Inquiry and Design Approach to STEM Education using Project-based Learning

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ABSTRACT

In the 21st century it is time to effectively apply the Chinese Proverb, "Tell me and I'll forget; show me and I may remember; involve me and I'll understand" to Science Technology Engineering and Mathematics (STEM) K-12 education (Edwards and Muir, 2004). An effective means to apply this proverb to STEM learning is through the use of combining Project-Based Learning (PBL) with Inquiry and Design (I&D) Instruction. PBL is accomplished by conducting a comprehensive study of a particular topic by means of engaging at several different decision making junctures (Moursund, Kafai, Sandoval, Enyedy, Nixon, Herrera, and Stewart, 2002). Currently PBL activities are used extensively in post-secondary academia and by industry (internships). Learners who are exposed to PBL environments not only actively apply engineering and science understanding, but also tend to obtain a more concrete foundation of science and mathematical knowledge (Lou, Shih, Diez, and Tseng, 2011). Research indicates it is essential to engage a learner's interest in a technical career path by establishing a link between the theoretical knowledge and its application to solve real life problems early on in the learning experience (Verma, 2011). I&D, which is attracting interest among STEM educators nationwide, emulates the scientific method in the classroom. I&D is a student-centered approach emphasizing the integration of inquiry (science, technology and mathematics) and design (engineering) elements. The intent of this paper is to illustrate how three existing PBL programs can be successfully combined with the I&D teaching methodology to effectively teach K-12 STEM education curricula. The three programs are: 1) Engineering our Future, 2) Materials World Modules, and 3) SeaPerch. From these exemplar programs, schools can better decide with confidence how to adopt these or similar STEM programs into their formal and informal STEM programs.

ABOUT THE AUTHORS

Mrs. Danielle McNeely is an Assistant Project Manager (APJM) for Research & Technology Programs at Naval Air Warfare Center Training Systems Division (NAWCTSD) and directly supports the Command's extensive STEM outreach program efforts. Mrs. McNeely received her M.S. in Modeling and Simulation from University of Central Florida (UCF) and her M.S. in Psychology from Capella University. Her B.S. is in Human Factors from Embry-Riddle Aeronautical University. Mrs. McNeely has also served as an APJM for the Surface and Expeditionary Warfare Directorate with direct support to the Surface Fire Fighting, Damage Control, and Fire Fighting Contractor Operation and Maintenance Services (COMS) training systems.

Mr. Robert Seltzer currently serves as the Deputy Director of the Research and Technology Program Office and as the Command's STEM Outreach Coordinator (since 2009). Mr. Seltzer has worked for NAWCTSD for 32 years as an aerospace engineer and research program manager. He holds a B.S. in Aerospace Engineering (Polytechnic Institute of NY) and M.S. Degrees in Aerospace Engineering (Purdue University) and Engineering Management (National Technology University). He serves as NAWCTSD's liaison to the Central Florida STEM Education Council.

Dr. Stephen Priselac is Executive Director of the National Center for the Advancement of STEM Education (nCASE), an educational non-profit organization located in Uniontown, Pennsylvania. Dr. Priselac received his Ed.D. in education administration from West Virginia University (WVU) and M.A. from WVU emphasizing physics and chemistry. His B.S. is in physics and mathematics from Waynesburg College (PA). He strongly believes that the total education network and the community at large must work cooperatively to make a good educational system better. He emphasizes the mastery of the basics while integrating manipulatives and technology into the curriculum to build a better citizen for the 21st century.

Dr. Nancy Priselac is Director for Programs and Training for nCASE located in Uniontown, Pennsylvania. Dr. Priselac received her doctorate from West Virginia University in Educational Administration with minors in Mathematics and Personnel Management. Her M.A. is in Mathematics and Physical Science from WVU and a B.S. in Mathematics with a minor in Physical Science from Waynesburg College. She has more than 50 years of experience in education. She is an activity-based teacher-facilitator and trainer who loves to work with students of all ages as she leads them to discover why they need to learn and understand math in order to solve real-world problems. She believes that learning mathematics and science can and should be "FUN."

Ms. Heather Norton is Orlando Science Center's (OSC) Vice President of Education, has worked in the field of informal education for over 10 years. In her current position, Ms. Norton oversees all educational programming at the Orlando Science Center. Under Ms. Norton's leadership, our educational offerings have transformed into best practice examples of STEM learning. Ms. Norton has developed countless research-backed curricula and science programming for OSC school outreach programs as well as developed and facilitated several teacher development seminars for Orange County teachers. Under her leadership, OSC's school programs have skyrocketed in popularity and in community support. She currently supervises a team of over 30 trained educators.

