Recommended Resources
for the National Defense Education Program Pre-Engineering Partnerships

Final Report 2009

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CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

The National Defense Education Program (NDEP) contributes to the education, training, recruiting, and retention of individuals in science and engineering disciplines that are critical to the national security functions of the Department of Defense (DoD). The NDEP's mission is helping to meet the increasing demand for science, technology, engineering, and mathematics (STEM) professionals in DoD laboratories. NDEP's Pre-Engineering Partnership (PEP) with middle schools supports scientists and engineers (S&Es) from DoD laboratory sites working with teachers on STEM activities in classroom settings. The literature on joint efforts between teachers/students and S&Es stresses the *partnership* aspects of the collaboration, and the quality and quantity of contacts, their relevance, and their alignment with other content being taught. Existing PEP sites report the importance of leadership from the PEP site coordinator and the unique contributions that S&Es can bring to students. PEP sites and schools alike are seeking hands-on, technology-based resources that engage students in STEM learning and anchor teacher and S&E activities in class. This SRI International (SRI) report presents the selection criteria applied in selecting five resources for recommendation to PEP. Accompanying narrative scenarios illustrate how the resources can support S&Es who work in middle school classrooms.

INTRODUCTION

The National Defense Education Program (NDEP) contributes to the education, training, recruiting, and retention of individuals in science and engineering disciplines that are critical to the national security functions of the Department of Defense (DoD). The NDEP's mission has become increasingly urgent as defense-relevant science, technology, engineering, and mathematics (STEM) degrees awarded to U.S. citizens have declined, demands for more scientists and engineers (S&Es) have increased, and many DoD technical personnel near retirement. NDEP provides a range of programs, implemented from precollege through postgraduate education, that promote development of the skilled workforce of S&Es essential to our nation's security and prosperity. NDEP's Pre-Engineering Partnership (PEP) is a program that aims to promote interest in science and engineering disciplines by extending NDEP's impact to middle schools. By design, PEP leverages current DoD science and engineering talent to promote the development of the STEM workforce of the future at the same time that it helps meet the instructional needs of middle school teachers by having DoD S&Es visit middle school classrooms to conduct instructional activities with students and their teachers. Achieving PEP's mission requires thoughtful and well-supported activities that connect teachers' needs, S&E resources, student motivation, and learning materials and technologies.

The DoD is not alone in promoting the development of a science and engineering workforce. The National Science Board (2009)—the governing board of the National Science Foundation and policy advisors to the U.S. President and Congress—recently published its top recommendations for the incoming presidential administration. It counseled the formation of a "Science Corps" of active and retired STEM professionals who would volunteer to assist teachers in teaching STEM content and communicate to students their passion and excitement about STEM careers. Among the many other examples of STEM professional outreach programs are IBM's "On-Demand Community," which helps company employees and retirees prepare for school visits, improve the use of technology for teaching and learning, and mentor students; and the American Chemical Society's "National Chemistry Week" and the resources it offers on its Web site for scientists to use in preparing for classroom visits.

Against this national backdrop, NDEP contracted with SRI International's (SRI's) Center for Technology in Learning (CTL) to study and recommend resources for continuing use in the PEP program. NDEP desires resources that it can provide to PEP sites for S&Es to use in middle school math and science classrooms. Resources that NDEP already supports and uses include Materials World Modules, a set of hands-on, inquiry-based activities in materials science; and Tabula Digita's Dimension M prealgebra/algebra learning video game. The new resources selected, like the existing ones, need to support S&Es' role in the classroom and be robust enough to scale up immediately.

To better understand the roles that S&Es could play in effective K-12 STEM learning, we reviewed the literature that dealt with S&E interaction with students in both formal and informal settings. We also investigated principles for fostering cooperative partnerships between teachers and S&Es and the ways that programs can empower S&Es who otherwise would not participate in outreach. This work is described in the *Literature Review* Section.

PEP sites are located at DoD laboratories throughout the U.S. and are managed by site coordinators who may also have other outreach responsibilities as well as a research role at the laboratory. We sought to understand how DoD laboratories participate in middle school outreach programs by interviewing PEP participants—teachers, scientists, and engineers—at a variety of sites. We talked with them about the roles S&E play in the classroom, the resources that support teachers and students, and successes and challenges they encountered in conducting the PEP program. The findings are summarized in the *Interview Findings* Section.

Using literature information gained and local DoD contexts, we created criteria for use in selecting resources. Our researchers then gathered resources that met those criteria from Internet sites, published papers and press releases, discussions with the NDEP program team, and internal consultation with CTL educational researchers. After reviewing the initial set of resources, we selected five resources for recommendation. We describe the resource review and selection process in the *Resource Selection* Section.

Finally, to demonstrate how the selected resources could be used in the context of a partnership between teachers and S&Es, we created narrative scenarios, each one of which sets forth one possible use of the resources. The scenarios are presented in the *Scenarios* Section.

LITERATURE REVIEW HIGHLIGHTS

A student can learn about STEM in many ways: through school classes, in informal settings, through use of tools and manipulatives, and through interactions with the community. Outreach activities enable many S&Es to visit classrooms and conduct instructional activities that motivate students and teachers to take an active, participatory role in the STEM enterprise. In successful programs, S&Es effectively *partner* with teachers and *connect* with students.

In reviewing evaluation and research literature on STEM outreach efforts, we sought results that demonstrated the effects on students, teachers, and S&Es who participated in programs that engaged S&Es in K-12 classrooms or in after-school programs. We learned that the following elements are often important:

- **Authentic Challenges.** When students work with practicing S&Es on authentic challenges, such as projects in their community or collaborative research with a local college, they gain STEM knowledge, appreciation for S&Es' work, and enthusiasm and motivation. However, engaging in authentic projects over an extended period entails high costs of entry and of sustainment for all parties involved because original projects must be planned, resources secured, training provided, and follow-up completed. In lieu of conducting authentic projects, S&Es can make learning authentic and increase student engagement by connecting in-class activity to their work, helping in modeling the students' scientific thinking, and encouraging meta-level understanding by explicitly characterizing thinking as scientific.

- **Extended Contact.** Students involved in STEM through informal apprenticeships that extend over time learn how S&Es work collaboratively on teams, become interested in STEM topics, and can begin to self-identify as a scientist or engineer by learning how practicing S&Es pursued their career from middle school onward.

- **Relevance and Alignment.** Scientists and engineers should work with materials that are aligned with the teacher's curriculum. Projects of local relevance and visits to STEM-oriented workplaces help connect communities to schools.

- **Teacher Learning.** Teachers learn new content such as innovative scientific discoveries and new procedures in workshops and through collaboration with academic and practicing S&Es.

- **Technology Use.** The use of learning technologies can improve STEM motivation, learning, and understanding, and S&Es can help implement the classroom use of technology. Technologies should (1) support learning in real-world contexts, (2) connect learners with experts and communities of learners, (3) use visualization and analysis tools to enable thinking with data, (4) scaffold problem solving to enable more complex reasoning than would otherwise be possible, and (5) provide opportunities for feedback, reflection, and enhancement of what has been learned.

- **Student Persistence in STEM.** Students in middle school may be starting to develop ideas about whether they are "good" at math and science, and recommendations about how to talk to students about their abilities and efforts can be useful for S&Es (Dweck, 2002). Showing students that learning and intelligence are expandable and not fixed will make their persistence in the face of challenges more likely.

Most of the outreach literature focuses on outreach in the sciences. K-12 teachers generally have a good understanding of science careers but a poor understanding of what engineers do (National Academy of Engineers [NAE], 2008). This finding suggests an especially unique role for engineers working with middle schools to help foster student's interests in conducting design experiments or building robots and tying these activities to the engineering profession. These activities may then influence the types of courses a middle school student chooses such as math, which in turn has the potential ultimately to influence their career options. Contact with a practicing engineer may also encourage harder work in middle school math which is important because a poor math foundation can hinder student performance in higher-level math and science classes. Outreach programs, especially those that focus on engineering, must promote students' interest and knowledge of STEM, while also ensuring that students are not discouraged by overemphasis on the necessity of math course-taking. Achieving this balance is important because students may not pursue careers in engineering, in part, because they believe their math skills are insufficient (NAE, 2008).

Appendix A provides more background on outreach projects that have been reported in the literature. These projects emphasize authentic challenges in the context of student-scientist partnerships, projects that leverage local geographical regions around schools, and projects that extend over time. Appendix A also reviews teacher learning as a result of outreach program participation, the need for S&Es to understand learning challenges, and the role that scientist and engineering professionals can play with underserved populations.

