

Unveiling Standards-Based Professional Development: A 21ST Century Model Applying Problem-Based Learning

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Abstract

Problem-Based Learning (PBL) has been recognized as an effective inquiry learning process (Albanese & Mitchell, 1993; Wang, Thompson, & Shuler, 1998). The definition and essential components of PBL are discussed in this study which unveils a model of professional development for inquiry science instruction. The California Science Project at the USC Center for Craniofacial Molecular Biology (CCMB) has applied PBL in designing professional development since 1994. The CCMB PBL Summer Institute 1998 was examined to assess the extent of its accordance with the professional development criteria described by the National Foundation for the Improvement of Education (NFIE) in its 1996 report. The evaluation benchmarks of this study were based on the professional development standards described in the *National Science Education Standards* (NRC, 1996). There were eighty-eight K-12 teachers from the Los Angeles Unified School District who participated in the 1998 CCMB PBL Summer Institute. The methods involved in this study include analysis of surveys and content analysis of reflective writings. Our findings indicated that PBL was an effective model for designing professional development to enhance teachers' science content knowledge and skills in inquiry science instruction.

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In the mid-1980's, fueled by the high expectations set forth in Department of Education's report *A Nation at Risk*, the education community was bombarded by the public's thirst for reform in mathematics and science education. At the same time a plethora of studies were distributed concerning teacher quality issues. Recently, the aftershock of the Third International Mathematics and Science Study (TIMSS) (Pursuing Excellence, 1997a; 1997b; 1998) led the public to question the effectiveness of the teacher preparation and professional development efforts during the past decade. In a recent educational policy report about teachers in California, Bullard (1998) states that the increasing numbers of new teachers resulting from California's 20 to 1 educational policy for K-3 classrooms creates a mandate for the education community at large to reflect on current practices in teacher education and professional development.

Long before the National Foundation for the Improvement of Education (NFIE) released their report *Teachers Take Charge of Their Learning: Transferring Professional Development for Student Learning* (NFIE, 1996), Joyce and Showers (1987) advocated the idea of linking staff development to students' performance. This outcome-based ideology for teacher training workshops has shifted the emphasis from "how to teach", "development of organizational or management skills", or "challenging teachers' beliefs or attitudes", to an emphasis on connecting teachers' content knowledge to the improvement of students' academic performance (Ball, 1988; Hashweh, 1987; Howe & Stubbs, 1996).

Schmidt (in press) recently used the findings of TIMSS to echo a need for focused subject knowledge preparation for our mathematics and science teachers. Schmidt states that content knowledge should be a critical component in defining both teacher quality and quality of instruction. What Schmidt has proposed is to establish a set of coherent and focused educational standards to guide teacher education and professional development. The learning standards for students would be the minimal requirement for teachers' subject content knowledge.

The purpose of this study is to report a successful model of a standards-based professional development program, in which emphasizes the enhancement of teachers science content, pedagogy, and pedagogical content knowledge. The model program is based on an inquiry model: Problem-Based Learning (PBL).

The Study Environment

The Center to Advance Pre-college Science Education (CAPSE) was established at the University of Southern California's Center for Craniofacial Molecular Biology (CCMB) in 1991 to promote inquiry science instruction for Teachers of K-12. Inquiry-based learning is not a new concept but has been advocated for nearly four decades (Schwab, 1962; Wang and Marsh, 1998). The most recent wave of outcome-based, standards-based science education reform urged researchers and educators to engage in further research to assist teachers with inquiry science education (NRC, 1996).

Since 1995, Charles Shuler, the director of CCMB, has been leading the USC-California Science Project cohort to a deeper level of partnership with the Los Angeles Unified School District (LAUSD) as they work to provide inquiry-based science education in K-12 classrooms. This partnership has been further strengthened through collaboration with the reform-driven force from

the LAUSD's National Science Foundation funded Urban Systemic Initiative (LA-SI). In addition to this university-school district partnership, local science museums such as the California Science Center, the Natural History Museum, and the Aquarium of the Pacific, are also contributing partners to this effort aimed at providing inquiry-based learning for all students.

This partnership reflects what has been exclusively described in the NFIE report (NFIE, 1996) describing a quality professional development program:

- uses long-term programs that can be incorporated into teacher's daily routines, with opportunities for further discussion;
- involves teachers in the planning process;
- creates sufficient blocks of time for professional development; and
- provides incentives and holds districts and teachers accountable for participating in relevant, high-quality professional development programs.

