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NASA Enriched Collaborative STEM Teacher Professional Development Institutes within the California State University System
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Abstract

The State of California must remain a leader in science, technology, engineering and mathematics (STEM) education to maintain its competitive edge and economic vitality. The California State University (CSU) system has a long-standing commitment to providing a quality education to its diverse student population. The CSU recognizes the urgency to increase the STEM talent pool for California.

A research review on teacher quality and student achievement from the Center for Public Education (November 2005) states that more than two decades of research findings are unequivocal about the connection between teacher quality and student learning. The CSU is a leader in teacher preparation programs and issues the largest number of new preliminary teaching credentials in the State. Sustained teacher professional development is a path to increased teacher quality.

This paper presents a study conducted on CSU-NASA/JPL Collaborative Teacher Professional Development Institutes located at: California Polytechnic State University San Luis Obispo; CSU Fresno and CSU Bakersfield. The three institutes implemented unique practices based on trial and error, past experiences, and institutional learning. The best practices from each of these institutes and the collective wisdom of their directors are drawn out in this paper. A potential model is proposed as a framework for other campuses and institutes to consider implementing.

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Introduction

Recent reports such as "Rising above the Gathering Storm" (2007) and "Critical Path Analysis of California's Science and Mathematics Teacher Preparation System" (2007) clearly show a critical link between science, technology, engineering and mathematics (STEM) education and United States' economic competitiveness and growth. This critical link has been well documented for decades and recent reports have shown the United States losing ground in the fields of science and engineering.

Science and math are the foundation for engineering and technology careers. Many experts have warned of an impending crisis in the STEM fields. One of the recommendations of the "Rising above the Gathering Storm" report was to "Increase America's talent pool by vastly improving K-12 science and mathematics education." There were three implementation actions given for the aforementioned recommendation: 1. Increase recruitment of science and math teachers, 2. Strengthen the skills of teachers through training and education programs, and 3. Enlarge the pipeline of students who are prepared to enter college and graduate with a degree in STEM.

There are several ways to address the declining STEM talent pool. The "No Child Left Behind Act" (NCLB) of 2001 attempts to help children reach high academic standards by requiring that every class is taught by a "highly qualified teacher." NCLB requires academic achievement of every student in every school. As teacher quality is now understood to be the greatest predictor of academic success, it follows that teacher professional development is a means to increase teacher quality.

Teacher professional development can improve classroom instruction and student achievement when it focuses on teacher knowledge of the subject matter, how it is conveyed to students and how students understand and learn from it.[1] This paper presents and analyzes three NASA Enriched Collaborative STEM Teacher Professional Development Institutes. The collaborative institutes were each located at three different California State Universities: Cal Poly, San Luis Obispo, CSU Fresno, and CSU Bakersfield. The focus of this paper is to highlight the critical components, extract the best practices from the three institutes and propose a potential model as a framework for other campuses and institutes to consider implementing.

Background

California's public education system has undergone unprecedented change over the last decade. The state's standards-based reform movement has transformed the focus and goals of public education, challenged schools to set higher expectations for all students, and holds everyone from superintendent to students responsible for academic performance.[2]

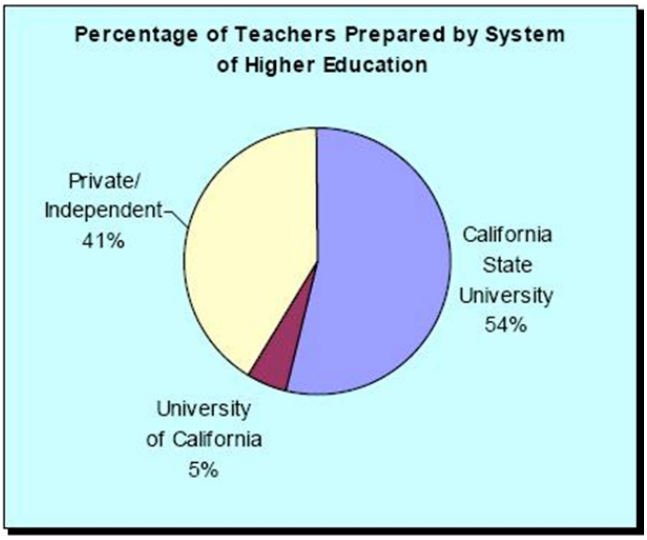
California's teacher workforce is the largest in the country with more than 300,000 teachers serving a student population of over six million. Yet, California continues to experience severe shortages of qualified teachers for specific teaching assignments, such as math and science. The California State University (CSU) system is the largest producer of teachers, and awards the largest number of bachelor degrees in California. In 2005-06, the CSU system issued 12,036 new preliminary teaching credentials, independent institutions issued 9,284 new preliminary teaching credentials, and the University of California (UC) system issued 1,099 new preliminary teaching credentials. The number of teaching credentials issued by various California University Systems for the fiscal year 2005-2006 is shown in Figure 1.[3]