INTERVIEW FINDINGS

Factors for Success

- Quality of Partnerships
- Leadership from Site Coordinator
- Appropriate Materials and Activities
- Strong Role for S&E in the Classroom

> I am very hopeful that it [PEP] continues and grows... When we look at our students and we look at our nation, and math and science scores that say that we are going in the hole... I think the more exposure kids have to the real world [the more chance you have to show] this is what you can do with your life. There is fun and excitement in science. You don't have to be a pro basketball player, pro football player, or a disc jockey or a recording artist to be successful. There is another world out there.
>
> – *A Middle School Science Teacher in PEP*

Our research findings were greatly enriched by interviewing a selection of site coordinators (chosen by the NDEP office) and participating teachers and S&Es (selected by the site coordinators). Between October 2008 and February 2009, we conducted telephone interviews with these participants to learn what resources they have used in their classroom, what they regarded as useful for supporting an S&E's role in the classroom, and how they viewed prospective resources for PEP. The interviews also elicited reactions to the overall PEP program (as illustrated by the quote above), which were largely positive.

FACTORS FOR SUCCESS

We heard many times that the professional partnership between the teacher and the S&E is the most important aspect in determining PEP success. Before PEP projects begin, therefore, teachers and S&Es need to jointly participate in training and professional development that provide both needed information and opportunities for mutual discussion and thoughtful practice. Establishing such early communication and planning together from the outset of the partnership are crucial to success.

PEP site coordinators play an important role in establishing partnerships and in providing materials and opportunities for training. Several teachers and S&Es indicated that the site coordinators made it much easier to make connections between a school and a laboratory. We heard that, at some sites, coordinators need to provide more support. A few S&Es we spoke with wanted to understand what is expected from their participation: S&Es may be reluctant to engage if their roles, expectations of them, and middle school classroom practices are unclear to them. Site coordinators, we learned, should provide information in addition to classroom materials such as tips on working with middle schoolers and ways of interacting with differently sized groups of students.

Teachers can assist with making the S&E's role relevant to current instruction by helping S&Es translate their knowledge to the level appropriate for a middle school classroom. One teacher we interviewed explained to an S&E how his work with artillery aligned with the school's physics curriculum, which helped the S&E choose what to talk about in the classroom.

Materials and activities used in PEP programs must be appropriate for the interests, abilities, and schedules of students, teachers, and S&Es. Examples we heard from participants included the need for tailoring instructions and technical descriptions for students who read below grade level (e.g., one teacher reported that his eighth graders were reading at a fifth-grade level). In addition, teachers expressed impatience with resources that were not aligned with their school's goals and standards. To ensure a successful experience, resources must provide teachers with the opportunity to do something new: one teacher said that having kids conduct "hands-on science is a great idea for teachers who don't do that already, but I do that." Cultural difference must also be considered: one teacher mentioned that his students did not understand baseball, which was the basis of one activity. Some S&Es we spoke with were concerned about the amount of time they would have to devote to PEP. Successful programs engaged all participants in planning and considered all important constraints.

A final factor for success that we heard about in the interviews is that the most important reason for an S&E to work in a classroom is to contribute their unique experience in, and passion for, their career of science and engineering. Helping students understand the intellectual and hands-on pursuit of design, experimentation, and theory-testing can be valuable for students who have little access to models in the sciences. Harnessing S&Es' capabilities—their professional expertise, as well as their enthusiasm, curiosity, creativity, sense of purpose, and sense of duty—is crucial. Teachers reported that S&Es brought in useful exhibits and experiments that demonstrated "lots of neat principles that I've talked about and shown somewhat but… [they] had more gadgets and materials… [students] could play with."

CHALLENGES

Challenges

- Recruitment and Retention of S&Es
- Differing Goals for Learning
- Managing Participants' Expectations
- Measuring Program Maturity and Effectiveness

Recruiting sufficient numbers of S&Es from DoD laboratories who can obtain release time for the classroom can be a challenge. At some sites, S&Es are recruited into PEP after they have first conducted shorter activities before they commit to longer tasks. For example, we learned of an engineer who started with a 1-day workshop and then committed to a longer training and in-class work with PEP. After training is complete, maintaining communication between the teacher and S&E is necessary to assure the S&E's continued participation. For example, one S&E we interviewed was not contacted by a teacher after investing time in a summer workshop and thus was discouraged from further participation.

Another challenge for PEP is establishing and maintaining teacher and S&E partnerships when the partners have to adjust to differences in approach. For example, one S&E we interviewed felt that her teacher ignored important learning opportunities because the teacher was "driven" to finish the tasks in the activity. Another S&E felt her teacher was rushing to finish the assigned unit instead of realizing that the important lessons included "it was ok to make mistakes" and that "trying again is not bad." Establishing good communication and defining shared goals for student learning can help with this challenge.

Managing participants' expectations may pose a challenge for PEP site coordinators. For successful PEP projects, teachers and S&Es must be prepared to engage in a partnership, and this requirement may not be clear to everyone. For example, one S&E reported that she believed that her role would be to "serve as the expert who answered questions while the teacher looked on." Also, expectations about what can be accomplished under the PEP program need to be realistic. For instance, some S&Es expressed broad concern about the state of K-12 education and felt that NDEP should, among other things, "revolutionize science teaching," " reform mathematics education to teach students deep knowledge," "teach students to engage in the inquiry process," and "determine how to apportion national resources to gain the best return on investment." These concerns are legitimate, but the PEP program cannot accomplish these objectives given its limited scope.

A final challenge for PEP, as a program distributed across many sites and enacted in many local contexts, is determining how to create and implement consistent methods for measuring program effectiveness. Examples of data that could be collected include the numbers of S&Es trained, contact hours with students, and the types of classroom activities completed. Observations of classroom interactions, teacher logs, and student work in the PEP activity could be analyzed to build case studies that illustrate effective partnerships.

RESOURCES

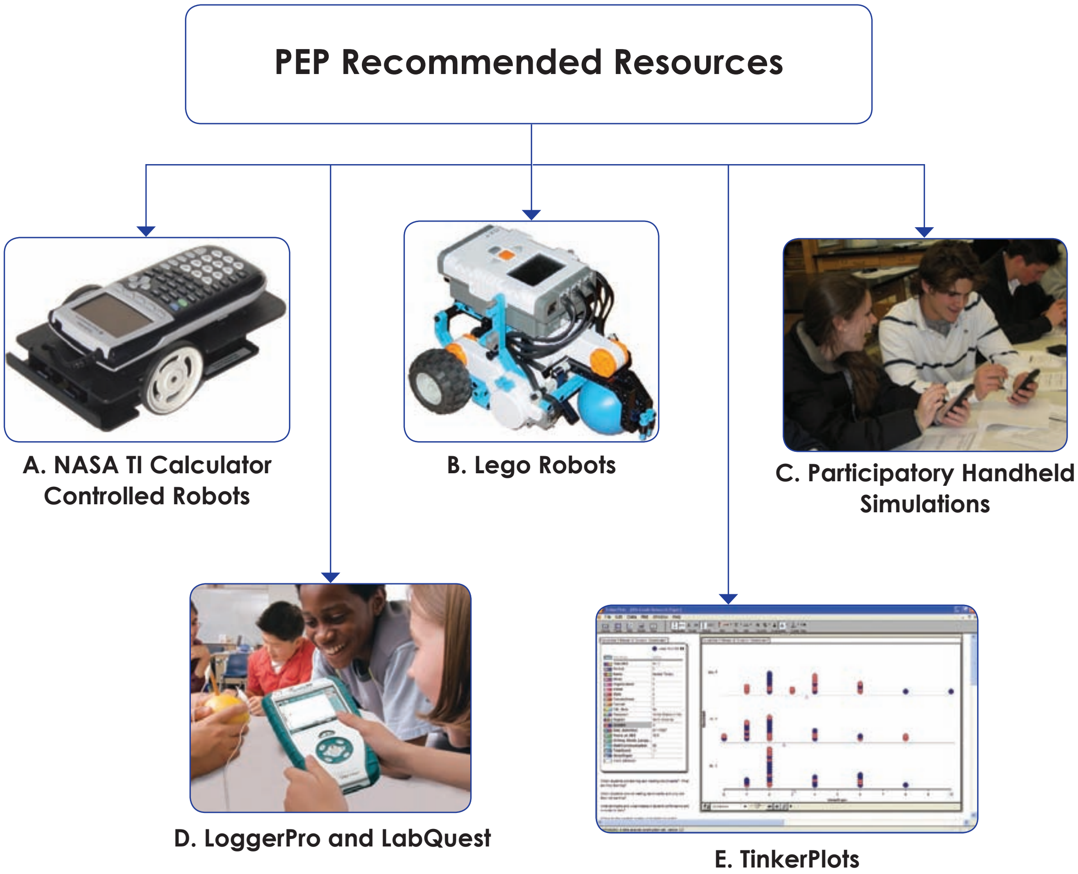
One of the discussion questions during our interviews with teachers and S&Es was what resources they have brought into the classroom and what resources they would like to use. S&Es, we found, brought in novel demonstrations such as blowing up a balloon in a bell jar. Teachers primarily mentioned resources designed for classroom use. The specific resources that were reported in the interviews are summarized below.

