Hands-On Science for Grades K-5: An Industry, School, University Collaboration

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Abstract:

The Penn-Merck Collaborative for the Enhancement of Science Education is a five year teacher enhancement program, underwritten by the National Science Foundation, that uses a multifaceted approach to make science a fundamental, exciting and successful part of the education of urban, minority, elementary school children. The Collaborative was formed in recognition that reforming science education requires active, long-term partnerships among industry, schools and universities. As such, the Penn-Merck Coll aborative brings together Merck and Co., the world's largest pharmaceutical company, 25 elementary schools in Philadelphia, the nation's fifth largest city, and their neighbor, the University of Pennsylvania, a major research university with a commitment to urban education. Multiple, additional partnerships within this broad collaborative work together in a program of mutual benefit and support. The program addresses four aspects of science education: 1) hands-on science in the classroom, 2) integrated science and language arts curricula, 3) teacher leadership in science education, and 4) pursuit of science careers by children from under-represented groups. To focus these efforts, teams of teachers participate in a thirteen month cycle of activities, comprised of a year-long graduate seminar framed by two summer institutes. Their work is guided by University faculty and master classroom teachers, supported through activities designed by undergraduate engineering students, and enhanced through interaction with Merck scientists and engineers. This approach not only broadens teachers' knowledge of science concepts and instructional strategies, but also forms the basis for their role as change agents and mentors for other teachers at their schools.

Needs and Goals

In recent years, educational policy makers, researchers and practitioners have been investigating effective approaches to developing the science literacy skills that today's students require for a changing world [1]. Of particular concern is the fact that women and minorities, who are rapidly becoming the majority of new entrants into the labor force, are dramatically under-represented in the fields of science and technology [2]. While there are complex cultural, social and economic reasons for this under-representation, it is not likely to change without systemic and holistic educational intervention beginning in the earliest grades.

Children enter school with an active interest in themselves and the world around them. However, instead of

encouraging exploration of the natural and physical world, science education too often consists of memorizing a series of facts from textbooks. The challenge facing elementary educators is to develop approaches that build on the curiosity and questions of children-approaches that nourish their interest and excitement, provide the foundation for further science study and build an enthusiasm for science that will extend throughout their lives.

Penn-Merck Collaborative Partners

Partner	Areas of Expertise	Contributions
University of Pennsylvania		
Graduate School of Education	Prof. development of teachers Language & literacy development Curriculum reform Teaching and learning processes	Princ. Investigators (Pica;Streim) Program design & curr. planning Program implementation Program evaluation
School of Engineering & Applied Science	Basic and applied science Hands-on laboratory learning Applications of technology	Curriculum planning Discovery labs Technical support
School of Veterinary Medicine	Basic life sciences Field-based clinical education Educational outreach	Curriculum planning Laboratory facilities Technical support
Merck Institute for Science Education	Prof. development of teachers K-12 science curriculum reform Corporate/school partnerships Science ed., resources & materials	Princ. Investigator (Parravano) Program design & curr. planning Science materials & computers Volunteers in classroom
School District of Philadelphia	Prof. development of teachers Inquiry-based science curriculum School reform	Program design & curr. planning Administrative & teacher support Linkages to broader USI

Figure 1

Current educational research provides compelling evidence that students learn best when they are actively engaged with ideas and materials that grow from their experiences and have meaning in their lives [3,4]. The School District of Philadelphia, like many school systems across the country, is moving from a model where teachers deliver information, to one where students actively construct meaning from their interactions with materials. Clearly, this approach to science education requires teachers who are competent and confident in their science knowledge and in their ability to use effective classroom strategies to engage children in the exploration and discovery of knowledge. Unfortunately, many of our elementary teachers lack adequate knowledge about science and confidence in their ability to teach science to their students. We have found that science often gets little attention in the elementary classroom. In contrast, many of our elementary

teachers are skilled at using inquiry-based approaches to teaching language arts. This has led us to pose the possibility that we might build on these strengths to help teachers improve science learning in the elementary grades.

The Penn-Merck Collaborative recognizes that classroom teachers are primary agents of curricular change [5,6]. For us, the key to improving science education lies in building teachers' enthusiasm for, and competence in, their role as science educators. We recognize further that sustained curricular change takes time, and cannot be accomplished through traditional, short term workshops. Success in transforming the science curriculum requires our commitment to helping teachers transform their educational practices. Toward these ends, the Penn-Merck Collaborative works toward accomplishment of three goals:

1. Improve the teaching of science through the development of a cadre of science leader teachers to serve as mentors and change agents in their schools.

2. Deepen and extend students' knowledge and understanding of science by integrating science learning with instruction in language arts.