Ms. Alicia Frascati is OSC's Director of Strategic Partnerships, holds a B.A. from University of Central Florida in psychology and a Masters of Nonprofit Management also from UCF. For the past 7 years she has provided fundraising support, grant and project management for organizations like the Jane Goodall Institute, UCP of Central Florida and now the Orlando Science Center. As Director of Strategic Partnerships, she manages partnerships between Orlando Science Center and various corporations, community groups, school systems and Universities with the overarching goal of generating resources and opportunities to deliver high quality STEM learning experiences to the community.

Mrs. Susan Nelson currently serves as the Executive Director of SeaPerch, an outreach program managed by the Association for Unmanned Vehicle Systems Foundation (AUVSIF). The program, founded by Nelson in 2007, is designed to find the next generation of STEM professionals, reaches students throughout the U.S. and extends to 10 countries. She is currently studying for a graduate degree in Integrated Marketing Communication at Lasell College. Nelson received her undergraduate degree in Organizational Development at Geneva College in Beaver Falls, Pennsylvania.

Ms. Eileen Smith is the Director of the UCF Institute for Simulation & Training's E2i Creative Studio, bringing a thorough knowledge of the lifelong learning journey from 25 years leading creative teams in interactive learning experience research, development, implementation and assessment. She works with the Florida High Tech Corridor Council in developing initiatives for secondary educators and students in the 23-county Corridor service area to strengthen the pipeline of high-tech workforce development from middle school to career. Her overall research goal is to explore how the spectrum of technology can be used in understanding and improving human performance.

Mr. Abdul Siddiqui started working for the US Army as a Systems Engineer in 1991. He was the Software Engineering Manager for the Bradley Fighting Vehicle System, TACOM from 1998 to 2004. He is currently the resident subject matter expert in software architecture development for systems and product lines at US Army Program Executive Office for Simulation, Training and Instrumentation (PEO STRI). He is the Engineering Mentor and STEM Coordinator for PEO STRI and serves as the liaison to the Central Florida STEM Education Council. Mr. Siddiqui received his Master of Science in Software Engineering at the Naval Postgraduate School, California.

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BACKGROUND

The intent of this paper is to illustrate how three existing Project-Based Learning (PBL) programs can be successfully combined with the Inquiry and Design (I&D) teaching methodology to effectively teach K-12 Science, Technology, Engineering, and Mathematics (STEM) educational curricula. The three programs discussed as exemplars are: 1) Materials World Modules, 2) SeaPerch, and 3) Engineering our Future. Using these exemplars, schools can better decide with confidence how to adopt these or similar STEM programs into their formal and informal STEM programs.

A national STEM crisis has been on-going since 2008 and there is no sign of it waning. There will not be enough qualified STEM workers to fill open positions. The growing demand for STEM workers will likely outpace the supply by about 1 million additional STEM workers by 2020, although the gap might be as high as 2.5 million workers (National Research Council, 2012; and Carnevale and Rose, 2011). In 2013 job listings for software developers pulled from all over the World Wide Web were found to be up 120 percent over the previous year (Lombardi, 2013).

Using the national statistics for the U.S. high school class of 2005 as an example, Figure 1 illustrates how the flow