Furthermore, USC-CSP adopted the *National Science Education Standards* (NRC, 1996) as the benchmark for assessing the effectiveness of the professional development that assists K-12 science teachers in the LAUSD to implement inquiry-based science instruction. The standards of professional development in inquiry instruction as stated in *National Science Education Standards* (NRC, 1996, p59) are:

- involve teachers in actively investigating phenomena that can be studied scientifically, interpreting results, and making sense of findings consistent with currently accepted scientific understanding
- address issues, events, problems, or topics significant in science and of interest to participants
- introduce teachers to scientific literature, media, and technological resources that expand their science knowledge and their ability to access further knowledge
- build on the teacher's current science understanding, ability, and attitudes
- incorporate ongoing reflection on the process and outcomes of understanding science through inquiry
- encourage and support teachers in efforts to collaborate

Traditionally, school reform efforts have adopted a rather top-down format, changes in education rarely came from the teachers of local schools but generally from educators of higher education institutes or policy makers from administrative offices. The professional development tended to become "one-shot" programs or workshops with little or no continuous support in program implementation. These practices frequently failed their mission of school reform, yet have provided valuable experiences for other educators in designing future programs. Based upon lessons learned from many educators' experiences, the USC-CSP and LAUSD lead teachers generated a set of ideas describing six critical aspects of effective professional development for a cluster-wide science education reform:

1. coordination of K-12 cluster-wide education requires a shared vision
2. high educational standards should guide the reform initiative

3. teacher participation should take place from the beginning of any initiative and be continuously involved in the process
4. preparation of teacher leaders to become change agents is critical in assisting administrators in institutionalizing programs
5. advancement of content knowledge, effective instructional practices, and improvement in students' academic performance should be used as indicators of success in preparing teacher-leaders
6. networking and partnerships with community and educational entities are crucial to the success of the change process

The Los Angeles Unified School District (LAUSD), a school district with more than 600 schools, was recently organized into 27 Clusters. Every Cluster consists of one or more high schools with their feeder middle and elementary schools. This new organization provides a more feasible structure for school reform and coordination of education programs. The objective was to insure that the curricula within each Cluster was coordinated so that students benefited from experiencing a planned progression of learning based on a common set of high learning standards. This objective was part of the program mandate given to the USC-CSP with an assigned cluster—the Venice/Westchester Cluster—to pilot a model for cluster-wide science education reform program known as the *Orchid Project* (Wang, Thompson, & Shuler, 1999).

The reform initiative act was started in the spring of 1997. Since then, there have been a two-day mini institute for *Strategic Planning*, a one-day *Standards Awareness* workshop to identify standards-based instructional resources, a two-week 1997 Summer Institute, on-going monthly instructional enhancement workshops, and a two-week 1998 Summer Institute. In this study, we will focus on the examination of the 1998 Summer Institute for its unique design based on the inquiry model—Problem-Based Learning (PBL).