Figure 1. 2005-06 Teaching Credentials Issued By California University Systems

Fiscal Year 2005-06

University System	New Teachers	Percent
California State University	12,036	54%
University of California	1,099	5%
Private/Independent	9,284	41%
Totals	22,419	100%

Source: CTC Teacher Supply Report, April 2007



The CSU system, consisting of twenty-three campuses, conferred 69,350 bachelor's degrees in 2005/2006.[4] The UC system conferred 41,640 bachelor's degrees in 2005/2006.[5] The CSU system recognizes its critical role in educating California's diverse student population and understands the urgency to increase the STEM talent pool, as California's world-class leadership economically and technologically is dependent on a highly skilled STEM workforce. The CSU Chancellor's Office has been very supportive of STEM Teacher Professional Development Institutes within the CSU system. The CSU Chancellor's Office strongly supports advancing and promoting the scholarship of teaching and learning science for California's faculty, K-12 teachers and K-12 administrators via the Science Education Community portal (http://teachingcommons.cdl.edu/sec/).

Industry directly benefits from a skilled STEM talent pool and has become an active partner in fostering STEM professional development in education. The California Space Education and Workforce Institute[6] (CSEWI) works with parents, educators and students to foster STEM education. Its parent organization, the California Space Authority[7]

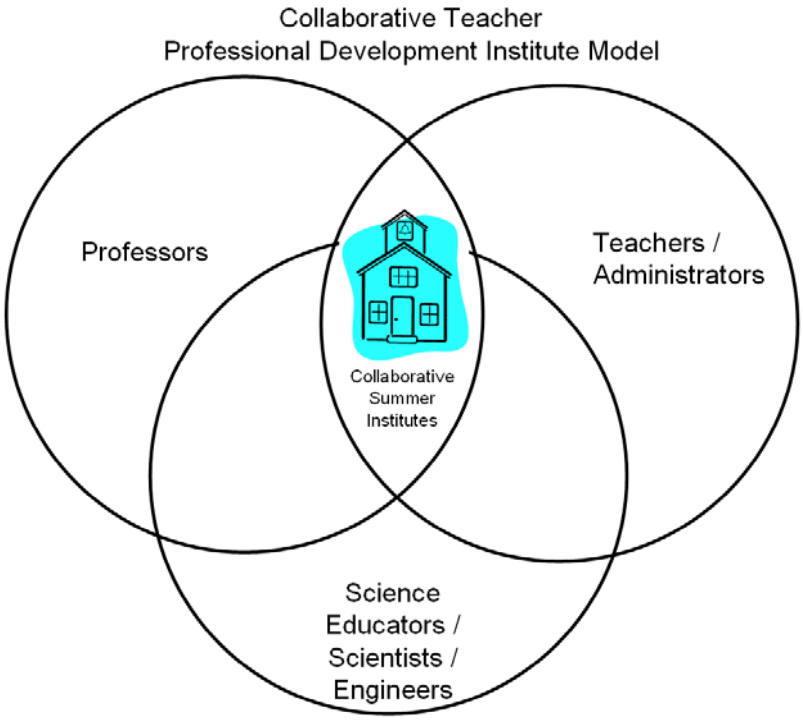
(CSA), is an organization of space-related companies, entrepreneurs, government agencies, and academic research programs. CSA recognizes the critical link between education and our nations' competitiveness. CSA, along with the California Space Education and Workforce Institute (CSEWI), sponsored this STEM teacher professional development institute study as part of their commitment to facilitate California's competitiveness by engaging stakeholders in California-based space-related education and attracting, integrating and retaining a robust California space workforce. National Aeronautics and Space Administration (NASA) is one of many agencies and industries dependent on a highly skilled science and technology workforce requiring United States citizenship of its employees. NASA employs 18,000 workers nationwide and has three of its ten NASA research centers located in California. NASA recognizes the importance of increasing the STEM talent pool, as it is critical to achieving NASA's and the nation's long-term space exploration vision.

