Darling-Hammond 1998) that takes into account their own individual learning preferences (Rosenfeld and Rosenfeld 2006).

A number of studies have reported how professional development programs that take into account the teachers' personal and professional development enhance their feeling of ownership. For example, in the Salter approach, teachers were included in the process of curriculum planning; this chemistry program became part of the National Curriculum for about 20 years (Bennett et al. 2002). Also, in the PEEL Project, classroom teachers shared with each other various learning strategies in a wide variety of disciplines. That teacher-developed program has been running for more than 20 years (White and Mitchell 1994).

Teacher Customization of Project-Based Learning in Science and Technology

In the two studies, we found that the participating teachers customized PBLSAT to fit their own needs, both as learners in the first support framework and as teachers in their classrooms in the second support framework. Our first support framework was largely based on giving teachers the responsibility and free choice to choose their own driving questions. In our second support framework, teachers had a big input in choosing which issues of enactment were discussed at any given meeting. We found that this teacher customization was based on teachers actively developing their own solutions to challenges involving PBLSAT via a continuous dialogue with their academic mentors.

Other studies support this finding. Fishman et al. (2001) made the case for encouraging teachers to present student difficulties in a teacher development program, to foster potential design responses by the professional development team. A similar model is the constructivist learning model (CLM) of the Scope, Sequence, and Coordination project (SS&C), in which teachers design teaching modules, participate in analyzing and assessing the impact of these modules, and use this information to continuously improve their teaching and student learning (Yager and Weld 1999).

There are also reports of single teachers who, by customizing PBL to the local conditions of their schools, thereby developed a sense of ownership. In one case (Polman 1999), a high school teacher, involved his students in PBL on topics in ecology; the teacher received early support from university mentors. Although he initially experienced many difficulties, he found solutions to them. After a few years, he became a coordinator and helped other teachers in his school adopt his approach. In a similar single case (Berger 1996), an elementary school teacher engaged in PBL with his students on the topic of the radon level in the school environment. He also received support from university mentors, and his customized innovation was adopted by his school.

Connection with Curricular Goals

In the Israeli science and technology syllabus for middle schools (Ministry of Education 1992), there is a reference to the importance of (a) teaching inquiry skills and (b) integrating science and technology. From our discussions with Israeli middle school science and technology teachers, we understand that the PBLSAT approach can provide connections with these two curricular goals. This connection with curricular goals is another way in which teachers have developed ownership for the PBLSAT program.

In conclusion, our two studies support our CPD model, based on two of our three support frameworks. At the same time, we recognize that much of what we have been able to show is based on CPD principles that have been demonstrated in many other studies. In addition to our contribution to this literature—as another example that supports these principles—perhaps the unique contribution of our work is demonstrating the effectiveness of a CPD model that supports an approach that integrates elements of formal and informal science learning. This approach, which we call free-choice PBL, combines the interests of the educational system (through the science teacher’s choice of any specific curricular program) with the interests of individual students (through the development of projects based on their own free-choice driving questions).

This approach to PBL poses several open questions. What distinguishes teachers and schools that adopt this approach as part of their ongoing professional practice? What factors can enhance the sustainability of this approach in schools and school systems? Can expert PBLSAT teachers play a significant role in developing such sustainability, and, if so, how? How might other nonschool institutions, such as museums, science-based industries, and research institutions, be involved to help develop and support this approach in schools? As a result of our two studies, we have good reason to believe that many people—and not least, science and technology teachers—would be interested if these questions were addressed in future studies.

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Appendix

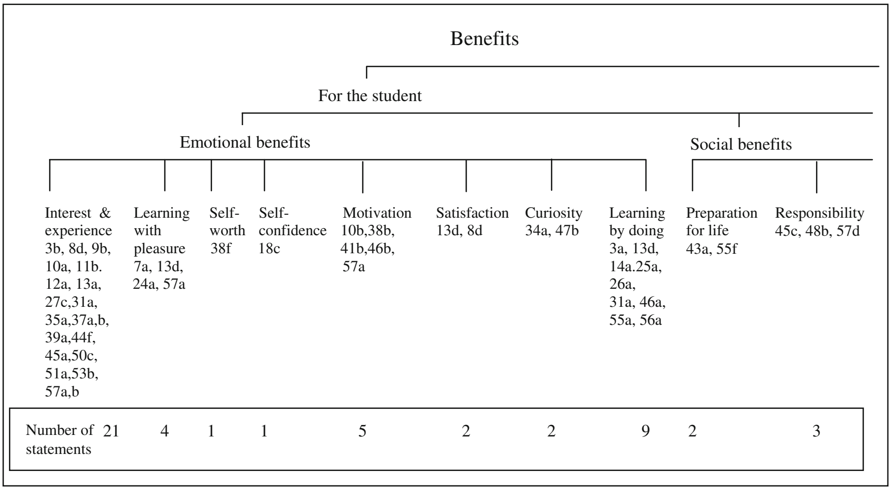
7a. (It provides) learning with pleasure
7b. (It focuses on) the student's will to learn
7c. (It provides) cooperative learning
7d. (Students improve their) personal relationships with the teacher
7e. (It gives) students the opportunity to express themselves differently than in formal lessons
7f. Teachers appreciate students for more than what they know.
8a. (It develops) student interest
8b. (It helps) students with learning difficulties
8c. (It fosters) student self-confidence
8d. (It develops) student interest
9a. (It's a) very good way to develop skills in a systematic and structured way.

Step 1a. Primary Analysis. Taken from the questionnaires, the teacher statements were divided into two lists: benefits and difficulties. Above is part of the resulting list of student benefits, written by the teachers. Each teacher received a different number (e.g., 7,8,9 above) and each statement received a different letter (e.g., a,b,c,d, etc.).

Benefits for the student:

Emotional	Interest and experience
	Learning with pleasure
	Self-worth
	Self-confidence
	Motivation
	Satisfaction
	Curiosity
	Learning by doing
Social	Preparation for life
	Responsibility
	Tolerance

Step 1b. The two lists from step 1a were further subdivided into categories of benefits and difficulties. Above is a partial list of categories of student benefits which emerged from the benefits list.



Step 2. Mapping and focusing analysis. After step 1, an analysis of the teacher's statements revealed PBLSAT benefits and difficulties as relating to (a) students, (b) teachers and (c) the school. In the next step, these categories were organized into a "benefit tree." Below is part of the student "benefits tree," with the categories and the teacher statements (e.g., 51a, 53b, etc.). In the following steps, the number of statements in each category were counted and illustrated in a histogram (See Fig. 5).

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