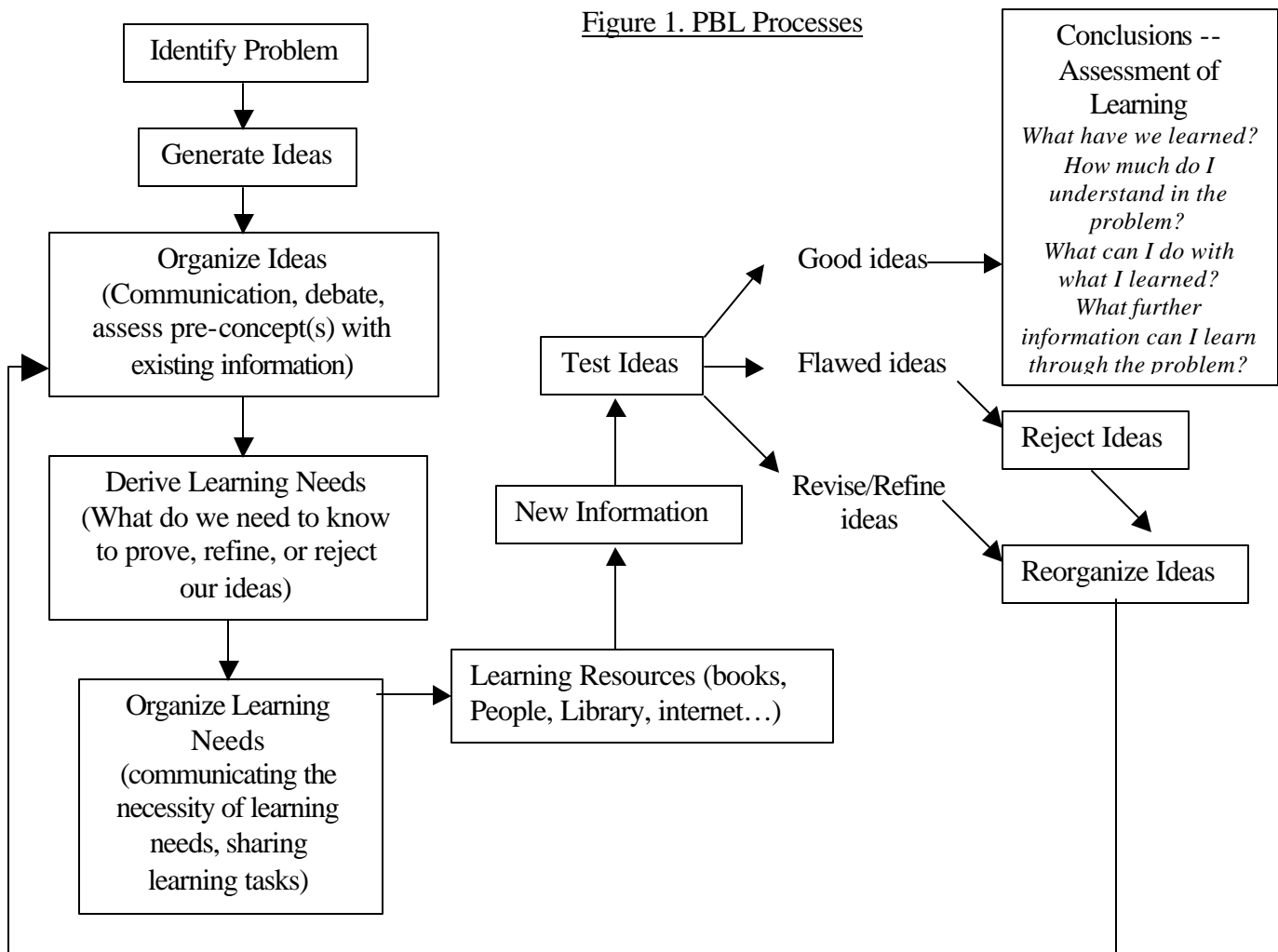
PBL: Conceptual Framework for Professional Development

PBL was introduced in medical education by a Canadian medical school in 1968 (Neufeld & Barrows, 1974), and has recently begun attracted growing interest among K-12 educators as an exemplary inquiry approach (Checkley, 1997; Glasgow, 1996; Jones, Rasmussen, & Moffitt, 1996a; Jones, Rasmussen, & Moffitt, 1996b). PBL as an instructional model demonstrates that any learning can be accomplished through “learning prompts,” which serve both to intrigue the learner and insure high quality learning outcomes. PBL for inquiry learning has been widely reported as producing desired learning outcomes: students became responsible for their own learning, developed active inquiry habits, and learned effective research techniques (Albanese and Mitchell, 1993; Wang, 1998b). Inquiry-based instruction using the PBL approach has also produced significant improvements in student performance in multiple-choice examination (Shuler & Fincham, 1998). This distinguishes PBL from other inquiry attempts that were criticized because they only enhanced students' attitudes and process skills, but did not significantly improve their acquisition of content knowledge.

Three key components of PBL were introduced to the teachers involved in the professional development programs: (1) learning cases, (2) student-centered learning, and (3) small group learning. The *learning cases* represent the core of PBL. Cases have specific learning outcomes

embedded and these outcomes represent the curricula content. In our cases, the learning outcomes were carefully aligned with educational standards described in the national science education documents. The *student-centered learning* component of PBL transforms teachers into group learning facilitators who facilitate the students' learning process. With teacher acting as a facilitator, student drive the process of learning through engagement with understanding the learning case. Facilitators introduce students to various strategies to effectively utilize learning resources, and establish questioning techniques to stimulate student thinking. *Small group cooperative learning* in PBL is based on students working in small groups, where they are responsible for both their peers' and their own learning. Learning needs identified in each learning case become the responsibility of both individual and the group. The responsibility of the peer group is to expect and demand quality sharing in scheduled group exchange sessions. Wang, Thompson, and Shuler (1999) present Figure 1 to illustrate a flowchart of the basic structure underlying the PBL approach.