The NASA/Jet Propulsion Laboratory (JPL) center located in Pasadena, California is fully committed to supporting STEM education in California. NASA/JPL has established a CSU-NASA/JPL Education Collaborative with a focus to increase the availability and quality of STEM education for current and future teachers of California. In support of this goal, NASA/JPL has partnered with the CSU for seven years to establish CSU-NASA/JPL Collaborative Teacher Professional Development Institutes. Dr. Parvin Kassaie, Manager of the JPL Education Office and Dr. Susan Robb of the CSU Chancellor's Office of Teacher Professional Development initiated the CSU-NASA/JPL Collaborative. Dr. Kassaie continues to be the director of the Collaborative. Dr. Arthur Hammon, Elementary/Secondary Education Specialist at JPL facilitated an initial workshop for CSU faculty at the Chancellor's Office and all three of the NASA/JPL summer institutes.

Cal Poly, San Luis Obispo-NASA/JPL Institute

The Cal Poly-NASA/JPL collaborative institute was an inquiry-based, hands-on, one-week long, teacher professional development institute that covered the earth science topic of "Water in the Solar System." Twenty-five in-service K-12 teachers with diverse backgrounds attended the institute. Approximately twenty-five hundred students per year will potentially benefit from the teacher professional development. The topics covered during the institute were relevant to the California Science Standards for grades three through twelve. The institute was co-led by a Cal Poly physics professor, Dr. John Keller and a JPL science educator, Dr. Art Hammon. In this institute, significant effort was dedicated to team building, and creating a positive learning environment with the teachers. The teachers worked in teams and utilized problem-solving games, which were readily transferable for use with their students. A Collaborative Professional Development Institute Model was the foundation for shared teaching and learning during the institute, as shown in Figure 2.

Figure 2. Collaborative Professional Development Institute Model



The key goals of the "Water in the Solar System" institute were to provide teachers with science content and hands-on, inquiry-based classroom activities that were connected to the California Science Standards. The institute provided focused discussions on science content, literacy, and lesson studies. The NASA/JPL science material is an outcome of actual NASA missions; therefore, participants can connect science content to meaningful science applications and begin to see themselves as teacher scientists in their own classrooms.

The Central Coast Science Project[8] (CCSP) has focused its efforts in the Santa Maria and Guadalupe school districts, where there is a highly disadvantaged student population. Prior to and subsequent to the summer institutes, the CCSP has interacted with teachers and administrators from these school districts by offering four hours of intensive professional development once a month during the school year. These continuous institutes provide a process for establishing a stronger and more sustainable partnership between Cal Poly professors and in-service educators. Follow-up meetings with the teachers during the academic year are based on the lesson study methodology, which aids in the development of a research-based professional learning community in the teaching and learning of science.

The NASA/JPL Educational Collaborative provided in-kind support to Cal Poly's institute by providing NASA educational curricula and resources, such as access to JPL scientists and engineers during the institute. The specific curriculum covered was a unit

entitled, “Water in the Solar System.” This collaborative institute was held in conjunction with four other inquiry-based science institutes supported by the Central Coast Science Project (CCSP), directed by Dr. Lola Berber-Jimenez at California Polytechnic University in San Luis Obispo. Funding and in-kind support for the summer 2007 institutes was provided through the California Science Project (CSP), the Math and Science Partnership (CaMSP), and the Teacher Retention Initiative (TRI). A stipend and university course credit was made available to participants.

CSU Fresno-NASA/JPL Institute

The third annual NASA/JPL collaborative institute, held at CSU Fresno (Summer 2007) and facilitated by the Science and Mathematics Education Center under the direction of Dr. David M. Andrews, was a hands-on, guided, inquiry-based, two-week, teacher professional development institute which covered the topic of “Modeling Physical Science.” The program was based upon the modeling approach to teaching science developed by David Hestenes at Arizona State University. The Hestenes modeling approach has a solid reputation as an effective pedagogical approach for teaching the physical sciences.[9] The Science and Mathematics Education Center housed under the College of Science and Mathematics has sponsored Modeling workshops since 2001. Previous summer institutes in collaboration with NASA/JPL examined Physical Oceanography (2005) led by CSU-F faculty Dr. Steve Lewis and Planetary Geology (2006) led by CSU-F faculty Ms. Kerry Workman-Ford. Twenty-five fourth through eighth grade teachers, both pre-service and in-service, and several administrators participated in the summer 2007 institute. Approximately, fifteen hundred students per year will potentially benefit from the teacher professional development.