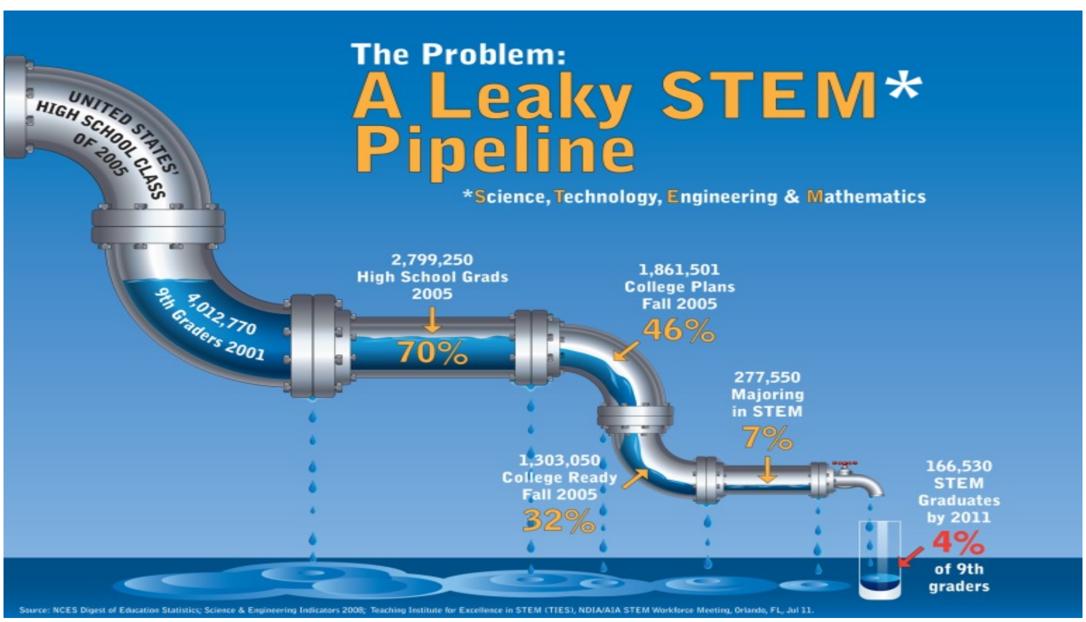


Figure 1. STEM Student Pipeline

of students through the K-12 educational system diminishes between 9th grade and college and its failure to produce a sufficient number of students interested in pursuing a post-secondary STEM discipline. It further shows how even after self-selecting a STEM major in college, the U.S. is not producing a sufficient number of post-secondary graduates in STEM disciplines (National Center for Education Statistics, 2011 & 2013). Using the 2001 9th graders as an example, the National Center for Education Statistics (NCES) (2011) shows that of the 32% of students who were college ready in 2005, only 7% of them chose to major in a STEM discipline and of those, only 4% actually graduated. This supply is not sufficient for the U.S. Department of Defense (DoD) to satisfy its demand for scientists and engineers (S&Es) when you consider the additional security requirements (citizenship, etc.) required to work in the defense industry (Xue and Larson, 2015). For example, in 2012 there were 800 funded positions left open for 90 days or more for S&Es positions (Xue and Larson, 2015). Recruiting at the bachelor's level has been found simpler than recruiting personnel with advanced degrees due to: (1) skillset mismatches (2) citizenship, (3) security clearance requirements, and (4) lack of competitive salary compared to private sector employers (Xue and Larson, 2015), so not having enough recent graduates further exacerbates recruitment.

As recently as March 23, 2015, during the White House Science Fair, President Obama announced there were more than $240 million in corporate pledges toward a total of $1 billion to boost study in STEM fields. This effort is to encourage early career scientists to stay on track and also to expand STEM opportunities to under-represented youth, such as minorities and girls. More than 100 colleges and universities have committed to training 20,000 engineers, and a coalition of Chief Executive Officers (CEOs) has promised to expand high quality STEM education programs to an additional 1.5 million students this year. (National Science and Technology Council, 2013).

HISTORICAL INSTRUCTIONAL METHODS

Disputes about the impact of instructional guidance during teaching have been ongoing for at least the past half-century (Ausubel, 1964; Craig, 1956; Mayer, 2004 Shulman & Keisler, 1966). On one side of this argument are those advocating the hypotheses that people learn best in an unguided or minimally guided environment, generally defined as one in which learners, rather than being presented with essential information, must discover or construct essential information for themselves (e.g., Bruner, 1961; Papert, 1980; Steffe & Gale, 1995). On the other side are those suggesting that novice learners should be provided with direct instructional guidance on the concepts and procedures required by a particular discipline and should not be left to discover those procedures by themselves (e.g., Cronbach & Snow, 1977; Klahr & Nigam, 2004; Mayer, 2004; Shulman & Keisler, 1966; Sweller, 2003). Direct instructional guidance is defined as providing information that fully explains the concepts and procedures students are required to learn as well as learning strategy support compatible with human cognitive architecture. Nowhere has this debate appeared more clearly in the literature than in the series of three articles published in Educational Psychologist in 2006/2007. In the first of the related articles, Kirschner, Sweller & Clark (2006) argued that unguided PBL instructional approaches are less effective and efficient for novices than guided instructional approaches.