- Robotics, which many participants mentioned as opening the door for students who are intimidated by math and science, and as a good way to involve S&Es. Some teachers mentioned their participation in the First Robotics Competition and the use of Lego Robotics kits.
- Measurement instruments designed for the classroom were a desired resource. One teacher who had just started using Vernier Software and Technology's probes reported that his S&E "helped him think about ways to… interpret the data from the probes."
- Computer software for data analysis that accompanies measurement instruments was also seen as desirable. Specifically mentioned was Vernier's LoggerPro data analysis software, which works with the Vernier suite of probes.
- S&Es described tried-and-tested materials such as Tesla coils and electronic balances.
- Teachers mentioned interactive whiteboards, interactive online textbooks, and online resources such as Brainpop, an animated educational Internet site for science and other subjects.
- Teachers were willing to experiment with resources they learned about from working with S&Es. One described her interest in software for computer-based modeling of 3D objects called SolidWorks (http://blogs.solidworks.com/teacher/) but reported that computer availability was a problem.

RESOURCE SELECTION

Using data from interviews with PEP participants, SRI researchers explored a range of resources that teachers and S&Es working in partnership could use in middle school classrooms to complete STEM-related activities. Figure 1 depicts the five resources that emerged from our review.

Figure 1. The five resources recommended for PEP



Below, we indicate how we generated the list of potential resources, present the metrics we used to evaluate each resource independently, and then describe each resource in detail. We provide information about its subject area, start-up costs, ongoing costs, and the extent to which it is characterized by more open-ended or more structured lessons and activities.

SELECTING RESOURCES FOR CONSIDERATION

Resources that we considered for PEP included, but were not limited to, manipulatives, simulations, virtual worlds, robots, probeware, games, and curricula. We generated the list of resources from our investigation of recent books, book chapters, conference programs and proceedings, journal articles, listservs, National Research Council reports, and online bibliographic and full text databases. Conversations with PEP teachers, S&Es, site coordinators, and program management, as well as subject matter experts, indicated additional resources. Figure 2 presents the full list of resources.

Figure 2. Resources considered by SRI Researchers for the PEP

Arc Explorer
Arduino
Armadillo Run
BioLogica
Bowlan Trust Activities
Cooties
Dimension M
DIY Drones
Electro City
Engineering is Elementary
Engineering the Future
Environmental Detectives
EnViSci Network
Exploratorium Snack Book
Fathom Dynamic Data Software
FOSS: Full Option Science System
GEMS
GenScope
GEODE Project: Earth Structures and Processes
GEODE Project: Planetary Forecaster Project
Geometer's Sketchpad
GSS: Global Systems Science
HOU: Hands on Universe
Immune Attack
JASON Project
JavaGami
Lego Mindstorms NXT Robots
Lego Robotics Kits
LoggerPro + Vernier LabQuest
MARE: Marine Activities, Resources, and Education
Mega Math
Mr. Vetro
MyWorld
Nano Legends
Nanozone
NASA Calculator Controlled Robots
NetLogo Simulations
Participatory Handheld Simulations
Plant Cells
Quest Atlantis (QA)
Race to Mars
Resilient Planet Game
Rethinking math
River City
Schmartboard
SEPUP: Science Education for Public Understanding Program
SimCalc
Sloan Digital Sky Survey: SkyServer
The Nobel Prize in Chemistry
The Nobel Prize in Medicine
The Nobel Prize in Physics
The Reconstructors
Time Engineers
Tinkerplots
TryEngineering
Whyville
WISE
WolfQuest

EVALUATING SELECTED RESOURCES

To align potential resources with the goals of PEP, we developed primary selection criteria (*must haves*) and secondary selection criteria (*would be good to haves*); the criteria were informed by our review of relevant literature and interviews with PEP participants. As summarized in Table 1, the selected resources had to target STEM content, be appropriate for middle school students, have the potential to involve a scientist or engineer actively, have a technology focus, put the learner in the center of the learning activity, and have the potential for scaling up.

Table 1. Resource Selection Criteria

Criteria	**Description**	**Research Base**
Target STEM content	The resource should focus on content standards from science, technology, engineering, and mathematics, or a combination thereof.	American Association for the Advancement of Science, 1993; American Society for Engineering Education, 2008; International Society for Technology in Education, 2007; National Council for Teachers of Mathematics, 2000, 2006; National Research Council, 1996
Appropriate for middle school students	The resource should be developmentally and cognitively appropriate for middle school students.	National Research Council, 2005, 2007a, 2007b
Active involvement of a scientist or engineer	The resource should have the potential for letting a scientist or engineer actively participate in middle school students' learning experience.	National Academy of Engineering, 2008; National Academy of Sciences, 2009; National Research Council, 2000b
Technology focus	The resource should have a technology focus and thereby make possible the connection of learners with experts and communities of learners over distance and time; visualization and analysis tools for thinking with data; supports for complex problem solving; and opportunities for feedback, reflection, and revision of understanding.	Borgman et al., 2008; International Society for Technology in Education, 2007; Jonassen, 2004; National Research Council, 2000a
Learner-centric	The resource should put the learner in the center of the learning activity.	National Research Council, 2005
Scalable	The resource should have the potential to scale up and meet the needs of diverse classrooms, teachers, and students.	Coburn, 2003; Dede, Honan, & Peters, 2005

Secondary considerations for selecting resources were that they support students working collaboratively as compared to individually, be easy to access and/or install, include curricular materials to assist and support educators, provide evidence that teachers are using the resource in schools, and be fun to use.

Of the 60 resources SRI evaluated, 12 scored high on the primary and secondary selection criteria. Table 2 groups the 12 resources into three categories—those with a math focus, a science focus, and an engineering focus. The resources with a math focus tend to align strongly with national math standards (National Council for Teachers of Mathematics, 2000, 2006) and cover areas relevant to general math instruction covered during the middle school years, as well as prealgebra and algebra. The resources with a science focus tend to align strongly with national science standards (National Research Council, 1996) and map well to the course objects of physical science, life science, and earth science. The resources with an engineering focus align with the draft versions of the National Content Standards for K-12 Engineering and Engineering Technology standards (American Society for Engineering Education, 2008) and tend to focus on engineering design and process.

Table 2. STEM-Focused Resources Recommended for PEP

Math-Focused Resources

Bowland Trust Activities–math case studies designed to help students explore core middle school concepts. Each case study includes (1) standards that describe learning goals, (2) teaching materials, (3) professional development support, and (4) performance assessments. All activities include technology resources to varying degrees.

Geometer's Sketchpad–supports for students as they visualize and explore mathematical relationships by building and investigating models. Software is appropriate for all grade levels and curricular modules are available for grades 5-12..

NASA TI-Calculator Controlled Robots–supports middle school students as they create programs in TI-BASIC to control robots. Sequential missions gradually lead students to create their own programs. Students use and apply math and science concepts to direct their robots through a variety of challenges.

SimCalc–supports learning the mathematics of change and variation by making concepts such as proportionality, linearity, and rates of change accessible to middle school students. Students use interactive software to engage in mathematical inquiry. (SRI co-developed SimCalc.)

TinkerPlots–software, designed for grades 4-8, that motivates and scaffolds students' investigation of data. Students create visual representations to reveal patterns and trends contained in real data. Data can be accessed online, and curricular modules are available separately.

Science-Focused Resources

Exploratorium Snack Books–scaled-down versions of Exploratorium exhibits, covering all areas of science. Most Snacks can be completed by one person. Snacks include (1) assembly instructions, (2) descriptions of how to use the completed exhibits, and (3) the science behind the Snack.

Vernier LoggerPro and LabQuest–a data collection program and a multifunctional handheld probe. Together, they allow students to collect data in real time and represent it in tables and graphs. Curricular materials provide teachers with hands-on experiments.

My World GIS–a lightweight geographical information system (GIS) designed for middle school through college-level students. It allows students to manipulate variables and map, explore, and analyze data systematically. User manuals and datasets are available online. Arc Explorer is a similar GIS capable of performing basic GIS functions. The GEODE Project, as are other projects, is built on the My World GIS application.

Participatory Handheld Simulations–Palm OS handheld computers used to embed users in active simulations. Interactions between students are mediated by peer-to-peer "beaming," transmitting information from one device to another. Simulations cover a variety of content areas and target middle school students.