The topics covered during the institute were relevant to the California Science Standards for grades four through eight and the hands-on activities were grounded in research-based practices designed to enhance teacher effectiveness. A team representing the CSU, JPL and the local school district led the institute. Two School District faculty, Ms. Jean Pennycook, of Fresno Unified School District and Mr. Paul Lake, of Clovis Unified School District delivered the science content with Paul Lake taking the lead as the content and Modeling expert. Dr. Arthur Hammon of Jet Propulsion Laboratory brought the JPL Scientists and NASA education resources to Fresno. Ms Pennycook helped in assuring that connections were made to the classroom. The Collaborative Professional Development Institute Model, previously shown in Figure 2, was the foundation for shared teaching and learning during the institute.

The key goals of the “Modeling Physical Science” institute were to engage teachers in conceptual development through modeling best practices while providing NASA materials, use of technology for lesson plan development and hands-on, inquiry-based classroom activities that were connected to the California Science Standards. A NASA/JPL website, the NASA Curriculum Standards Quilts (http://quilt.jpl.nasa.gov/) was introduced as a peer-reviewed search engine to search and find NASA curricular

materials, organized by education standards. Middle school physical sciences curricular resources were provided for a full year course.
The Central Valley Science Project recruited eighteen of the twenty-five science teachers from the Fresno Unified School District and the remaining 28% from other districts within the area. A stipend and university course credit was made available to the participants. Some of the school districts used their professional development funds to directly support registration fees for teachers enrolled in professional development provided by the institute.

The NASA/JPL Educational Collaborative supported CSU Fresno's institute by providing NASA educational curricula and resources for the institute, such as visits to Fresno by JPL scientists and engineers during the institute. Funding and in-kind support for the summer 2007 institute was provided through the California Science Project (CSP), under the Director of Dr. Jim Marshall, and the CSU-NASA/JPL Education Collaborative. Support for past Science and Mathematics Education Center/NASA/JPL summer programs at Fresno has come from the National Science Foundation, the CSU Chancellor's Office, and of course JPL and NASA. Another program is planned for summer 2008 in conjunction the Science and Mathematics Education Center's NSF-funded Noyce Scholars II program.

CSU Bakersfield-NASA/JPL Institute

The second CSU Bakersfield-NASA/JPL collaborative institute called "We Know From Evidence: As Only NASA Can!" was a hands-on, three day teacher professional development institute focused on developing a deep understanding of science through the use of web-based NASA Mission content and resources, while simultaneously creating exemplary science lesson modeling via MERLOT[10] (Multimedia Educational Resource for Learning and Online Teaching). MERLOT is a leading edge collection of peer reviewed online learning materials shared by an online community. Thirty-seven pre-service and in-service K-12 teachers and four school district administrators participated in the institute. Approximately three thousand students per year will potentially benefit from the teacher professional development.

The key goals of the CSU Bakersfield Institute were to engage teachers in exploring the NASA Mission resources, provide best instructional practices for the teacher scientist to successfully apply the NASA resources in the classroom, and to offer two online technologies, MERLOT and Cabrillo,[11] for future classroom curricula development.

The topics covered during the institute were relevant to the California Science Standards for first through twelfth grades and the hands-on tutorials on technologies were designed to support the teaching scientist to successfully apply the NASA resources in the classroom. CSU Bakersfield also used the Collaborative Professional Development Institute Model, previously shown in Figure 2, as the foundation for shared teaching and learning during the institute. Both Bakersfield institutes were co-led by Dr. Stefanie Saccoman (CSU-Pomona) and Dr. Arthur Hammon (NASA/JPL science educator) who

delivered the science content, JPL scientists, with assistance of a teacher, Mr. Troy Tehnet from the local school district to ensure that connections were made to the classroom using the published learning objects in MERLOT. The participants were guided on how to develop and publish learning objects in MERLOT and were provided technical training for accessing the NASA Mission Content and resources. MERLOT is strongly supported by the CSU Chancellor's Office. MERLOT has created a variety of Community Portals to provide MERLOT members with resources to online teaching and learning. The CSU Chancellor's Office supports a Science Education Community portal that directly links to MERLOT (http://teachingcommons.cdl.edu/sec/index.html).

Unique to this institute, and central to participants' professional development, was a web-based communication and networking problem-solving system, Cabrillo, a collaborative framework for facilitating learning object development. Cabrillo was utilized as a tool for the teachers to address problems and provide working solutions to those problems as part of an on-line learning community.

The participants were recruited from local K-12 school districts and a stipend was made available to the participants. Immediately following the institute, a local elementary school hosted a two-week NASA Children's Science Program taught by institute participants using institute-developed hands-on activities.