3. Motivate students from historically under-represented groups to pursue further study and career selection in science and technology.

Meeting Needs through Collaboration

The Penn-Merck Collaborative brings together the complementary strengths and resources of Merck and Co., the University of Pennsylvania and the School District of Philadelphia. Several innovative partnerships underlie the Penn-Merck approach. These are shown in Figure 1.

Collaboration among three schools within a large, complex university is one of the unusual features of the Penn-Merck endeavor. The Graduate School of Education brings expertise in the areas of teacher enhancement, language and literacy learning, cross-disciplinary curricula and multicultural education. Faculty in the School of Engineering and Applied Science contribute content knowledge and experience with successful, innovative approaches to teaching novice and expert learners. The School of Veterina ry Medicine houses the Penn-Merck Summer Institute and provides the support of faculty and students for teaching the life sciences component of the curriculum.

Merck and Co., through the Merck Institute for Science Education (MISE), is both the co-founder and co-sponsor of the Penn-Merck Collaborative. The Institute is dedicated to improving K-12 education in science and math, with a particular commitment to elementary education. MISE staff bring extensive experience in staff development for teachers and knowledge about materials for elementary science education. The Merck Institute also operates a large volunteer program which builds linkages between corporate scientists and public school teachers.

As noted earlier, the School District of Philadelphia is undergoing major curricular change. Under the umbrella of an NSF Urban Systemic Initiative, the District has made a commitment to science, math and

technology education throughout the grades, inclu ding professional development for teachers. One significant strength of the Penn-Merck partnership is the extent to which school district leaders have embraced the Collaborative as a key component of the Urban Systemic Initiative.

Structure of the Penn-Merck Experience

The Penn-Merck Collaborative provides teachers with three interconnected professional development activities which occur over 13 months, reinforcing and building on one another. These activities are designed to enhance participants' teaching of science, and help them develop into a community of leaders in their schools. Since the Collaborative aims to respond to the needs of both teachers and students, all activities emphasize:

1. Helping children to learn by doing science and constructing their understanding of science concepts, content and procedures. Participating teachers develop strategies to help students develop critical thinking skills-to think like scientists-and to use speaking, listening and writing to extend and deepen their understanding of science.

2. Engaging teachers in the same types of hands-on learning, demonstrations, mentoring, problem solving and peer coaching that they will use in the classroom. This gives the participating teachers first hand experience as learners in an inquiry-based science curriculum, and a greater awareness of their students' needs.

3. Helping teachers reflect on the teaching and learning that goes on in their classrooms. The best teacher development programs lead participants to work together as professionals, redefine their roles in the schools and classrooms and examine their beliefs about the processes of teaching and learning [7, 8]. Encouraging teachers toward teamwork and collaboration provides the tools and self-confidence for continued professional development after their formal participation has ended.

4. Building a community of staff and administrators within the schools to sustain an active network for improvement. The Collaborative prepares teachers to promote mentoring, team teaching, experimentation with materials and analysis of teaching.

The sequencing of the program is shown in Figure 2. Teachers begin in the summer, with a three-week, hands-on Summer Institute held at the University. Participants work in teams, as well as in partnership with University faculty, engineering students and highly experienced master teachers from the School District. This intensive science and leadership experience is followed by a graduate-level, continuing education Science Seminar which meets during the academic year, on-site in the schools. A three-week advanced Summer Institute follows during the second summer. During the school year, participating teachers are paired with volunteer science mentors from Merck and the University's Engineering School. These partners make regular visits to the classroom where they assist teachers and serve as role models for students.