WISE (Web–based Inquiry Environment)–an online learning environment where students examine real-world evidence and analyze current scientific controversies. Students in grades 5-12 complete in–depth, scaffolded, inquiry–based projects in pairs. Curriculum projects meet national standards and complement existing science curricula.

Engineering-Focused Resources

Lego Robotics Kits–kits and activity packs appropriate in formal and informal learning environments. Students learn to design, program, and control fully functional models that carry out life-like automated tasks. Science, technology, and engineering concepts are all covered through hands-on creation and applied inquiry.

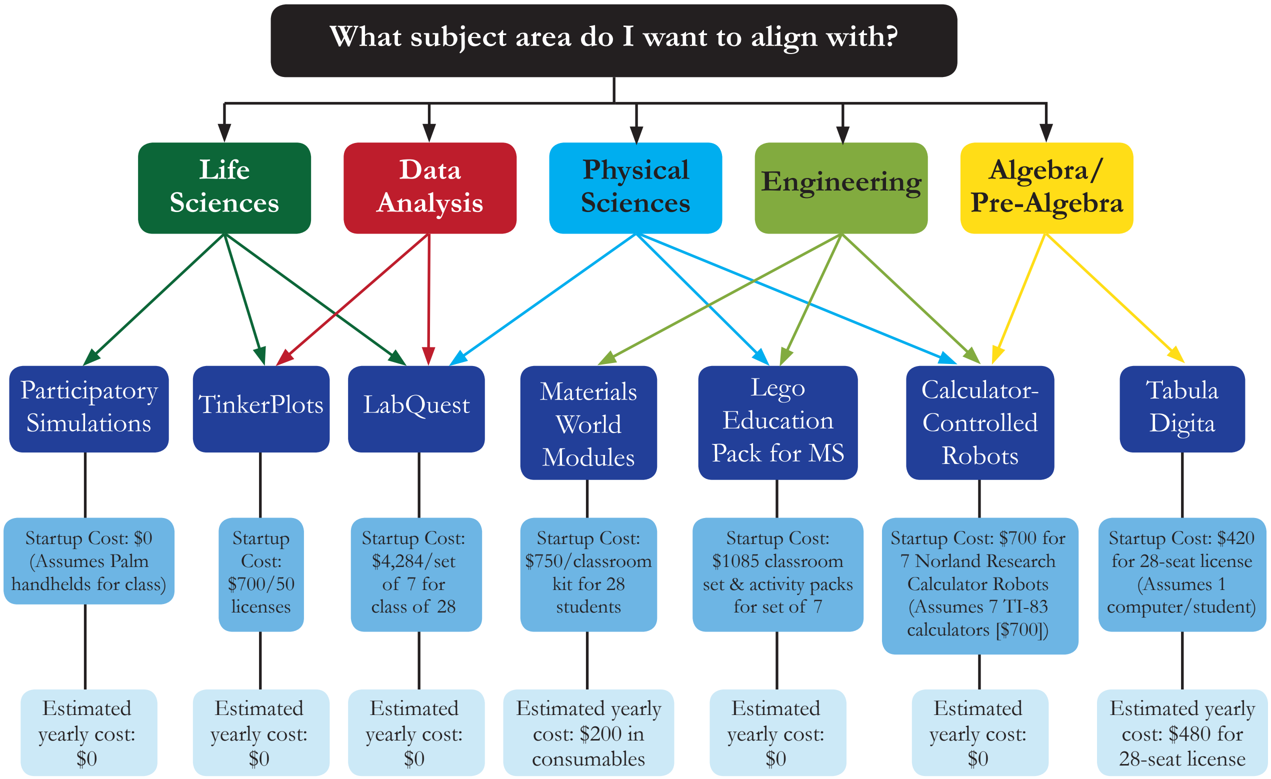
NetLogo Simulations–a programmable modeling and authoring environment for simulating natural and social phenomena for K–12 instruction. Extensive documentation and tutorials relevant to simulations are available online. Users can also access a Models Library that includes more than 100 unique simulations.

From the 12 resources, SRI researchers and PEP management staff selected 5 for further consideration. The next section summarizes our recommendations concerning PEP's use of the resources.

RECOMMENDED RESOURCES

Figure 3 shows the subject area coverage for each resource selected, and for comparison includes information about the resources PEP already supports: the hands-on kits for physical science called Materials World Modules and the algebra/prealgebra video game from Tabula Digita called Dimension M. (Costs are current as of the date of this report.)

Figure 3. Comparison of recommended with existing resources



Calculator Controlled Robots

With *Calculator Controlled Robots,* middle school students use relevant math concepts and computer programming techniques to develop programs in Texas Instruments (TI)-BASIC that direct their robots (*CalcBots*), as shown in Figure 4, to meet a variety of challenges. Sequential missions increase in difficulty and gradually lead students to create their own programs.

Figure 4. Photograph of CalcBot with a Texas Instruments graphing calculator

Source: http://www.generation5.org/content/2002/images/calcrobot2_02.jpg

The start-up costs of $200 include $100 for each calculator-controlled robot and $100 for each Texas Instruments graphing calculator. Students typically work in teams to complete missions and activities. Therefore, the start-up cost for a class of 28 students working in teams of 4 is approximately $700 for the robots, plus $700 for the calculators. (Costs cited for all resources in this section are as of June 2009.)

Preparation for a typical lesson, which includes gathering robots, calculators, and activity-specific materials, generally takes between 15 to 30 minutes. The curricular materials associated with the robots include 10 lessons, which are called missions, and 3 extension activities. Hands-on activities, sample code, data collection templates, and reflection questions characterize each mission and are available free and online. Additional activities are available from Norland Research. More information about *CalcBots* and supporting curricular materials is reported in:

> Tuchscherer, T. (2009). *Bringing math to life. Learning and Leading with Technology, 36*(6), 36–37.

Lego Education Pack for Middle School

The *Lego Education Packs* include all of the materials needed for students to begin learning how to design, program, and control models that carry out real world tasks. Science, technology, and engineering concepts are all covered through hands-on creation and applied inquiry.

The start up costs for each Simple and Motorized Mechanisms Base Set is $135 or $945 for a class set, assuming a class of 28 students and groups of 4 students sharing a single kit. The activity guides that accompany the kits, *Introducing Simple and Motorized Mechanisms Activity Pack* and *Advancing with Simple and Motorized Mechanisms Activity Pack,* together cost $140 and include a printed guide and a CD ROM with printable worksheets. Optional add-on sets include *Pneumatics Add-On Set* ($55), *Pneumatics Activity Pack Teachers Guide* ($55), and *Motor Add-On Set* ($36). Preparation for a typical lesson, which includes gathering robots, calculators, and activity-specific materials, generally takes between 15 to 30 minutes. To learn more about how Lego Robotics Kits affect learning and self-identity, see the following article and book chapter:

> Chambers, J. M., Carbonaro, M., & Murray, H. (2008). Developing conceptual understanding of mechanical advantage through the use of Lego robotic technology. *Australian Journal of Educational Technology, 24*(4), 387–401.
>
> Robinson, A., King, K. P., & Thompson, R. (2007). The power of robotics in the lives and learning of alternative high school students. In M. Gura & K. P. King (Eds.), *Classroom robotics: Case stories of 21st century instruction for millennial students* (pp. 105–114). Charlotte, NC: Information Age Publishing.

Participatory Handheld Simulations

Researchers in MIT's Scheller Teacher Education Program developed these participatory simulations, which use Palm OS handheld computers to enable students to step inside active simulations. Interactions between students, as shown in Figure 5, are mediated by peer-to-peer "beaming"—the transmitting of information from one device to another. Simulations, such as *Big Fish - Little Fish, Live Long and Prosper, Sugar and Spice, Tit for Tat* (Prisoner's Dilemma), and *Virus* cover a variety of content areas, but are primarily based on epidemiological and other life science topics.

Figure 5. Students engaged in participatory simulations.

Source: http://www.cfkeep.org/html/snapshot.php?id=68848064

No cost is associated with the simulations, with start-up costs for this resource limited to handheld devices that run Palm OS (e.g., Palm's M100 series and M500 series, Tungsten, Zire, and many Handspring and Clie models). These devices cost, on average, $100 each. Because all students participating in a simulation will need a device, approximately $2,800 will be needed to purchase a class set (unless donations of used equipment can be made). No annual costs associated with this resource are known, other than those for upkeep and maintenance of the handhelds.

For a typical lesson, preparation takes between 30 to 45 minutes to gather and program the handhelds, as well as to print student materials for the given simulation. The curricular materials that come with Participatory Handheld Simulations include background information, graphic organizers, discussion questions, and lessons that are highly interactive and collaborative. Additional information about these simulations and their impact on student learning is available in the following article and book:

> Klopfer, E. (2008). Augmented learning: Research and design of mobile educational games. Cambridge, MA: MIT Press.
>
> Klopfer, E., & Yoon, S. (2005). Developing games and simulations for today and tomorrow's tech savvy youth. Tech Trends, 49(3), 33–41.