The NASA/JPL Educational Collaborative supported CSU Bakersfield's institute by providing educational curricula and resources, such as a distinguished JPL scientist, Dr. Ross Salawitch, who presented his work on global climate change during the institute. Dr. Ron Hughes directed the institute at CSU Bakersfield. The Chevron Corporation and the CSU-NASA/JPL Education Collaborative provided major funding and in-kind support for the summer 2007 Institute.

Analysis

In studying the three different CSU-NASA/JPL Collaborative Institutes, there were some similarities and differences, as expected. In the study, it became clear that although NASA was a collaborator in all three institutes, the NASA resources were used quite differently in each institute depending on the needs of the participants. In this analysis, significant effort was dedicated to understanding the successes, challenges and sustainability of each institute, and then common themes were identified to leverage opportunities across institutes.

The similarities found among all three institutes were that the NASA scientists were very involved in the presentation of the materials and the NASA scientists/engineers were brought in to inspire and engage the teachers. At the conclusion of each institute, all participants received a certificate from NASA. The institutes all received in-kind support including NASA materials and resources worth thousands of dollars. The participants worked in a professional environment across grade levels and took on the role of teacher scientists during the investigations and discussions. All three institutes administered

daily surveys to gain feedback from the participants and made necessary modifications in response to the feedback.

The institutes all provided a positive environment for the teachers to develop a collaborative professional learning community as teacher scientists. All three institutes worked with local K-12 school district teachers and had some level of district administrator support. The overarching similarities between all three institutes were to provide rich science content, infuse best practices in teaching and provide professional development opportunities for teachers to continue collaboration beyond the institute. The Collaborative Professional Development Institute Model, previously shown in Figure 2, was fundamental in establishing an environment of shared teaching and learning during all three institutes. This model allowed all collaborators to equally share their knowledge and genuinely learn instructional best practices from each other.

Several differences were found among the three institutes: the program structure, length of the institute, target audience, implementation of the NASA materials, evaluation methods of desired outcomes, follow-up methods and funding sources. Each institute implemented the NASA materials, which were integrated into the program structure, recruited participants and varied the program length based on local needs. The evaluation methodology, follow-up methods and funding sources were unique for each institute, depending on the desired outcomes.

Cal Poly measured its goals through both formative and summative assessment techniques. A multiple-choice and open-ended written content survey was administered pre- and post- instruction to the participants. The open-ended questions were graded on a rubric. The pre-instruction mean scores were 55% correct and 35% correct for the multiple-choice and open-ended questions, respectively. The corresponding post-instruction mean scores were 73% and 68%, respectively. Normalized gains were calculated for each survey: 39% gain for multiple-choice and 54% gain for the open-ended section.

Cal Poly has future plans to study the effect teacher professional development has on student achievement in science. Cal Poly is taking an innovative approach to the academic year follow-up meetings with the institute teachers and is pioneering a lesson study methodology based on Dr. Catherine C. Lewis' research. Lesson study is an approach to instructional improvement based on careful observation of students and their work. Lesson study places teachers in an active role as researchers. In lesson study, teachers work collaboratively using an ongoing methodology to increase student learning and develop long-term goals that support continuous improvement in instructional strategies. Lesson study is a process, not an event, and its long-term goals emphasize both social and academic development as a foundation for life-long learning for both teachers and students. The lesson study process is flexible, dynamic and responsive to student needs. Lesson study provides a powerful mechanism for system-wide improvement of education. Grants were the major funding source for Cal Poly's institute, and two years of grant funding remain.

CSU Fresno assessed their goals based on pre- and post-instruction testing as well as daily reflections and end of program evaluation. The majority of teachers who attended the Modeling Physics Institute indicated that their desired outcomes from the institute were to enhance their science content knowledge and expertise in instructional strategies. An evaluation at the conclusion of the institute was used to determine the institute's strengths and areas for improvement based on teachers' feedback. Due to funding constraints, a formal follow-up program has not been conducted during the academic year with institute participants. However, many of the in-service teachers who attended the institute serve as Mentor Teachers to pre-service teachers in the Early Field Experience program, and these in-service teachers have employed into their own classroom settings many of the strategies learned at the institute. As teachers may make contributions to the MERLOT online learning community during the academic year, it provides a potential source of information on how teachers are implementing into their classrooms the learning gains from the institute. Grants were the major funding source for the institute, and funding is not predictable, as it is granted one year at a time.