In the first of two follow-up/rebuttal papers, Schmidt, Loyens, Van Gog and Paas (2007) counter argue that PBL is an instructional approach that allows for flexible adaptation of guidance and that contrary to Kirschner et. al.'s (2006) conclusions, its underlying principles are very compatible with the manner in which human cognitive structures are organized. The second of the papers written by Hmelo-Silver, Duncan &

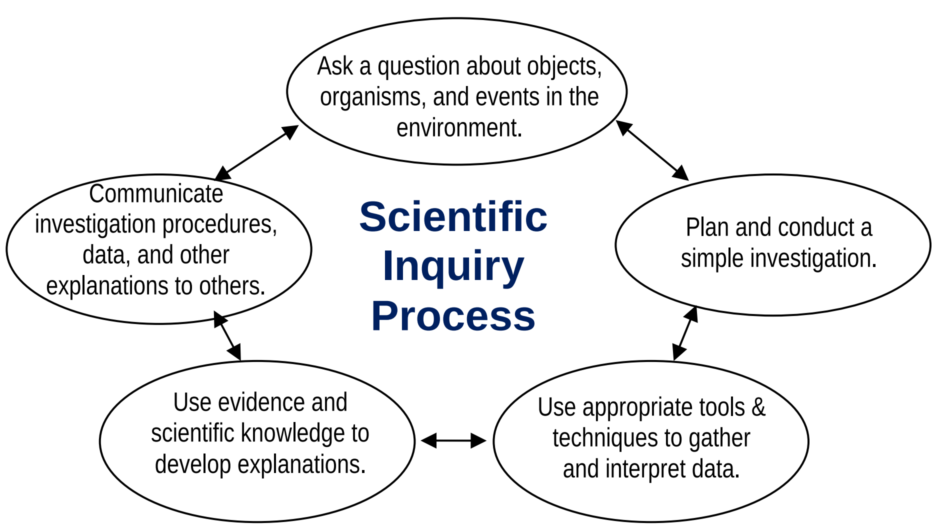


Figure 2. Inquiry Process Model

Chinn (2007), takes exception with Kirschner et. al.'s grouping of PBL and inquiry learning (IL) with discovery learning methodology and then goes on to present evidence demonstrating that PBL and inquiry learning are powerful and effective models of learning. Additionally, PBL and IL employ scaffolding extensively thereby reducing the cognitive load and allowing students to learn in complex domains. Moreover, these approaches to learning address important goals of education that include content knowledge, epistemic practices, and soft skills such as collaboration and self-directed learning (Hmelo-Silver et. al, 2007).

PBL THROUGH I&D INSTRUCTION

PBL through I&D instruction, which is attracting interest among STEM educators nationwide, emulates the scientific method in the classroom. The ultimate goal of the PBL through I&D instruction is to improve teacher content knowledge and pedagogical skills such that they create a "research environment" for STEM classrooms where **inquiry** becomes the process used by students to learn new content and **design** is the process that allows students to assume the role of scientist or engineer as they innovate and create.

A well accepted inquiry process model was developed by Carin, Bass & Contant (2005). According to the National Academy of Sciences (NAS), when students learn through inquiry (NAS, 1995), they: 1) question; 2) investigate; 3) use evidence to describe, explain, and predict; 4) connect evidence to knowledge; and 5) share findings. Each of the NAS factors can be found in the inquiry process (see Figure 2).

Researchers at Northwestern University (NWU) have adopted the Design Process Model shown in Figure 3 (Northwestern University, 1999). This is the process associated with one of the STEM exemplars called Materials World Modules that will be discussed in the next section. The hands-on design process is interactive, and students apply what they learn during the inquiry activities in real and satisfying ways.