Figure 1. PBL Processes



In the summer of 1998, the USC-CSP faculty and teacher leaders designed eight PBL cases to provide the teacher participants with an in-depth, adult-level inquiry experience. Prior to the Summer Institute, at a mini-institute held in April, approximately forty teachers were introduced to the PBL cases and used PBL approach to determine the necessary learning objectives to better

understand the problem. This information shaped the planning of the inquiry-based investigations pursued by the teachers during the first week of the Summer Institute. The embedded science content behind these eight cases was based on the learning areas of archaeology, microbiology/ecology, molecular biology, marine mammal biology, marine plant biology, botany, and earth science. Appendix A contains the eight PBL scenarios used during the Summer Institute. Each teacher participated in the PBL process as a learner to better understand the process per se, the skills it requires and its potential strengths and weaknesses as an instructional method to facilitate science learning. During Week One the PBL groups collected data, went on field trips, and met with content experts from university and public institutions as they sought solutions to their research learning needs generated from the PBL scenario. Every group brought back their research findings, prepared research posters, and gave presentations to the whole group in the second week of summer institute.

The Study

The objectives of designing the institute around PBL were to assist science teachers in enhancing their science content knowledge and gaining mastery of the PBL approach for inquiry instruction. Four instruments were used to study the effectiveness of the summer institute.

1. *Guided Daily Journal and Homework*. Sets of questions were designed to guide participant's focus on their daily reflective journal writing during the two-week summer institute. The questions were designed to reveal three aspects of knowledge involved in the professional development program, Content (science knowledge), Pedagogy (knowledge about PBL), and Pedagogical Content (knowledge of how to apply PBL).
2. *Facilitator Survey and Group Skill Survey*. The surveys were modified based on two instruments used in the USC School of Dentistry PBL Parallel Track. These two surveys provided information about participant's perceptions toward PBL facilitators and their own skills in a group learning format.
3. *Orchid Project Stage of Concern Survey*. This survey was designed based on Hall and Hord's (1987) CBAM model. It assessed teacher's implementation concerns in terms of the change process initiated by the Orchid Project.
4. *Overall Perceptions about the Summer Institute Survey*. This survey was modified from the identified professional development factors presented by the NFIE (NFIE, 1996). It was applied to study participants' perceptions toward the professional development institute in general.

There were eighty-eight ($n=88$) participants in the Summer Institute 1998. Daily journal return rate ranges from .65 to .55, Facilitator Survey return rate was .77 and Group Skill Survey rate was .63.

The journals collected were coded based on the three general categories (content, pedagogy, and pedagogical content) using three levels (Limited, Moderate, and High). Figure 2 is the coding

matrix applied to code the journals. The matrix rating the participant's journals was applied independently. The inter-rater reliability is .83. The reliability (α) of the *Overall Perceptions about the Summer Institute Survey* is .92. The reliability (α) of the *Orchid Project Stage of Concern Survey* is .90.

Figure 2.

PBL Journal Coding Matrix

	<i>Limited</i>	<i>Moderate</i>	<i>Extensive</i>
<i>Content</i>	Participant describes little or limited science information	Participant describes general or commonly held science information	Participant describes specific science content information
<i>Pedagogy</i>	Participant demonstrates little or no understanding of the PBL process; response is superficial.	Participant refers generally to parts of the PBL process but leaves out significant concepts or offers a superficial response which does not contain enough evidence of understanding to code as an Extensive response.	Participant includes descriptions of PBL processes and skills required by students. Response shows evidence of understanding beyond educational "buzzwords."
<i>Pedagogical Content</i>	Participant demonstrates little ability to apply PBL principals to teaching practice. Application is superficial at best.	Participant demonstrates the ability to apply PBL principals in a general fashion—principals are not fully developed or only partially applied.	Participants applies PBL principals fully

Findings

Effects on Gains in Content, Pedagogy, and Pedagogical Content Knowledge

Table 1 shows the mean score for the questions asked in the three aspects of knowledge before, during and after the PBL investigations. Overall, content knowledge shows a statistically significant increase (mean difference = .97; $t = 4.89$; Sig. = .000). Table 2 shows the participants' pre- and post-investigation performance in science knowledge within their research topics.