CSU Bakersfield took a different approach in assessing the goals of the institute since their institute was not focused on one specific science topic. Rather, it was focused on exploring a variety of web-based NASA Mission content to enhance the classroom learning experience for all teachers. To this end, some of the participants were interviewed and asked to identify their concerns about classroom teaching. These interviews were recorded on a pod cast located at: (http://www.professional-educator.com/POD.html) which allowed participants to voice their concerns in a safe environment. Participants were surveyed daily and modifications were made in response to their comments. This institute was only three days long, therefore, it was anticipated that participants develop and publish learning objects in MERLOT during the academic year. For example, five summer institute participants have published learning objects on MERLOT concerning the NASA Reading, Writing and Rings curricular materials, which were introduced at the institute. It was also anticipated that participants would stay connected during the academic year as part of an on-line learning community via the web-based communication and networking problem-solving system Cabrillo. Due to the unanticipated level of work that would be required to support Cabrillo, the institute leaders are seeking additional funding to support the time and effort required to sustain the communication and networking throughout the academic year. The Chevron Corporation was the primary funding source for this institute and has committed to funding the institute for at least two additional years.

A summary table of best practices used at each institute is shown in Table 1.

Table 1. Summary of Practices By University

Summary of Teacher Professional Development
Collaborative Institute Practices

University	Key Goals	Evaluation Methods	Continuing Professional Learning Community Methodology
Cal Poly SLO	•Enhance Science Content, Literacy and Lesson Studies •Hands-on Inquiry-Based Classroom Activities Connected to CA Science Standards	•Pre and Post Content •Teacher Daily Reflections •End of Program Evaluation •Lesson Study Follow-up Surveys	•Monthly Follow-Up Meetings and Biannual Conferences Using a Research-Based lesson Study Methodology
CSU Bakersfield	•Engage Teachers in Exploring NASA Mission Resources •Establish Best Practices for Teacher Scientists in Using NASA Materials •Offer New Online Technologies for Curricula Development	•Teacher Daily Reflections •Cabrillo * •MERLOT ** •Recorded Interviews	•MERLOT •Cabrillo
CSU Fresno	•Engage Teachers in Physical Science (Hestenes) Modeling Methodology •Establish Best Practices for Teacher Scientists in Using NASA Materials •Provide Resources for Developing Hands-on, Inquiry-based Science Curricula	•Pre and Post Content •Teacher Daily Reflections •End of Program Evaluation	•MERLOT

* Cabrillo (Web-based communication and networking, problem solving system)
** MERLOT (Multimedia Educational Resource for Learning and Online Teaching)

Successes, Challenges and Sustainability

In this analysis, it is important to understand that each institute was asked to share insights about their successes, challenges and sustainability for the separate institutes and then common themes were identified to leverage opportunities across institutes.

One common successful aspect of these institutes is their existence as a collaborative effort between faculty, NASA scientists/engineers, K-12 teachers and school administrators, where a Collaborative Professional Development Model, as previously shown in Figure 2, facilitated a genuine environment of shared teaching and learning among all participants. These institutes represent a unique collaboration between a NASA research center and the CSU in reaching pre-service and in-service teachers. A second common theme is that research-based pedagogy, best practices in teaching were embedded in the entire process. A third theme is that the institutes provide rich NASA science content, a supportive, safe environment for the teacher scientist to explore,

contribute and exchange knowledge collaboratively with other professionals, thus providing professional development opportunities for teachers to continue collaboration beyond the institute. These institutes provided participants with an interactive, supportive learning environment, as teacher scientists with subject matter competence, working with real NASA science applications and the opportunity to collaborate and leverage NASA scientists' expertise. The overall benefits that schools and districts gained from participants who attended the institutes were: empowered teacher scientists, creative problem-solvers and life-long learners.

The major common challenge for all institutes was sustainable, long-term funding. The other most common challenges included limited financial support from institutes of higher education (IHE), limited advanced planning without secure funds, difficulty recruiting fee-based students and somewhat limited district administrator support. The potential funding solutions suggested were: partner with CSU Chancellor's Office to develop a unified long-term funding strategy plan and access to potential funding sources, fund institutes with registration fees or school district funds, develop a long-term partnership with industry for and, if fee-based, provide a credible curriculum such as NASA materials to attract participants.