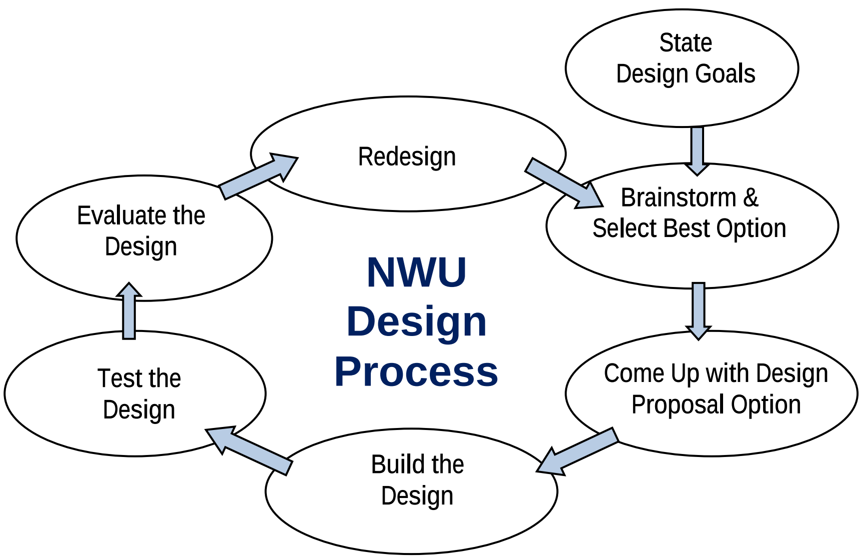


Figure 3. NWU Design Process Model

The authors of this paper agree with the PBL definition from Hmelo-Silver, Duncan & Chinn (2007): In PBL, students learn content, strategies, and self-directed learning skills through collaboratively solving problems, reflecting on their experiences, and engaging in self-directed inquiry (see Figures 2 and 3).

COMBINING PBL AND I&D INSTRUCTION

This paper demonstrates how three existing Navy-supported PBL programs can be successfully combined with the I&D teaching methodology to effectively teach K-12 STEM educational curricula. The three exemplar programs are: 1) Materials World Modules, 2) SeaPerch and 3) Engineering is Elementary®. Training for all three initiatives is strategically aligned with the National Defense Education Program (NDEP) (Domestic Policy Council, 2005), President Obama's STEM Education 5-Year Strategic Plan (National Science and Technology Council, 2013), and President Obama's "Educate to Innovate" Initiative (Office of the Press Secretary, 2009); all of which encourage U.S. youth to pursue excellence in STEM.

Additionally in 2013, the Navy System Command (NAVSYSCOM), in its Navy model for building STEM capacity through community engagement, focused on inquiry and design as one of its ten actionable components. This model provides a template for community-based STEM outreach across the federal government as well as the private sector. (NAVSYSCOM, 2013).

Exemplar 1: Materials World Modules (MWM)

The Materials World Modules (MWM) were developed by Dr. Robert Chang and his colleagues within the Materials Science Department at Northwestern University (NWU) with a multi-year grant from the National Science Foundation (NSF). MWM are hands-on inquiry and design-based units for middle school and high school students. Based on materials science and nanotechnology principles, an interdisciplinary approach is used to engage students and add relevance to traditional science curriculum.

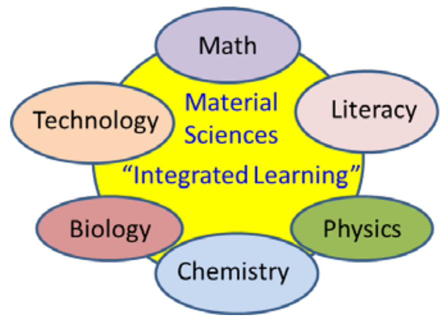


Figure 4. Integrated Learning Across Science

Each module is theme based (i.e., food packaging, sports materials, composites, nanotechnology, smart sensors, bio sensors, concrete). All use the same basic format: An initial "hook" activity to stimulate topic interest, a series of three to five activities to assist students in learning content, and a final design project that requires students to apply lessons learned while creating a solution to a proposed problem.

As an exemplar, MWM has two complementary sets of goals for the modules: content goals and process goals. The content goals focus on the science and technology content in the modules. Because they are based on topics in materials science, the modules help students see how science relates to their lives. The process goals focus on the kinds of activities students will perform. The major goal of MWM is to engage students in the processes of inquiry and design.

This exemplar integrates concepts that cross traditional subject barriers (see Figure 4). The modules address concepts from chemistry, physics, and biology and also incorporate various mathematical and technological applications. Along with the integrated science and math experience, the modules offer a well-rounded educational experience by also including supplemental lessons in history, social studies, and language arts.

In summary, the pedagogical basis of the modules is simply inquiry through design as covered in the first section of this paper. It unites the abstract quantitative methods of scientific inquiry with the more concrete methods of technological design, helping students develop and integrate these interlinked skills (Northwestern University, 1999).