Table 1.
Mean Scores of Content, Pedagogy, and Pedagogical Content Knowledge

<i>Items</i>	<i>Means</i> (limited=1; moderate=2; extensive=3)
<u>Pedagogy:</u>	
Q1(d723). How would you describe PBL to a colleague?	1.78
Q2(d724). What types of skills do you feel students need in order to perform well in a PBL environment? (e.g., effective use of learning resources)	2.03
<u>Pedagogical Content:</u>	
Q3(d723). Reflecting on your teaching style, in what ways can you use PBL Strategies to strengthen your teaching practice?	1.60
Q4(d724). Reflecting on this week's activities, how can you help your students become scientific problem solvers?	1.51
Q5(d729). What would a PBL assessment look like in your classroom?	1.97
<u>Content:</u>	
Q6(d720). As learners we make connections to previous knowledge.	1.22
Q7(d727). Describe what you already know about your PBL case. Last Monday you were asked to describe your knowledge of your PBL topic. Tell us what you know about that topic.	2.19

Correlation analysis shows that a significant correlation existed between how much participants know about the PBL process and the ability to apply PBL in their instruction ($r = .38$; $p = .02$). In addition, participants' knowledge about the pre-requisite skills needed related significantly to how they assist students in succeeding within a PBL environment ($r=.38$; $p = .02$). Subject knowledge gained after the PBL investigations positively correlated to the demonstrated ability in assisting students succeed through PBL approach ($r=.36$; $p=.04$).

Surprisingly, knowledge in designing a PBL assessment had a different result. Participants' abilities in designing a PBL assessment showed negative correlation with science content knowledge gained in the PBL investigation ($r= -.40$; $p=.02$). Moreover, knowledge in assisting students with success in a PBL environment negatively correlated with knowledge in designing a PBL assessment ($r= -.31$; $p=.07$).

Perceptions Toward PBL Facilitator and Group Skills

Table 3 shows the mean scores for the Facilitator Survey. Overall, the participants perceived their PBL facilitators as being highly effective. Item 5 is a reverse item, in which participants should ideally perceive their facilitators as providing as little assistance as possible in terms of determining their level of learning. The response finding showed this item as the relatively lowest compared to the other items ($m=3.96$).

Table 3.
Results from Facilitator Survey

<i>Items</i>	<i>Means</i> (lowest=1; highest=5)
Q1(f). Facilitator provided clear insights into the process involved in PBL	4.09
Q2(f). Facilitator was effective in assisting the group to identify relevant ideas	4.25
Q3(f). Facilitator communicated interest in the subject matter of the problem	4.18
Q4(f). Facilitator stimulated interest in the subject matter of the problem	4.44
Q5(f). Facilitator assisted the group in determining when an appropriate level of learning had been reached	3.96
Q6(f). Facilitator was punctual in the group-related activities	4.42
Q7(f). Facilitator challenged students to develop their knowledge to an appropriate level	4.32
Q8(f). Facilitator was attentive to discussions within the group	4.46
Q9(f). Facilitator assisted the group in the identification of appropriate learning resources	4.42
Q10(f). Facilitator assisted the group in the identification of appropriate learning needs	4.47
Q11(f). Facilitator demonstrated concern and empathy towards all members of the group	4.54
Q12(f). Facilitator conveyed enthusiasm regarding the PBL process	4.60
Q13(f). Overall performance of this facilitator	4.40

Table 4 shows the mean scores for Group Skills Survey. In general, the teachers rated themselves highly in the category of actively participated/engaged in the group learning process ($m=2.71$). After perception of engagement, the teachers rated themselves highly in the ability to critically evaluate data or information gained in the process ($m=2.64$). Feedback skills and learning needs identification also were also rated highly.