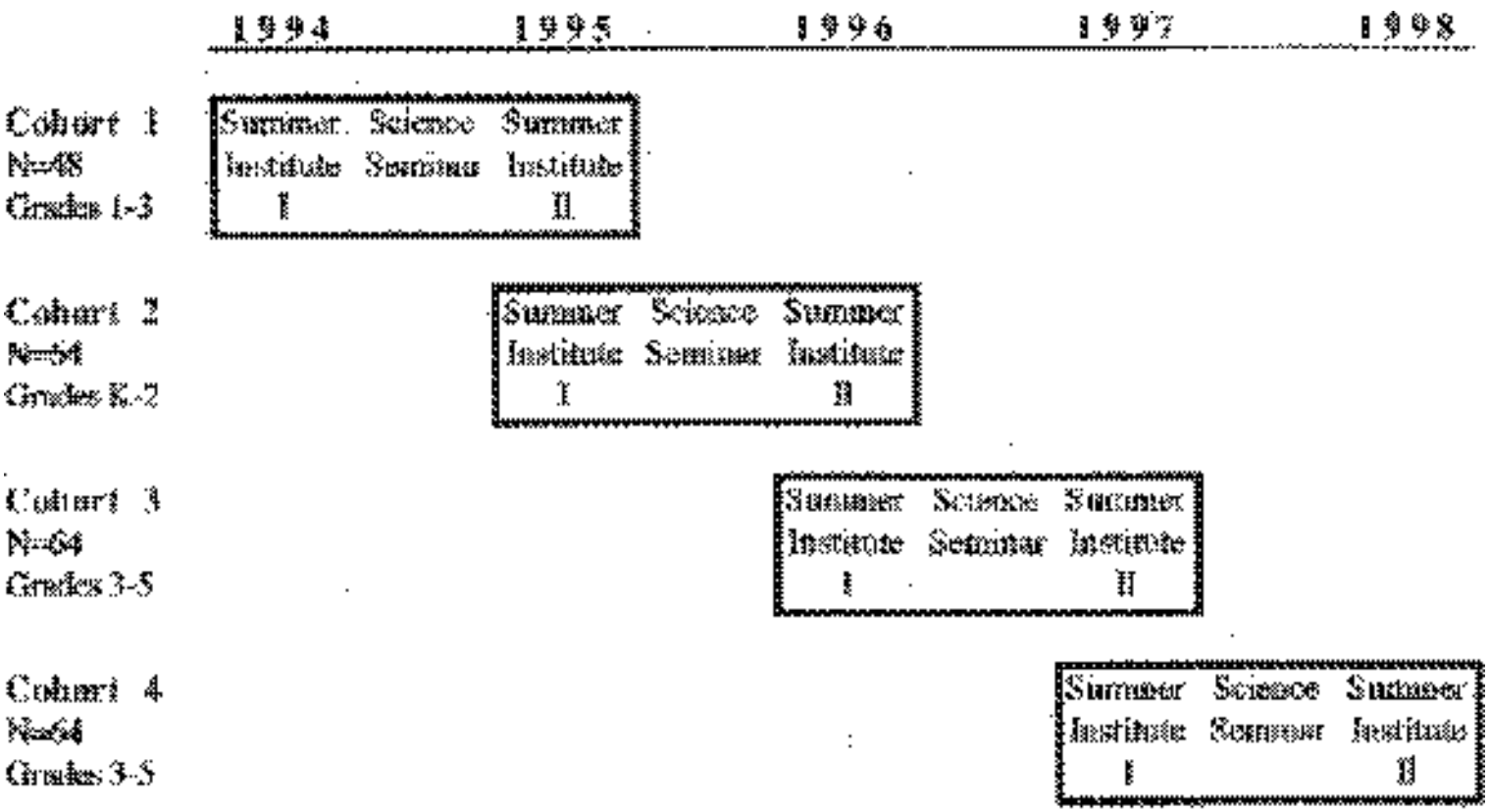

Figure 2

Contexts for Collaboration

Participants

Each year's cohort includes school teams made up of 4-6 classroom teachers and science specialists. Teams are recruited from the 25 elementary schools in the Collaborative's target area, which serve a predominantly poor, minority population. The Collaborative accommodates up to 64 teachers a year, all of whom must commit to participate in the 13 months of activities. Besides the school teams, other participants include volunteer scientists and professional staff from Merck, principals from participating schools and University engineering students.

Central to the program is the team of 6-8 master teachers who work alongside University faculty as facilitators in the Summer Institute and the school year Science Seminar. Master teachers are selected for their outstanding classroom teaching skills and staff development experience. They are key to the success of the Penn-Merck effort, because of their insiders' understanding of the context for teaching science in the school district. The Collaborative looks within the participating cohorts to identify new master teachers to include in this leadership group each year.

Summer Institutes

The first Summer Institute engages teams of participants in building a hands-on curriculum in the physical sciences. Topics include balancing and weighing, volume, sensory experiences, and chemical tests. In addition to these aspects of science content, equal weight is given to strategies for teaching basic scientific processes such as observation, inference, classification, hypothesis testing, measurement, and reporting.

All of the Institute activities are introduced through an inductive, constructivist approach to teaching and learning science [4,9,10]. Master teachers and University faculty model and guide participants as they explore a variety of teacher-made and commercial materials including science kits from the Science and Technology for Children (STC) and Franklin Institute Museum-to-Go series. Every team receives a set of these kits to have at their school. Participants also engage in specially designed Discovery Lab activities, created and implemented by undergraduate engineering students. These hands-on laboratory activities increase teachers' science knowledge through exploration of real-world science applications such as wiring a doorbell, and testing lung capacity with a spirometer. Throughout the Institute, teachers also learn how to integrate science activities into thematic units supported by language arts, to draw on community resources to enhance learning and to assess student learning using a varie ty of appropriate, performance based measures.