The curriculum meets current educational standards at the local, state and national levels with the following standards highlighted as examples:

- Developing the abilities necessary to do scientific inquiry
- Understanding scientific inquiry
- Understanding basic material science
- Taking part in iterative design
- Understanding the relationship between science and technology
- Understanding contemporary problems
- Presenting a historical perspective

The Student Centric Classroom using MWM

Since 2006, The National Center for STEM Education (nCASE) has been teaching middle and high school teachers teamed with DoD S&Es across the country how to use the MWM curriculum in a student centric I&D STEM Classroom Model. The I&D STEM Classroom Model encourages and instructs teachers to focus on opportunities to explore with the students the integrative nature of STEM and to do so as a collaborative endeavor with them in terms of the sharing and debating of ideas. Figure 5 identifies the five major components of the I&D STEM Classroom Model.

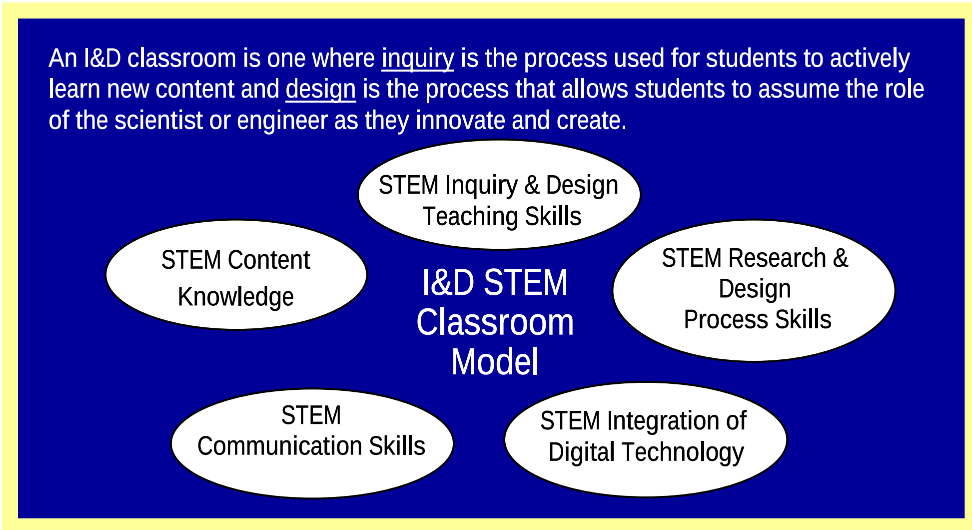
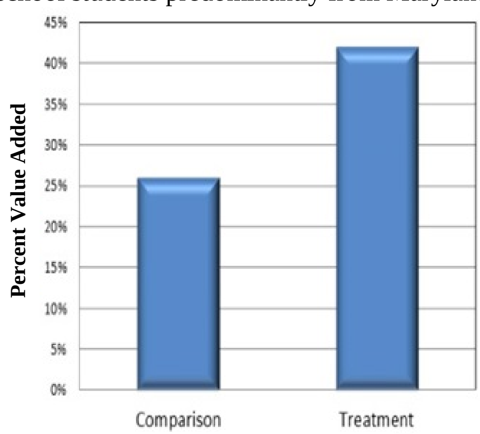


Figure 5. I&D STEM Classroom Model

Three things make the I&D STEM Classroom Model unique: 1) It combines the adaptability of the MWM program with the integration of technology, gives equal significance to the design component and uses a rigorous, data-driven, and relevant training program using problem-solving scenarios designed to mirror an authentic research environment; 2) Materials science crosses all areas of science, and the MWMs include topics not currently found in most textbooks. This gives the participating learners a level playing field so that everyone, teachers and students alike, learn the new STEM content together. Learning is assessed and modified on a daily basis. Classroom teachers are taught to use open-ended, thought-provoking questioning techniques to elicit higher-order, critical thinking from their students; 3) Inclusion of the S&E professionals in the classroom is significant because it gives teachers and students personal exposure to actual STEM role models performing cutting-edge, 21st century jobs. A mentor guide was developed in collaboration with a select team of S&Es for use in all programs. The program design and content, together with the use of the DoD S&E professionals, have created a powerful learning experience for all participants—teacher, students and S&Es.