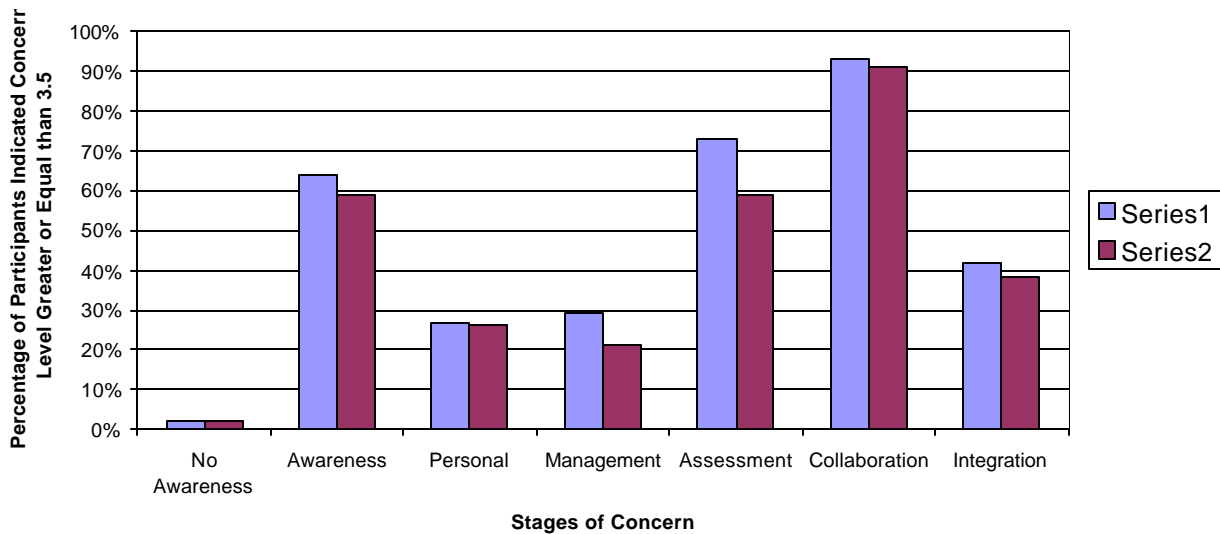
Table 4.
Results from Group Skills Survey

<i>Items</i>	<i>Means</i> (lowest=1; highest=3)
Q1(g). Actively participated in the work of the group showing a sensitivity to group needs as well as self needs and demonstrated respect for the aspirations of all members	2.71
Q2(g). Effectively identified group and individual learning needs and identified the appropriate learning resources	2.44
Q3(g). Demonstrated an ability to critically evaluate information, to synthesize and to critically appraise data	2.64
Q4(g). Demonstrated an ability to provide constructive feedback to the group, promoting the groups' ability to learn.	2.51

Implementation Concerns

Figure 3 reveals that the overall concerns of the participants in Summer Institute 1998 shared a similar trend with the participants from 1997 (approximately twenty participants from 1997 brought at least two or three teachers from their individual schools to participate 1998's Summer Institute). However, the general trend showed the degree of concern decreased in 1998 for every stage. (*Appendix B provides a more detailed definition of the Stages of Concerns abstracted from Hall & Hord*)

Figure 3.
Comparison Result Between 1997 and 1998 Participants' Stages of Concern



From Table 5, the majority of the participants indicated their strong concern (score ≥ 3.5 with the highest score 6) on the fifth stage of concern in terms of program implementation. This stage is the *Stage of Collaboration*, in which teachers are concerned with the other teachers' buy-in to the program and how to increase collaboration with other classrooms or schools within the cluster. The teachers had a similar level of concern for both the fourth stage—*Stage of Assessment*—and the first stage—*Stage of Awareness*. It shows that many participants have advanced beyond the initial stages of program implementation, which were mostly management issues to assess students' learning within the new approach. Thirty-eight percent of the participants indicated their advancement in the project implementation to the *Stage of Integration*. These teachers have started thinking about how to integrate what they experienced in the Summer Institute with other instructional practices or innovations.

Table 5.
Findings of the Participants' Stage of Concern Toward the
Program Implementation after the 1998 Summer Institute

Stage of Concern	Percentage of Participants Revealed Concern ≥ 3.5
No Awareness	2%
Awareness	59%
Personal	26%
Management	21%
Assessment	59%
Collaboration	91%
Integration	38%

Perception Toward Professional Development Summer Institute

In Table 6, the participants perceived the summer institute highly in terms of meeting needs priorities, program planning, training sessions' quality, follow-up components, and evaluation components. The participants reported that the 1998 Summer Institute's strength was pulling teachers together to collaborate and share good ideas and information ($m=4.8$). The follow-up component was slightly weaker when compared to the other aspects of the institute.