The Penn-Merck approach can be illustrated by the following example. For the Summer Institute unit on balance, teams of teachers first work through the exercises in the STC kit ``Balancing and Weighing'' which they will use in their classrooms during the year. Then we extend the kit activities with an exploration of simple machines. At a series of *challenge stations*, participants solve everyday problems involving gravity, balance and force. At one station, teams are challenged to design a pulley system to lift a bucket of pennies; at another, they map a road up the side of a paper mountain; a third calls for participants to test the effects of levers for facilitating household chores. Discussion of the relevant scientific principles follows. As a subsequent extension, teams of participants record observations of simple machines seen on a walk across campus. Finally, participants suggest ways to integrate this unit with children's literature, often mentioning the children's classic, *Mike Mulligan and the Steam Shovel*, as well as many other writing, speaking and drawing activities. As this example shows, all Summer Institute activities are appropriate for adults and children, and can be adapted by the teachers to different grade levels.

During the second Summer Institute, returning teachers build on their classroom experiences from the school year, extend their familiarity with science materials and kits in earth and life sciences and develop their leadership skills. The University's arboretum, geology labs and veterinary facilities serve as learning sites for these activities.

Science Seminar

The academic year Penn-Merck Science Seminar provides the structure for supporting individuals and teams as they implement a hands-on science curriculum in their classrooms. Seminars are led by master teachers and University faculty. The seminar brings participants together every three weeks to share successes, solve problems, discuss classroom experiences in light of readings from the science education literature, try out new science activities, and discuss practical issues that affect their ability to implement a science-rich, integrated curriculum. Throughout the seminar, participants develop skills as reflective practitioners by analyzing their teaching and their children's learning. Each teacher keeps a journal to integrate seminar

readings with observations about the issues arising in the classroom. Every participant also conducts a case study of the development of science knowledge and skills in one or two students over the course of the school year.

Two examples convey the value of the seminar as a context for collaboration. In one session last year, teachers created a model science lesson using M &M candies. Given a bag of candy, a sheet of paper and access to measuring tools, participants examined, counted, weighed and measured the candies, compared characteristics across bags, formulated research questions, generated hypotheses, designed strategies for collecting additional data, created writing and graphing activities and planned field trips. This exercise provided a dry-run for a unit that the teachers then used with their students. In another session, a guest presentation on silk worms as a vehicle for teaching about life cycles so inspired the participants, that the Collaborative distributed silk worm eggs and the presenter's curriculum to every teacher in the cohort. As a result, 42 classrooms of elementary students (over 1,200 children) simultaneously engaged in feeding, observing, measuring, recording, graphing and reading about silk worms. Meanwhile, their teachers shared strategies, findings and extension activities at subsequent seminar sessions in this model of curriculum collaboration.

Relationship with Science Mentors

A variety of science mentors visit the classrooms during the year, serving as partners to participating teachers and role models for their students. Over 40 volunteers from Merck participate in this way. The qelationship begins in the summer with an inquiry-based, joint science activity. The teachers send their Merck partners a pouch of mystery powder from the STC ``Chemical Tests'' kit. Teachers and scientists work independently to identify the substance and then compare notes about the processes they each use to solve the mystery.

During the school year, classroom visits involve science mentors in such experiences as team teaching, helping students with science kit activities, classroom demonstrations and science fair projects. Engineering students from the University also bring Discovery Labs to the classrooms where they introduce children to science applications in everyday life.

Undergraduate Students

The Discovery Labs, developed by students in the School of Engineering, represent an unexpected innovation that has grown from the project. Under the direction of mechanical engineering professor Jacob Abel, six student interns a year design or refine hands-on laboratories for teachers that use common experiences as a basis for teaching science concepts. Labs have involved teachers in wiring a doorbell, assembling a hairdryer, testing lung capacity with a spirometer, building bridges from spaghetti, simulating the effects of earthquakes on structures and investigating properties of solutions. As noted earlier, the labs have been so successful for teaching science concepts to teachers, that we have begun to bring modified versions of the labs to elementary grade classrooms.

The lessons taught through the Discovery Labs have mutual benefits for the engineering students and the teachers. In fact, the value of the program is perhaps most intriguing for undergraduate education. The

process of developing and implementing the labs engages students in testing their knowledge of fundamental engineering concepts, stimulates problem solving, fosters collaboration and introduces students to principles of effective teaching and learning. More information about the development of the Discovery Labs is reported at this conference (Abel, J. DOLFFEN: Discovery Oriented Lab for First-year Engineers).