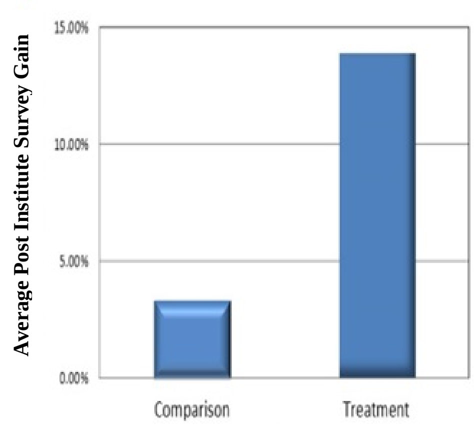
Program Metrics & Assessments

To gain insight into the effectiveness of this exemplar, two special programs were designed and conducted during the summers of 2006-2011: 1) One week of intensive, hands-on inquiry and design (I&D) training for 20 teachers from across the U.S. (grades 5 to 12), and 2) A month-long summer school session for 100 middle and senior high school students predominantly from Maryland.



Base: Pre-Test Scores

Figure 6. 2006 Summer Student Gains in Science Knowledge



Base: Pre-Institute Survey Scores

Figure 7. 2006 Summer Student Self-Assessed Gains in Attitudes and Science Skills

An independent external evaluator research firm with test development expertise was contracted to assess the summer programs. A series of data collection instruments was developed to measure cognitive and attitudinal changes towards STEM. Results for the 2006 summer students are shown in Figures 6 and 7 (ARA, 2006). The Comparison and Treatment groups were randomly selected from a pool of 401 applicants from throughout Maryland to be representative of the state's demographics (ARA, 2006). Figure 6 indicates the Treatment group exhibited a 61% increase in science knowledge over the comparison group based on pre-test scores, while Figure 7 indicates more than a triple increase in student self-assessment gains in attitudes and science skills.

An evaluation of the five-year program (2006-2011) provided compelling data regarding student gains in science knowledge and student self-assessment and attitudes toward science skills. The treatment group had statistically significant gains ($p<0.0001$ level) in science knowledge and in attitudes toward science skills statistically significant at $p<0.07$. Subsequently, two other research studies were performed with similar results reported in 2008 and 2009 (ARA, 2008; 2009). Additionally, a 42-state MWM evaluation performed by Northwestern University (Pellegrini, 2010) evidenced similar findings during its national study on the effectiveness of this exemplar.

Exemplar 2: SeaPerch

The second exemplar, SeaPerch, introduces middle and high school students to the wonders of underwater robotics by teaching them how to build an underwater robot (called a SeaPerch), build a propulsion system, develop a controller, and investigate weight and buoyancy. Teams then compete with their SeaPerches against other teams. Funded by the Office of Naval Research and managed by the Association for Unmanned Vehicle Systems International Foundation, the initiative focuses on inspiring and training the next generation of STEM professionals.

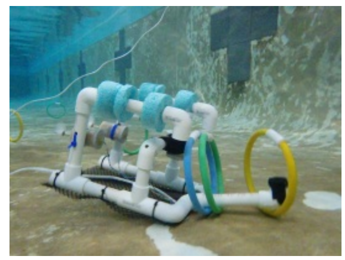


Figure 8. SeaPerch Vehicle

The SeaPerch remotely operated vehicles (ROVs) are made with PVC pipe, small electric motors, and controllers. This exemplar teaches basic skills in ship and submarine design and encourages students to explore naval architecture and marine and ocean engineering concepts independently.

The curriculum includes discussion of potential careers in technical and engineering fields, as well as related fields of study. An important piece of the exemplar's success is the existence of a curriculum which can be mapped to national science standards. Including topics such as buoyancy, displacement, motor movement, circuits and switches, ergonomics and attenuation of light, the curriculum can be applied to science, physics, math and technology classes (see Table 1).