Table 6.
Findings of Participants' Overall Perceptions Toward 1998 Summer Institute

<i>Descriptions</i>	<i>Mean (lowest=0; highest=5)</i>
In this institute, the programs have responded to identified national, state, or local needs/priorities	4.5
There was a planning component that	
defines clear expectations	3.8
encourages collaboration	4.8
takes into consideration participants' needs and beliefs	4.3
has a clearly defined timeline/agenda	4.2
The training sessions	
provides a presenter appropriate to the planned activity	4.3
treats participants as professionals	4.6
encourages the exchange of ideas	4.8
allows for flexibility	4.5
allows for creativity	4.7
provides a facility appropriate for activity	4.6
has a demonstrated effect on teaching and learning	4.5
There was a follow-up component that	
is planned	4.0
provides for realistic implementation	4.0
is supportive of application and practice	4.3
allows for institutional reinforcement	4.0
There was an evaluation component that	
provides for review of project/presenter(s) by participants	4.4
examines impact on learning	4.2
reflects program purpose	4.4

Discussion

Analysis of the data indicates that using the Problem Based Learning approach to design a professional development institute was effective in enhancing teachers' science content knowledge, pedagogical knowledge, and knowledge of inquiry pedagogy in terms of PBL. The literature and our interactions with the participants suggested that teachers, especially elementary school teachers, feel less confident in teaching science due to their limited knowledge in the subject areas. However, by choosing to participate in an inquiry-oriented learning group, the level of enthusiasm toward science learning and instruction is evidently high. This enthusiasm motivated teachers and provided momentum for the program implementation.

Since one of the essential components of PBL is learner-centered; the teachers revealed greater satisfaction in terms of professional treatment with this PBL-based institute. The USC-CSP staff members successfully played the role of facilitator instead of expert, which made a difference to the participants. The 1998 Summer Institute met the criteria of quality professional development envisioned by the NFIE. The PBL approach provided the teachers a training experience that was teacher-centered and provided substantial science learning and instructional knowledge enhancement.

Despite the highlights of accomplishment revealed in this study of the Summer Institute 1998 two critical issues need to be addressed—the attainment of content knowledge and knowledge in PBL assessment.

The attainment of science content knowledge requires long-term efforts. According to the descriptions of the Summer Institute, PBL learning groups only had one week for scientific investigation and learning. The increase in content knowledge in the analysis was significant. However, the starting point of participant teachers' content knowledge must be addressed. In most cases that point was quite low or at the *Limited* level. Most K-12 teachers only advanced to the *Moderate* level of content knowledge during the *Orchid Project*.

For quality science learning and instruction, a *Moderate* level of subject knowledge may be insufficient. The literature reviewed at the beginning of the paper stated that science teachers need to strengthen subject knowledge. While a moderate level of subject knowledge may not be sufficient; it may provide momentum to increase teachers comfort level with science instruction and motivation to continue self-growth in science knowledge. The one-week PBL experience limited extensive subject knowledge because the time for self-study and reflection of content knowledge was short. The participating teachers' enthusiasm for science learning was satisfactory; thus continuation of the program to further build content knowledge is critical.

PBL assessment was not immune to the issues surrounding the alignment between “what’s learned” and “what’s taught”. During the Summer Institute 1998, the USC-CSP staffs carefully integrated an assessment component in the program—poster display and oral presentation. Both assessment approaches aligned with the educational reformist's ideas of performance assessment.

Performance assessment has been hindered by lack of participant buy-in, it is time and labor intensive and frequently loses momentum. Unless teachers receive ongoing and practical support for performance-based assessment, it is unlikely that they will integrate performance assessments into their daily instructional practice. If performance assessment were omitted from the PBL classroom; teachers would likely return to the paper-and-pencil test mode which aligns poorly with PBL and inquiry ideology. While a good multiple choice assessment can help teachers evaluate students learning the literature reveals that it is insufficient for helping teachers understand students' abilities as scientific investigators.

Implications

We conclude that the PBL approach was successful and comprehensive in designing future professional development workshops for science teachers. The implications of this study are two-fold. In order to assist teachers to develop high standards of subject knowledge the PBL approach requires a more extensive period of time. We also believe that the support for performance-based assessment for science teachers must be integrated into the teaching profession.

Lastly, a PBL professional development program as described here offers a model to assist science teachers in offering high quality and standards-based science instruction. However, we believe that further research needs to be conducted regarding how to deepen science content knowledge and knowledge of PBL assessment design.