Outcomes of Collaboration: What We Have Learned

The first year of implementation of the Penn-Merck Collaborative affirms the strengths of this approach, and suggests areas for further development, both within and beyond our original goals. Thus far, formal and informal evaluation has focused on outcom es for participating teachers. A later paper will address the effect of the Penn-Merck Collaborative on student achievement and aspirations.

1. Teacher practices and attitudes about science education have changed in ways that are consistent with the Collaborative's goals.

   Participants in the first cohort have made significant changes in their teaching after one year. Classrooms are now centers of science activity, with projects, plants and animals, bulletin boards, and links between science and language arts evident throughout. Teachers spend more time on science than they did in previous years, and actively employ many of the teaching strategies developed during the Summer Institute and Science Seminar. Classroom observations and teachers' journals also show that teachers are very enthusiastic about teaching science, and routinely link science to other areas of the curriculum. We have stayed away from pencil and paper tests of teachers' knowledge of science as we have yet to identify a standardized test with the validity we are seeking. Thus, until we can locate or devise such a measure, we are asking participants to provide detailed pre- and post-Institute inventories of their familiarity with the science content taught in the summer.

2. Teamwork among teachers that sustains momentum for curricular change is facilitated by the sequence of Summer Institute followed by the Penn-Merck Science Seminar.

   The Summer Institute offers an intensive opportunity for learning. However, it is the monthly seminar sessions that provide the continuity and collegiality needed to ensure implementation and continued professional growth. Over the months of the year-long course, we have seen increasing numbers of teachers gain the confidence to report on, and share science activities they have carried out in their classrooms. Indeed, participants have reported the same to us on self-rating scales, and in written reflec tions on their learning. Teachers' evaluations of the seminar show that they especially value the opportunities for learning from one another, and using the research literature to better understand their students' learning.

3. Some teachers appear to need support that extends beyond their 13-month participation in Penn-Merck Collaborative activities.

   During their year of participation in the Penn-Merck program, teachers have developed great enthusiasm and confidence for hands-on science. However, an effective inquiry-based learning

approach requires sophisticated knowledge and skills for guiding student learning. Our evaluation and observation data show that some participants need to develop additional knowledge about science, while others need techniques for challenging students to move beyond superficial understandings. These findings have led us to secure funding for a second year mentoring program. This effort will pair master teachers or university graduate students with classroom teachers to give regular on-site feedback and support for their science teaching.

4. Volunteers must be carefully prepared for their classroom visits.

   The volunteer component of the Penn-Merck program has great potential for providing role models and specialists to work alongside children, deepening their understanding of science. However, it is critical that volunteers receive training and structured opportunities to develop partnerships with teachers. Corporate volunteers typically have limited release time to serve in the schools, just as teachers have limited planning time. A remaining challenge for the Collaborative is to get the teachers and volunteers to work together in advance of classroom visits to maximize the benefit for students. We have assigned a graduate assistant to oversee this aspect of the program in conjunction with the volunteer coordinator at Merck.

5. Integrating technology into the science curriculum has become an increasingly important aspect of the Penn-Merck effort.

   Technological literacy is a growing educational priority both nationally and locally. Teachers in the Collaborative have expressed great interest in acquiring knowledge and skills in computer technology to enhance their work in science education. Each year, the Merck Institute provides computer equipment to schools that participate in the Collaborative. The computers are intended to support curriculum, facilitate communication and contribute to teachers' professional development. Teachers also participate in training in the use of the hardware and software they receive. We have learned, however, that while motivation is high, logistical difficulties and limited planning time stifle some teachers' efforts to incorporate computer technology into the curri culum. The Collaborative is seeking additional partnerships to engage teachers in professional development on the application of computers in the classroom and across the wider community. We are hoping to create a second year seminar where participants would develop strategies for building computer activities into the science and language arts curriculum, and establish professional networks through electronic communication.

Conclusion

The Penn-Merck Collaborative offers a promising model for bringing together the education, science and corporate communities to support teachers in the implementation of sustainable curricular reform in K-12 science. This effort is noteworthy for the act ive collaboration among partners, its multi-faceted program of activities, and the year-long commitment to building teacher leaders. The first year of the program has produced significant changes in teachers' instructional practices and increased their enthusiasm for integrating science throughout the curriculum. The Collaborative has also produced interesting spin-offs in the Discovery Lab program, and in new partnerships for building technology into the science curriculum.

Our experience has provided s ubstantial evidence that this type of collaboration yields important benefits for *all* participants including teachers, children, university students, corporate scientists and university faculty.

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