LoggerPro and LabQuest, Probeware and Data Analysis Software

LoggerPro (hardware) and *LabQuest* (software) allow students to collect data in real time and represent it in tables and graphs. Available curricular materials provide teachers with hands-on experiments that cover a range of concepts and phenomena, primarily from the physical and life sciences.

The standalone *LabQuest Middle School Science Package* costs $612. The *LabPro Middle School Science Package* costs $491, and this package requires a laptop or desktop computer, calculator, or handheld computer for each package. The *Go! Middle School Science Package* costs $384, and requires a computer for each package. The *Easy Middle School Science Package* costs $346, and requires a scientific calculator for each package. All kits contain five sensors: light, motion detector, pH, temperature, and voltage. Students using this resource typically work in teams. Assuming a class of 28 students working in teams of 4, the start-up costs for the *LabQuest Middle School Science Package* is $4,284; $3,437 for *LabPro Middle School Science Package*; $2,688 for *Go! Middle School Science Package*; and $2,422 for *Easy Middle School Science Package*. Additional sensors that measure conductivity, force, gas pressure, heart rate, and magnetic field are available for all sets. An unlimited permanent site license for the *Logger Pro 3 software* is $189 and requires computers running Windows XP, Vista, or Vista 64-bit or Mac OS X 10.4 or 10.5.

Preparation for a single lab activity, which includes setting up a traditional lab with chemicals and other apparatus in addition to preparing the probeware and data analysis software, takes from 20 to 60 minutes. "Middle School Science with Vernier," by Volz and Sapatka, the curricular materials associated with the packages described above, comes with detailed instructions for setting up and running 38 experiments. It is available for $48 and includes a CD ROM with editable worksheets.

For more information about the affects of probeware and data analysis software on student learning, see the following journal articles:

Marcus-Dietrich, N., & Ford, D. (2002). The place for the computer is in the laboratory: An investigation of the effect of computer probeware on student learning. *Journal of Computers in Mathematics and Science Teaching, 21*(4), 361–379.

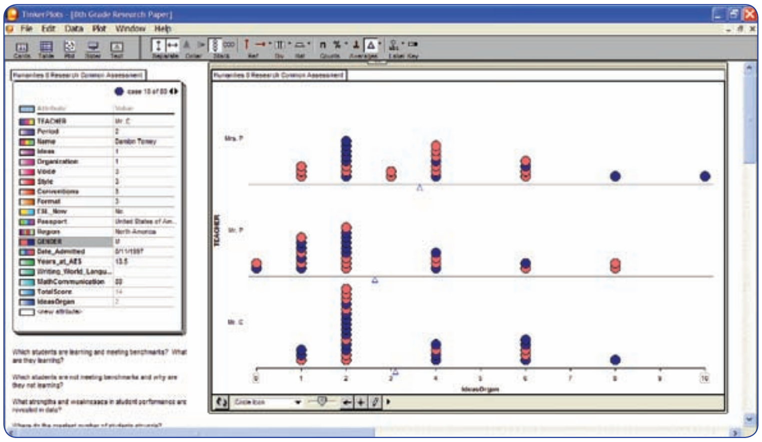
Metcalf, S., & Tinker, R. (2004). Probeware and handhelds in elementary and middle school science. *Journal of Science Education & Technology, 13*(1), 43–49.

Zucker, A., Tinker, R., Staudt, C., Mansfield, A., & Metcalf, S. (2008). Learning science in grades 3–8 using probeware and computers: Findings from the TEEMSS II project. *Journal of Science Education & Technology, 17*(1), 42–48.

TinkerPlots

The *TinkerPlots* software is designed for students in grades 4-8 to motivate and scaffold their investigations of data. Students create visual representations, as illustrated in Figure 6, to reveal patterns and trends contained in real data. Data used in the software can be accessed online. Curricular modules that align with middle school math learning objectives are available separately.

Figure 6. Screen capture of TinkerPlots



Source: http://urlPass.com/47y4

The start up costs for *TinkerPlots*, in addition to the cost of the computer, is based on the number of software licenses purchased: $90 for 1 license, $300 for 10 licenses, $700 for 50 licenses, and $1,000 for a permanent site license. Running *TinkerPlots* requires a computer with the Windows 2000, XP, or Vista operating system, or a Macintosh PowerPC- or Intel-based system running Mac OS 10.2 or later.

Konold's "Exploring Data with TinkerPlots," which is available for $19.95, provides installation instruction, an overview that indicates the software's capabilities, describes each of the 40 ready-to-analyze data sets, and provides advice about how to engage students in data analysis. In addition, seven activities are included, ranging from determining student backpack weight to purely numerical explorations. Preparation for a typical lesson, which includes gathering activity-specific materials, generally takes between 5 to 30 minutes. The following references provide more information about *TinkerPlots* and its effect on student learning:

Watson, J. (2008). Exploring beginning inference with novice grade 7 students. *Statistics Education Research Journal, 7*(2), 59–82.

Watson, J., & Donne, J. (2009). TinkerPlots as a research tool to explore student understanding. *Technology Innovations in Statistics Education, 3*(1), 1–35.

Watson, J., & Wright, S. (2008). Building informal inference with TinkerPlots in a measurement context. *Australian Mathematics Teacher, 64*(4), 31–40.

SCENARIOS

Some of the resources recommended in the previous section may be unfamiliar to S&Es and teachers. To create a more detailed picture of the classroom use of the resource and the STEM professionals' role, we provide scenarios below that describe hypothetical classroom implementations. Each scenario assumes there is a sustained partnership between one middle school math or science teacher and one scientist or engineer who makes regular visits to the classroom. We use S&Es for illustrative purposes, but any laboratory professional can play an important role in a PEP classroom.

Before the S&E begins working with students, teachers and S&Es gather in a workshop or training, organized by NDEP or a local community college, to understand how to use the resource effectively. As a result of these meetings, teachers and S&Es communicate and collaborate regularly before the S&E's first classroom visit and between subsequent visits. The teacher and the S&E also determine how best to balance their roles and responsibilities in a way that supports learning.

The first of the five scenarios involves the partnership between an oceanographic engineer and a science teacher who use sensors to model the mapping of the ocean floor. In the second scenario, a science teacher and a nuclear physicist have students use handheld computers to model the transmission and control of disease. In the third scenario, a physical science teacher and a mechanical engineer work together to help students construct and study different mechanical structures using Lego-based robotics kits. In the fourth scenario, an aeronautical engineer and a math teacher partner to help middle school students graphically represent and analyze real-world datasets. The final scenario describes the interactions among a robotics engineer, students, and a math teacher in the use of relevant mathematical concepts to program a robot to complete specific tasks.

Each scenario highlights the unique features and characteristics of the classroom use of the resource, at the same time emphasizing what the technology brings to student learning. In addition, the time and effort required of the teacher and S&E are indicated. The scenarios illustrate how participation in the program can affect content mastery as well as self-identity.

MAPPING THE OCEAN FLOOR WITH REMOTE SENSORS

Noemi Luby, an oceanographic engineer for 13 years, has some contact on a monthly basis with Darren Haggett, a science teacher for 22 years, and his eighth-grade physical science students. They met during a professional development workshop on *probeware* and *data analysis*. "Probeware" includes a wide range of data collection sensors designed to measure quickly, easily, accurately, continuously, and in some instances, remotely, physical properties such as temperature, pH, oxygen concentration, motion, and force.

Probeware and data analysis tools can help students explore phenomena, answer questions, and solve problems.

Noemi works with Autonomous Underwater Vehicles (AUVs), which transport sensors over large areas to conduct tests and surveys of various kinds. She was not familiar with the term "probeware," but quite familiar with electronic sensors and how the data they collect can be used to answer research questions and solve problems. Her knowledge of middle schoolers (how they think, what motivates them, how to interact with them?) is very limited.

Darren understands the kids of today, and his teaching style is student-centered. His students work in teams to tackle important and relevant content topics through hands-on activities. Darren has noticed that laboratory experiments often fall short in helping students reach a deep understanding of science; students spend the majority of their time collecting and plotting data instead of focusing on the important aspects of interpreting and discussing what the data reveal.

During training, Noemi and Darren tried activities from several middle school science workbooks and kits that had been written to engage students in analyzing data gathered from probeware. The trainer pointed to research evidence illustrating how probeware kits can enhance student learning through visualization and analysis tools used in working with real data The trainer also showed the wide range of sensors available through the probeware kits selected for use in PEP.