Acknowledgement

The completion of this study owed a great deal to the USC-CSP Leadership Cohort. Without their input in the project implementation and 1998 PBL Summer Institute design, this study will not be possible. We have learned so much from working with them. In addition, we would like to thank Dr. Shuler for his enlightened and perceptive comments for the analysis, and we in debt a lot to his expertise in PBL.

References

- Albanese, M., & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. Academic medicine, 68 (1), 52-81.
- American Association for the Advancement of Science. (1993). Benchmarks for science literacy. New York: Oxford University Press.
- Ball, D. L. (1988) Research on teaching mathematics: Making subject matter knowledge part of the education. In J. Brophy (Ed.). Advances in research on teaching, Vol(2). Greenwich, CT: JAI Press.
- Checkley, K. (1997). Problem-based learning: The search for solutions to life's messy problems. In the newsletter of the Association for Supervision and Curriculum Development (ASCD), Summer Issue. Alexandria, VA: ASCD.
- Glasgow, N. A. (1996). New curriculum for new times: A guide to student-centered, problem-based learning. Thousand Oaks, CA: Corwin Press.
- Hall, G.E., & Hord, S. M. (1987). Change in schools: Facilitating the process. New York: SUNY Press.
- Hashweh, M. (1987). Effects of subject matter knowledge in the teaching of biology and physics. Teaching and teacher education, 3, 109-120.
- Howe, A. C., & Stubbs, H. S. (1996). Empowering science teachers' A model for professional development. Journal of science teacher education, 8(3), 167-182.

Jones, B. F., Rasmussen, C., & Moffitt, M. (1996a). Real-life problem solving: A collaborative approach to interdisciplinary learning. Washington DC: American Psychological Association.

Jones, B. F., Rasmussen, C., & Moffitt, M. (1996b). Transformations: High school reform to promotes student performance. Oak Brook, IL: North Central Regional Educational Laboratory; and Waukegan, IL: Waukegan School District. Sponsored by the Illinois State Board of Education.

Joyce, B., & Showers, B. (1987). Student achievement through staff development. New York: Longman.

National Foundation for the Improvement of Education. (1996). Teachers take charge of their learning: Transforming Professional Development for student success. <http://www.nfie.org/takechar.htm>.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.

Neufeld, V. R., and Barrows, H. S. (1974). The “McMaster philosophy”: An approach to medical education. Journal of medical education, 49 (11), 1040-1050.

Pursuing Excellence (1997a). A study of U.S. eighth- grade mathematics and science teaching, learning, curriculum, and achievement in international context. NCES 97-198 (U.S. Government printing office, Washington, DC.)

Pursuing Excellence (1997b). A study of U.S. fourth-grade mathematics and science teaching, learning, curriculum, and achievement in international context. NCES 97-255 (U.S. Government printing office, Washington, DC.)

Pursuing Excellence (1998). A study of U.S. twelfth-grade mathematics and science teaching, learning, curriculum, and achievement in international context. NCES 98-049 (U.S. Government printing office, Washington, DC.)

Schmidt, W. (in press). The role of content in defining teacher quality: Implications from TIMSS regarding professional development. Paper is accepted by Science for publication.

Schwab, J. J. (1962). The teaching of science as enquiry. In J.J.Schwab & P.F. Brandwein (Eds.). The teaching of science. pp. 3-103. Cambridge: Harvard University Press.

Shuler, C., & Fincham, A. G. (1998). Comparative achievement on National Dental Board Part I between dental students in problem based learning and traditional educational tracks. Paper accepted for October issue of the Journal of dental education.

Wang, H.A., Thompson, P., & Shuler, C. (1999). Effects of problem-based learning as applied to the professional development for science teachers. Paper presented at the 1999 AETS Annual International Meeting at Austin, Texas

Wang, H.A., Thompson, P., & Shuler, C. (1998a). Essential components of problem-based learning for the K-12 Inquiry Science Instruction. Article submitted to the California science teacher association journal.

Wang, H.A. (1998b). A qualitative study of the PBL dental clinic at USC. Journal of dental education, 62 (9), 660-665.

Wang, H.A., & Marsh, D. D. (1998). Curriculum Conception: Pathways to Standards-Based Science Education Reform. Paper submitted to School Mathematics and Science.