A major theme for sustainability is the constant struggle in securing funding from grants and industry. Due to a lack of continuous, coherent funding sources, it is difficult to plan even a year in advance. Recruiting teachers to attend the summer institute needs to happen a year in advance, yet it is difficult to recruit teachers without consistently available funds. The other common sustainability themes were the need to leverage resources, share lessons learned, best practices via increased awareness and communications about these collaborative institutes, and the possible creation of "NASA" teachers that industry and business would support for the continued advancement in science education. Increasing awareness and communications using the Internet to build a media outlet about these institutes provides a powerful mechanism for system-wide improvement of professional development institutes where it is important to be flexible, dynamic and responsive to teachers' practices and student learning.

The common themes and leveraging opportunities across institutes were in-kind support for use of facilities and technology infrastructure. IHE provided a venue to hold the institute, but actual funding for professor stipends and materials had to be raised via external sources. Institute best practices and lessons learned could be easily shared among the three institutes. Early funding allows for early recruitment of teachers and more teacher-need-based institutes, thus increasing the success of each institute.

Initially, the CSU-NASA Collaboration focused on pre-service programs. Attendance by pre-service teacher students has represented only 10% of the total teacher population at the summer institutes. It is hoped that this percentage could grow in the future; given the difficulties these students have with the need to hold summer jobs and the intense time commitment of the institutes.

Recommendations

Based on this analysis, the Collaborative Teacher Professional Development Institute Model, previously shown in Figure 2, was used as a foundation for all three institutes and facilitated an open environment for shared teaching and learning for all participants as well as the development of a professional learning community beyond the life of the institute. This Collaborative Model was very effective in engaging teachers as scientists, focusing on content and pedagogy and embedding opportunities for practice, feedback and reflection during the institute. Therefore, the Collaborative Professional Development Institute Model contains critical characteristics that are likely to have the greatest impact on practice. The Collaborative Model is recommended as a best practice and is available for other professional development institutes to consider implementing. Currently, most teachers have no access to this kind of collaborative professional development institute, making it an opportunity for state and district teacher improvement plans to seek out effective professional development institutes, such as these found in this study.

The critical elements and best practices of a high quality collaborative teacher professional development institute model as found from this study are:

- High quality curriculum
- Sustained professional development
- Materials support
- Administrator support (K-12 and IHE)
- Assessment and evaluation

The curriculum materials provided by NASA are high quality science content rich and are based on actual NASA missions. Therefore, teachers using the NASA materials can relate their subject knowledge to real world applications, enabling the teachers to see themselves as teacher scientists. The teacher scientist then brings deeper science content knowledge and richer experiences into the classroom that can increase student learning.

It is critical to have sustained professional development for continuous learning to occur, as one model provided, by offering four hours of intensive professional development once a month during the school year. The recommended “lesson study” methodology aids in the development of a research-based professional learning community in the teaching and learning of science. As previously mentioned, lesson study is a process, not an event, and its long-term goals emphasize both social and academic development as a foundation for life-long learning for both teachers and students. The lesson study process is flexible, dynamic and responsive to student needs. Lesson study provides a powerful mechanism for system-wide improvement of education.

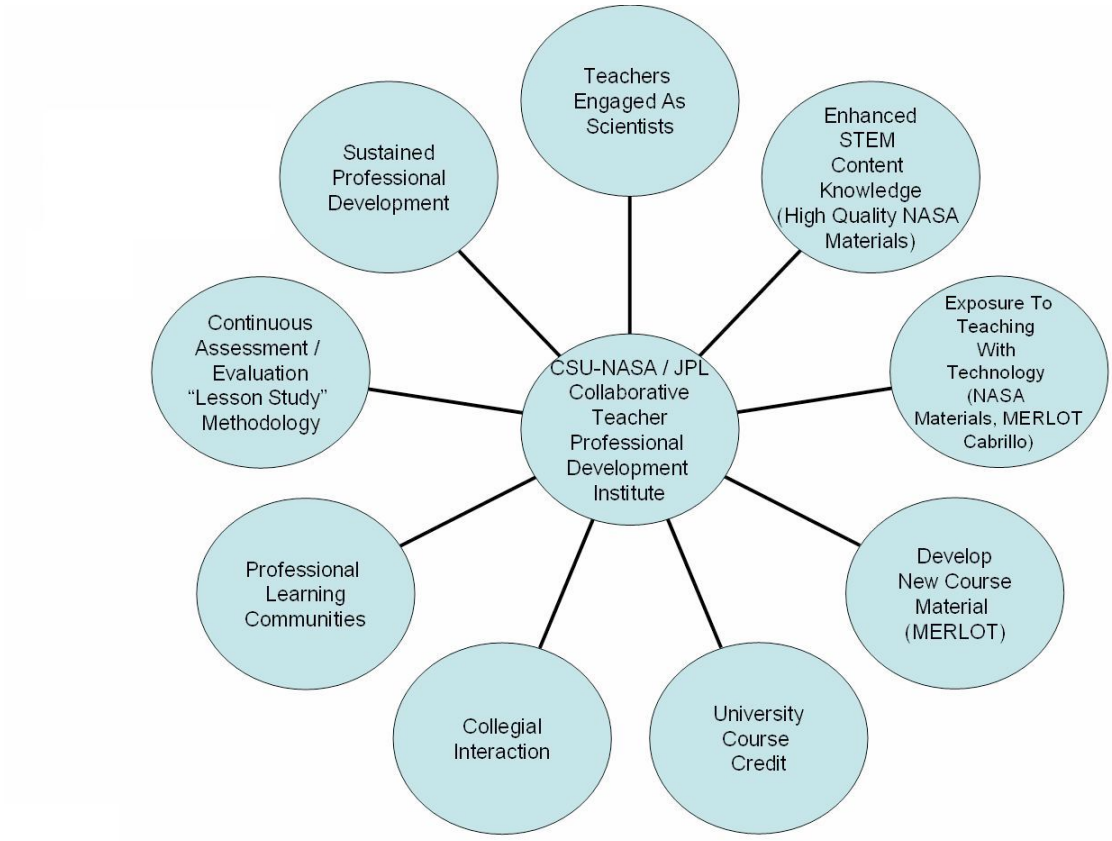
Another important component is the availability and support for the materials used in the classroom. NASA materials are teacher developed, aligned with national science and language education standards, and are available, copyright free, at no cost. There are a large number of online materials and tutorials available from NASA. There are also