Noemi and Darren agreed to collaborate in conducting intensive 1- or 2-day activities once a month. The first activity they selected, "Ocean Floor Mapping" (Volz & Sapatka, 2007), would enable Noemi to share with Darren's students her expertise and experiences as an engineer. Besides being hands-on and problem-based, the activity connected directly with Noemi's day-to-day activities and challenges as an oceanographic engineer.

In preparation for Noemi's visit, Darren explained to his students that, with the help of a DoD oceanographic engineer, they would be mapping a section of the ocean floor until recently too deep to explore. He asked students to prepare questions for Noemi like, "What do engineers do?" and "What motivated you to become an engineer?" Before coming to class, Noemi reviewed the teacher's guide for "Ocean Floor Mapping" and prepared sample ocean floors for students to investigate.

During the lesson, students collected data for the ocean floor mapping activity and studied graphs generated by the probeware software. Both adults walked around the room observing each team. They asked students for explanations: "What do you think is going to happen?" "Help me to understand what happened." "Would you explain why you did what you just did?" At the end of the class, Noemi explained the similarities and differences between the activity students had just completed and the kinds of missions she and her coworkers undertook with AUVs.

Between her monthly visits, Noemi and Darren explored different ways they could incorporate into different lessons the sensors aboard Noemi's AUVs such as the side scan sonar, conductivity-temperature-depth (CTD) sensors, and an acoustic Doppler current profiler (ADCP). They found that if Noemi described the sensors as they were used in the field (her area of expertise), Darren could connect her procedures and scientific concepts to his state and local curriculum standards (his area of expertise). These ongoing collaborations resulted in a growing collection of activities and lessons for Noemi, Darren, and the students to complete.

MODELING DISEASES WITH HANDHELD COMPUTERS

Participatory simulations actively involve students in modeling and reflection.

Matthew, a science teacher, and Henry, a DoD nuclear physicist, were paired to pilot a PEP activity at Matthew's school. Henry's site coordinator provided background on the role Harry would play in the classroom: to serve as an expert to answer questions posed by the teacher and the students, and to provide information about how the learning activity related to his work. The site coordinator chose MIT simulations for the classroom activity because of the hands-on, investigative nature of the participatory simulations, which use a handheld computer to facilitate individual and group participation. Instead of passively observing a simulation, students become part of the simulation itself.

Before Henry visited the classroom, Matthew and he met in a training to learn how to use the handheld simulations with other teachers and S&Es. After running the first simulation round, participants reflected on what had happened. A DoD engineer exclaimed, "Oh, this is like an After Action Review. Kids will learn a lot from a facilitated conversation that allows them to analyze what just happened, why it happened, and how it can be done better." For Henry, learning that the simulations focused on experimentation and the scientific process proved important—it was something he did every day.

After completing the simulation, Matthew told Henry about his students and explained what he hoped to gain from his visit. Henry explained his job to Matthew and shared his goals for their partnership. To ensure that everything ran smoothly, Henry asked Matthew about how to relate to middle school students, they agreed on their roles during the lesson, and planned the 45-minute period. They also exchanged e-mails and calls before the lesson to finalize their plans and answer each other's last-minute questions.

Matthew's five middle school science classes were studying the biology of disease transmission. Choosing among the available simulations, Henry and Matthew decided to run the Virus simulation with the students, and they started the group exercise with the Virus simulation. With Virus, each player starts out healthy, and he or she must meet (via infrared beaming) as many players as possible without getting sick. As players meet each other, their handhelds indicate their health status. Before class, Matthew had charged the handhelds and set the simulation parameters on each device: some players were tagged as "regular," a few were "immune," and one was designated as "patient zero." Henry gave a brief, 5-minute presentation that explained who he was and what he did at work. Matthew then introduced the Virus simulation to the class. All students were excited to use the handhelds and engage in an active lesson by walking around beaming other students, and sometimes beaming the same student several times—a process that was somewhat chaotic. As soon as the first student got sick, all heard her handheld beep noisily. Soon thereafter, several more handhelds beeped a student's unhealthy status.

After the first round, Matthew asked students to come up with a hypothesis that explained why some students got sick whereas others did not. Henry led everyone through the After-Action Review (AAR) process, which helped everyone one in the class figure out what the group as a whole understood and what it did not know. The class then ran through the simulation two more times, stopping to complete an AAR and then discuss their hypotheses and findings after each round. Matthew led these discussions; however, he relied on Henry as a real-world expert throughout the lesson.

At the close of the school day, Matthew and Henry reflected on their experience. They both felt that they had improved at leading kids through the simulation and hypotheses testing as the day progressed. Henry also felt that, as they day went on, he became increasingly comfortable in relating to students. Both agreed that the initial training had prepared them to use the simulations effectively, and that their collaboration before the lesson had ensured positive interactions both with the students and with each other. The students enjoyed trying a new activity and learning what it was like to be a scientist through their own experience and through their work with Matthew. In subsequent classes, Matthew, Henry, and his students completed other MIT handheld participatory simulations.

THE PHYSICS OF A DRAWBRIDGE

Ed Maloy, a physical science teacher, participated in a PEP summer workshop on Lego Mindstorms NXT kits where he designed NXT-robots (a simple rover, a mobile forklift, and a ball-hunting robot) with a DoD mechanical engineer, Annaluisa Solis. Once back at school, however, Ed could not think of a way to adapt the robotics work they had done for his science class. However, Annaluisa had recently received notice of a new PEP offering, Lego Education's "Advancing with Simple and Powered Machines" that fit with her work on portable bridges to allow armored combat vehicles to cross obstacles. She forwarded it to Ed.

Ed found that the Lego middle school education pack met his state's science requirement for "Investigating Power and Work" and that he could use it to teach his students to apply the idea of mechanical advantage and to understand how a machine makes work easier. With it, he could encourage experimentation with designs instead of having students follow "recipes," show how data collection supports decision-making, and add in math-related activities for data analysis. He e-mailed Annaluisa back, attaching a copy of the standards.

Ed and Annaluisa then conferred and selected a date for her to visit his classroom. Annaluisa notified the site coordinator at her laboratory and as a first-time visitor, spoke with the coordinator about the visit and also arranged to have enough Lego robotics kits for groups of 3-4 students to work together shipped to Ed to look over before the lesson.

Building mechanical models allows students to explore engineering design.

Annaluisa arrived with her drawings of bridge designs, which included the mathematics she used to analyze how much load the bridges could withstand. In response to questions about her experience in middle and high school, she talked about an uncle who sparked her interest in designing and her early love of Legos. She described how she was not a natural at algebra or geometry but how hard she worked to do well in her math classes and how much she continued to learn in that field in college.

The group first built simple machines and then a more open-ended design of a drawbridge. Annaluisa noticed a group carefully analyzing the drawing of a sample drawbridge. She explained that, although it is not a bad idea to reproduce existing designs when you are starting out, real learning comes from experimentation and making, and from learning from your mistakes. The effort along the way, she said, teaches you more than a final design that works.

In subsequent visits, Annaluisa, Ed, and his students built other robots with differing purposes. and over the school year, Ed's students developed a deeper understanding of the engineering design process and vocabulary.

GRAPHICALLY REPRESENTING AND ANALYZING REAL WORLD DATASETS

Kurt Bowersox, an aeronautical engineer with DoD, was interested in reaching out to the community and participated in a daylong training with interested middle school teachers. He was pleased to see that TinkerPlots—a dynamic tool designed for kids to represent and analyze data—was one of his options and fit with his research and day-to-day work activities on fighter jets, which frequently involved representing data graphically.

The workshop participants, who included Gabriela Vegas, a math teacher with 25 years of classroom experience, with whom Kurt would subsequently work, explored the

TinkerPlots application and learned how a visualization and analysis tool for thinking with data could be incorporated into a middle school classroom.

Exploring datasets visually develops data literacy skills.

In sharing what they hoped to get out of the partnership, both Kurt and Gabriela stated they wanted to bring “the real world” into the classroom. Gabriela felt that some of her students needed exposure to someone who used math day in and day out to solve challenging, real-world problems. Kurt responded, “Hey, I do that everyday.” When Kurt revealed that he found middle school students somewhat intimidating, Gabriela explained that as soon as he got into the classroom and worked with the kids, he’d feel more secure.

In a follow-up telephone conversation, Gabriela outlined her lessons for the coming weeks, including one of the *Digging into Data with TinkerPlots* lessons to address a common student confusion about comparing two attributes. They then scheduled Kurt’s first classroom visit.

On entering Gabriela’s classroom of 26 seventh-grade math students, Kurt was warmly greeted and proceeded to introduce himself. Gabriela framed the learning goals, followed by Kurt’s explanation of his thinking about problems that compare attributes, giving a recent example from his job.

In response to one student’s “I could never be an engineer,” Kurt noted he had never imagined he’d be an engineer either. But, in pursuing his passion for airplanes, he had ended up studying aeronautical engineering. Although he did not always learn concepts as fast as his classmates, he noted, he was not discouraged. Some people, as Kurt stated, pick things up faster than others do; the rest have to work hard at what they love.

As students were generating their plots, Gabriela and Kurt walked around the lab asking students whether they thought the students in the sample dataset spent more time playing sports or talking on the phone. When one student stated, “I don’t know” Kurt responded, “Okay, well what don’t you know?” After giving a detailed list of everything he didn’t know, Gabriela pointed out that the student knew a lot more than he first let on. When asked a second time, the student tried to explain why he thought that the students in the sample spent more time playing sports, Kurt responded, “Hey, that is how I would have described it.”

Between visits, Kurt and Gabriela corresponded by e-mail and telephone. After securing approval from his supervisor to do so, Kurt provided scaled-down versions of three datasets for student use in exploring through TinkerPlots.

As the school year progressed, Kurt visited Gabriela's classroom every other Tuesday. Students e-mail Gabriela questions for Kurt concerning not only math and airplanes, but also what it was like to be an aeronautical engineer and what classes they should take to prepare for careers in engineering.

PROGRAMMING ROBOTS USING APPLIED MATHEMATICS

Glenn Bursona, a math teacher, sponsors a Botball robotics club. Despite Glenn's sponsorship of the club and his love of math, he finds it challenging to introduce robots and robotics into his math lessons. Edith Tyrell, a robotics DoD engineer expressed interest to her supervisor in participating in outreach projects. Invited to a PEP interest meeting, Edith signed up for NDEP training on calculator-controlled robots and was paired with Glenn. They worked together to program a calculator robot to navigate a maze, retrieve a secret package, and return to the original starting point. Although both Edith and Glenn had experience with robots—Edith commented, "We do this sort of thing everyday in my lab."—they appreciated the opportunity to practice with the Texas Instrument calculators and robots and receive advice from the trainer.

Design challenges can be explored systematically using programmable robots and applied mathematics.

Between their formal training and Edith's first visit to Glenn's classes, they coordinated their classroom roles. Glenn would frame the design challenge, Edith would connect the challenge with her day-to-day work, and both would help students work through the lesson by asking questions such as, "What have you done up till now?" and "What is your next step?". Edith would also provide an unclassified video she and her group developed for a conference.

In the classroom, Glenn introduced the design challenge, Edith shared a short video of a robot she had designed to remotely detonate a bomb. Once the class began the activity, Edith overheard one student say, "She blows things up; that is so cool." In working with a group struggling to get started, Edith asked, "What steps have you taken?" It became apparent that the group was struggling with the design aspects of the problem. Edith helped the group develop a flow chart that broke the challenge down into steps. Glenn noted this technique and recommended that every group follow a similar procedure. "With a blueprint and some time and patience," Edith announced, "you can get your robot to do just about anything."

Between visits, Edith and Glenn talked through new and interesting challenges. Edith found it helpful to think about her work with her DoD colleagues and run her ideas by Glenn. Glenn drew on his experience with the Botball club. In subsequent visits, Edith, Glenn, and his students programmed robots to complete a range of different tasks based on real-world challenges. Wishing to do more with robots, many students joined the Botball Club.

RECOMMENDATIONS FOR FUTURE WORK

Our work in this study revealed that the PEP programs are spreading rapidly throughout the network of DoD laboratories and that participants generally welcome the opportunity to collaborate on improving student learning and interest in STEM. As with any developing program, areas for improvement and extension are present. In closing this report, then, we offer the following recommendations, in priority order, that NDEP may wish to consider based on the findings reported above.

- Develop a **common evaluation approach** for all sites. Consider applying or adapting an evaluation guidebook such as Shear and colleague's (2007), "Measuring Learning: A Guidebook for Gathering and Interpreting Evidence." Support sites in conducting self-evaluations to determine how they are progressing toward maturity and sustainability.
- Support and extend efforts already under way to develop **guidebooks for PEP sites.** Supplement the guidebooks with **research findings** that help STEM professionals appreciate the academic, social, and cultural challenges that students who are from underserved groups face, to help sites that work with such groups.
- **Localize teacher professional development** to leverage existing efforts by teaching colleges or community colleges.
- Share best practices for **training S&Es** to prepare for the classroom, including ways to prevent them from becoming overburdened and clarifying roles and responsibilities with teachers.
- Encourage sites to use **partnership models** between teachers and students and use the quality of the partnership as an evaluation criterion instead of measures such as contact hours or frequency.
- Support mapping PEP-supported resources to **state standards.**
- Offer a variety of PEP resources that are **more to less open-ended** and that can be **adapted** to different approaches to teaching.
- Document the existing models of S&E classroom participation and consider other roles for S&Es such as support for **student science competitions.**

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APPENDIX A:
OUTREACH PROGRAMS IN SCIENCE AND ENGINEERING

In this Appendix we provide more background information on outreach programs reported in the literature. One set of projects focuses on authentic challenges in the context of student-scientist partnerships (SSPs) both in school and after school. These projects do not encompass engineering activities. Closely related to these partnership projects are ones that leverage local geographical regions around schools (e.g., for studying local ecologies), and projects that extend over time. Teacher learning of science or engineering content can be an outcome of any outreach project and we describe one that focuses instead on teaching the process of scientific reasoning.

Finally, in this Appendix we provide background on the need for S&Es to understand learning challenges in order to be more effective in influencing students, and the role that scientist and engineering professionals can play with underserved populations.

Scientists and engineers work on challenges that are as authentic as possible. Active participation and collaboration among students and STEM professionals allow students to learn by doing, receive feedback from those with domain-specific expertise, and continually refine their understanding and build new knowledge about STEM and STEM-related careers. In student-scientist partnerships (SSPs), students work closely with one or more scientists for extended periods on authentic problems or projects. By undertaking authentic science "at the elbows" of experts, students learn from that process, with teaching and explanation in context, rather than through the direct teaching of science facts (Barab & Hay, 2001).

STEM-related conversations among students and professionals allow students to begin talking within the community of practicing STEM professionals. Active communication and collaboration serve as vehicles for students' identity changes, and "newcomers become part of a community of practice" (Lave & Wenger, 1991, p. 29). In the evaluation of the GLOBE Project—an international environmental education program in which students and teachers collaborate with scientists to collect and understand environmental data—Penuel and colleagues (2006) report instances in which students, when asked to draw scientists, drew pictures of themselves. In addition to changes in self-identity, they report positive and statistically significant student gain scores in science content and scientific inquiry.

For authentic learning to happen through interaction with scientists and their projects, students need to engage and perform authentic activities (Barab, Squire, & Dueber, 2000; Rahm, Miller, Hartley, & Moore, 2003). By working collaboratively with STEM professionals over time through SSPs, students self-identify as STEM workers as they (1) learn the disciplinary principles and concepts of STEM, (2) acquire the reasoning and procedural skills of STEM professionals, (3) devise and carry out investigations that test their ideas, and (4) understand why such investigations are powerful (based on NRC, 2000b).

However, SSPs can go beyond in-school learning. Penuel and colleagues note (2006): "SSPs provide valuable authentic learning opportunities because the contact with scientists provides motivation for learning science and pursuing science careers" (p. 54). The Aquanaut Program—a collaboration among students, teachers, and scientists to collect, analyze, and make public environmental data to answer fundamental questions about the marine environment—underscores the far-reaching impact of SSPs. Evaluations of the program, as reported by Babb, Scheifele, and Tedeschi (1997), reveal that not only were teachers and students motivated by scientists to participate in scientific projects, but many students also went on to attend college and pursue science careers. In a sample of more than half the program's 855 alumni, for example, 70 percent of those in college said the program had "directly and positively affected their choice to pursue a career in the sciences, engineering, or mathematics" (p. 79).

Students can conduct STEM activities in their own region. Through the "The Earth Day: Forest Watch Program," as Lauten and Lauten (1998) report, primary and secondary school students engage in field laboratories and remote-data analysis methods to assess the health of local coniferous species. Their activities model those completed by university scientists involved in ongoing research on assessing the health of coniferous species. This SSP provides opportunities for interdisciplinary science-mathematics learning as students quantify, represent, analyze, and interpret meaningful, real data.

Classroom activities should extend over time. During a long-running activity, students communicate and collaborate more with scientists and engineers. For example, GLOBE projects originally were short, but over the course of the program lengthened into multiyear partnerships between scientists and classrooms. In this model, graduate students made up some of the outreach personnel (an impractical solution for private industry and government laboratories, however). Tinker (1997) proposed four models of student-scientist partnerships: scientist-led, scientist-guided, instrument-centered, and student-led. Each of these partnerships has different affordances for scientists and students, and each also takes different amounts of time. Drayton and Falk (2006) have a similar model that takes into account whose questions are being asked, whether the information is for classroom or external consumption, and so on. These models can help in planning, if desired, a longer project.