many MERLOT peer reviewed online learning materials created by classroom teachers. MERLOT provides an opportunity for teachers to publish their lesson plans online, receive feedback from their peers, to develop collections of valuable resources, and make contributions to a growing digital library. MERLOT also supports an online professional learning community from around the world.

Supportive school administrators are crucial to ongoing teacher professional development. Also critical is the support provided by the institutes of higher education. A supportive infrastructure is essential in creating an environment that fosters the teacher scientist role and values life long learning in the teaching profession.

The Collaborative Model discovered in the process of this study is supported by important elements and best practices that become a system. Through reviewing common processes, an implementation model emerged for future professional development and is recommended as a framework for other campuses and institutes to consider implementing, as illustrated in Figure 3.

Figure 3. CSU-NASA / JPL Collaborative System



Assessment and evaluation can occur in many forms and are important to understanding teacher knowledge and student learning. The three institutes covered in this study used various ways in which to assess and evaluate their results. It is clear that pre and post content surveys do provide data on what was learned during the institute. This is only one measurement of teachers' knowledge. More importantly is how that knowledge translates to student learning. Using the "lesson study" methodology as a dynamic, responsive process in continuously assessing and evaluating student learning will build a solid framework in STEM education. In lesson study, teachers work collaboratively using an ongoing methodology to increase student learning and develop long-term goals that support continuous improvement in instructional strategies. Most importantly by using the lesson study methodology, teachers work collaboratively as change agents who become internally driven and are constantly adapting their instructional strategies and finding new ways to increase student learning.

Lesson study also serves as a foundation for sustained professional learning communities providing opportunities to deepen subject matter knowledge, improve instructional knowledge, increase collegial learning and share lesson plans that can lead to increased student learning. In addition to face-to-face delivery as in lesson study, online collaboration provides a venue for thinking about and reflecting on teaching and student learning. The use of a web-based communication tool such as Cabrillo/Professional Educator as another means for communication and networking can be important in providing the sense of presence, ownership and the personal-social connection needed for teachers to work with colleagues after the summer institutes have ended and the school year has begun.

Conclusion

Lastly, it is imperative that California remains a leader in science, technology, engineering and mathematics (STEM) education to maintain its competitive edge and economic vitality not only for California but also for the nation. California and the CSU system are well positioned to make positive contributions both in the teacher preparation programs and the STEM teacher professional development. A highly effective teacher workforce is crucial to increasing the STEM talent pool. Empowered teachers who are change agents can make a difference in the educational system. Our educational system can no longer afford to wait for change to occur, it must take immediate action. The teacher professional development recommendations from this study such as: a Collaborative Model, a CSU-NASA/JPL Collaborative System as the framework to implement, a lesson study methodology as a sustainable, continuous professional learning community and a supportive, committed infrastructure in both K-12 administrators and Institutes of Higher Education can serve as the foundation for transformational change of system-wide improvement in education.

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