Extended activities often arise from project-based learning, a common way to bring community experts into the classroom. Armstrong (2002) documents a geometry class in which teams of high school students compete yearly to design a high school for learners in 2050. After a 6-week course of study, design, and production, teams submit their budget, floor plans, scale model, site plan, and written proposal to established school architects for evaluation and feedback.

Teacher Learning. The Cornell Science Inquiry Partnerships (CSIP, described in Trautmann & MaKinster, 2005) looks at ways in which graduate students work to help their partner teachers overcome obstacles to inquiry-based teaching. Teachers identified four obstacles to implementing inquiry in their classrooms: (1) state-mandated curricula and the accompanying high-stakes final exams, (2) other time-related constraints, (3) students' expectations and abilities, and (4) teachers' fear of launching into the unknown. When teachers observe graduate students modeling inquiry activities where the results do not agree with the hypothesis, they see what is possible and take more risks than before. In the classroom, scientists and engineers can model experimental thinking and the discussion of unexpected results in further learning.

Engineers and scientists should understand learning challenges. Essentialism is the belief that certain characteristics (of individuals or categories) may be relatively stable, unchanging, likely to be present at birth, and biologically based. Gelman, Heyman, and Legare (2007) recently examined how different essentialist beliefs interrelate. For example, does thinking that a property is innate imply that the property is believed to be changeable? Four studies were conducted, examining how children (n = 195, grades 1-7) and adults (n = 187) reason about familiar and novel social characteristics. By third grade, children showed some coherence of essentialist beliefs. In contrast, younger children expected less interrelatedness among dimensions than older children or adults. These findings suggest that essentialist attributions at first consist of separate strands that children eventually link together into a more coherent understanding. Two naïve theories of learning contribute to what Perkins (1992) has characterized as "The Trivial Pursuit Theory" of learning: learning is a matter of accumulating a large repertoire of facts and routines, and success in learning depends on ability much more than effort. "Learning," as Perkins (1992) argues, "is a consequence of thinking. Retention, understanding, and the active use of knowledge can be brought about only by learning experiences in which learners think about and think with what they are learning" (p. 8). "Understanding," as Perkins argues, "means more than repeating explanations found in the book, and youngsters typically do not see models of that kind of generative thinking, nor are they asked to engage in such thinking themselves" (p. 50).

STEM professionals should serve as role models "for underserved students"? . SRI has experience with supporting underserved middle school girls in learning about design and information technology careers. Programs that expose girls to STEM careers can have influence girls' career choices (Halpern et al., 2007; National Center for Women & Information Technology (NCWIT), 2007) and interactions with role models and internships where youth are actively engaged in STEM tasks affect girls' career considerations (Denner & Werner, 2005; Hill & Pettus, 1990; Packard and Nguyen, 2003; Tisdal, 2005). In the NSF-supported BuildIT project, underserved middle school girls learned about design and information technology careers. SRI developed a curriculum that used design and communication technologies to inspire middle school girls to become more technology fluent and to consider information technology careers. This curriculum was tested and adopted by the Girls Inc. network of after-school programs. A new SRI project, InnovaTE3, will support girls engaging with STEM professionals through field trips, internships, and opportunities to present their own innovations to the science and business community for feedback and potential support. Girls will learn that solving "grand challenges" in science, such as the environmental issues that we face, requires expertise from multiple science disciplines. Having girls engage directly with grand challenges in STEM fields provides an opportunity to develop their interest by tying STEM learning to problems of great social importance. Girls will receive compelling evidence that "science matters" by seeing the basic science underlying these important social problems.

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APPENDIX B:
PROCUREMENT DETAILS FOR RECOMMENDED RESOURCES

Calculator Controlled Robots

	Instruments	Teacher's Guide	Optional Add-Ons
	Hardware: Calculator-Controlled Robots[1]	Calculator-Controlled Robots: Hands-on Mathematics and Science Discovery Educator Guide[2]	More activities from Norland Research[3]
Cost per Unit	$100		
Cost per Class of 28 Students	$700		
Notes: Assumes graphing calculator; e.g., Texas Instruments TI-83 (all editions), TI-73, TI-82, TI-83, TI-83 (all editions), TI-85(CBL model), TI-86, TI-89, TI-89 Titanium, TI-92, TI-92 Plus, and Voyage 200 (will not mount on base).			

Links:

[1] http://www.smallrobot.com/scimath.html
[2] http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Calculator-Controlled_Robots.html
[3] http://www.smallrobot.com/school.html

Lego Education pack for Middle Schools

	Instruments	Teacher's Guide	Optional Add-Ons
	Hardware: Simple and Motorized Mechanisms Base Set[4]	Activity Guides: • Introducing Simple and Motorized Mechanisms Activity Pack[5] • Advancing with Simple and Motorized Mechanisms Activity Pack[6]	• Pneumatics Add-On Set[7] ($55) • Pneumatics Activity Pack Teachers Guide[8] ($55) • Motor Add-On Set[9] ($36)
Cost per Unit	$135	$140	$141
Cost per Class of 28 Students	$945	$140	$141 (add on set for special projects, not one per group)
Notes: The printed guide includes a CD ROM with printable worksheets.			

Links:

[4] http://www.legoeducation.com/store/detail.aspx?ID=1667&c=0&t=0&l=0&bhcp=1
[5] http://www.legoeducation.com/store/detail.aspx?ID=1672
[6] http://www.legoeducation.com/store/detail.aspx?ID=1673
[7] http://www.legoeducation.com/store/detail.aspx?ID=1572
[8] http://www.legoeducation.com/store/detail.aspx?ID=1584
[9] http://www.legoeducation.com/store/detail.aspx?ID=1439

Participatory Simulations

	Instruments	Teacher's Guide	Optional Add-Ons
	Software: MIT Participatory Simulations[10]	Curriculum is available for three of the games.[11]	StarLogo: The Next Generation[12]
Cost per Unit	$0		
Cost per Class of 28 Students	$0		
Notes: Assumes PDA platform: Palm OS 3.5 or greater, including M100 series, M500 series, Tungsten, Zire, and many Handspring and Clie models			

Links:

[10] http://education.mit.edu/drupal/pda

[11] http://education.mit.edu/drupal/pda

[12] http://education.mit.edu/drupal/starlogo-tng

Vernier LabQuest

	Instruments	Teacher's Guide	Optional Add-Ons
	All kits contain five sensors: • light • motion detector • pH • temperature • voltage LabQuest Middle School Science Package[13] (standalone, $612) LabPro Middle School Science Packages[14] (one package is purchased per computer, calculator, or handheld, $491) Go! Middle School Science Packages[15] (one package is purchased per computer, $384) Easy Middle School Science Packages[16] (one is purchased package per calculator, $346)	Printed guide includes CD ROM with editable worksheets, available in Middle School Science with Vernier[17]	Additional sensors for any set[18]: • conductivity • force • gas • pressure • heart rate • magnetic field Software $189 unlimited. Logger Pro 3[19] (assumes computers running Windows XP, Vista, or Vista 64-bit Mac OS X 10.4, 10.5)
Cost per Unit	$612/$491/$384/$246	$48	$464
Cost per Class of 28 Students	$4284/$3437/$2688/ $2422	$48	$3248

Links:

[13] http://www.vernier.com/pkgs/labquest/middleschool.html

[14] http://www.vernier.com/pkgs/middleschool.html

[15] http://www.vernier.com/pkgs/gomiddleschool.html

[16] http://www.vernier.com/pkgs/easymiddleschool.html

[17] http://www.vernier.com/cmat/msv.html

[18] http://www.vernier.com/pkgs/labquest/middleschool.html

[19] http://www.vernier.com/soft/lp.html

TinkerPlots

	Instruments	Teacher's Guide	Optional Add-Ons
	Software: • $90 for 1 license • $300 for 10 licenses • $700 for 50 licenses • $1000 for a site license[20]	Exploring Data with TinkerPlots[21]	Digging into Data with TinkerPlots[22]
Cost per Unit	$300	$19.95	$50
Cost per Class of 28 Students	$300		$50
Notes: Assumes the following computer operating systems Windows 2000, XP, Vista or later. Macintosh PowerPC- or Intel-based system; Mac OS 10.2 or later. Inquiry-based lessons.			

Links:

[20] http://www.keypress.com/x5687.xml
[21] http://www.keypress.com/x18150.xml
[22] http://www.keypress.com/x17494.xml

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