Table 1. Mapping of SeaPerch Curriculum to National Science Education Standards

National Science Education Content Standards (Grades 5-8)	National Science Education Content Standards (Grades 9-12)
▪ **Science as Inquiry (8ASI)**	▪ **Science as Inquiry (12ASI)**
▪ Abilities necessary to do scientific inquiry (8ASI1)	▪ Abilities necessary to do scientific inquiry (12ASI1)
▪ Understandings about scientific inquiry (8ASI2)	▪ Understandings about scientific inquiry (12ASI2)
▪ **Physical Science (8BPS)**	▪ **Physical Science (12BPS)**
▪ Motions and forces (8BPS2)	▪ Motions and Forces (12BPS4)
▪ Transfer of energy (8BPS3)	▪ Conservation of energy and increase in disorder (12BPS5)
▪ **Earth and Space Science (8DESS)**	▪ Interactions of energy and matter (12BPS6)
▪ Structure of the earth system (8DESS)	▪ **Science and Technology (8EST)**
▪ **Science and Technology (8EST)**	▪ Abilities of technological designs (12EST1)
▪ Abilities of technological designs (8EST1)	▪ Understanding about science and technology (12EST2)
▪ Understanding science and technology (8EST2)	▪ **History and Nature of Science (12GHNS)**
	▪ Science as a human endeavor (12GHNS1)
	▪ Nature of scientific knowledge (12GHNS2)
	▪ Historical perspectives (12GHNS3)

From a growth perspective, this exemplar has seen phenomenal success. Figure 9 shows the growth experienced over the last seven years in terms of student participation and teacher mentors participation.

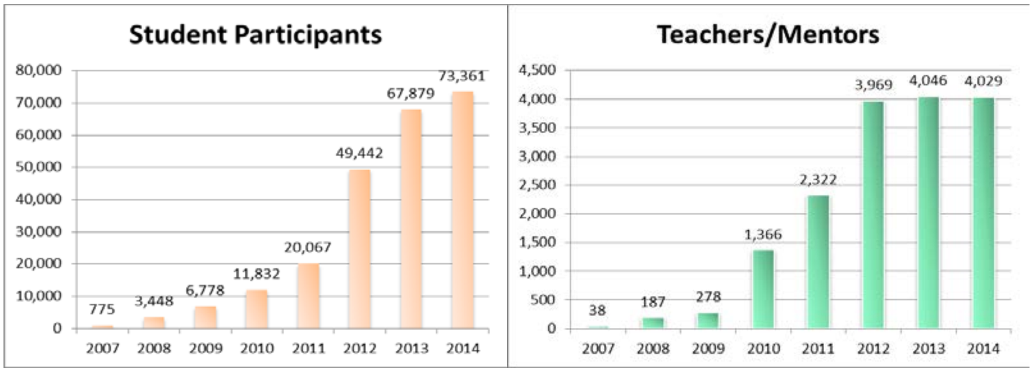


Figure 9. Growth over seven years

Program Metrics and Assessments

In terms of the impact this exemplar has had on students, the study results have been very positive. In a 2012 study, student participants (n=5,000) were surveyed and asked to respond to: 1) Helped me understand STEM better, 2) Made me think more about what I will do after graduating from high school, 3) Led me to a better understanding of my own career goals and 4) Increased my interest in studying STEM in college. Results of the survey are shown in Figure 10.

Since 2012, pre- and post-student surveys were developed to gather data on student interest in STEM-related subjects and activities before and after completing the SeaPerch exemplar. There were challenges related to the data collection based on the availability of technology and other school-related issues, including student absences and other classroom management issues. However, when the data were collected, the results showed a significant increase in student interest and efficacy in STEM subjects. In one program, 82% of students indicated a new interest in pursuing STEM in college after completing this exemplar.

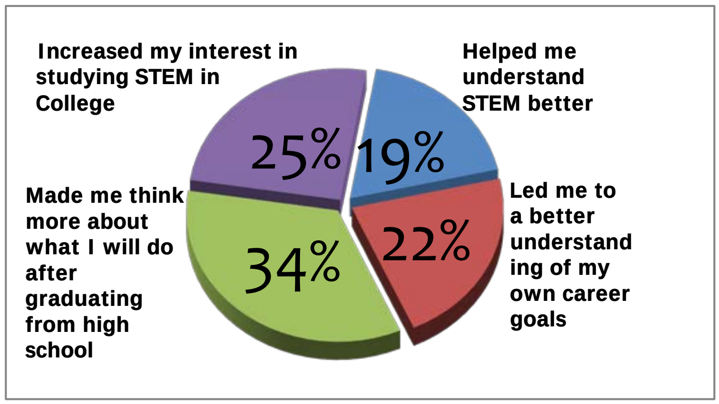


Figure 10. SeaPerch Survey Results

Since 2012, PEO STRI and NAWCTSD have teamed up to offer a ten week summer internship opportunity for high school students interested in STEM. In each of these years, the SeaPerch exemplar has been used as the baseline platform of choice to teach STEM concepts. In 2013, there were two goals: 1) Building and testing the SeaPerch and 2) Modifying the SeaPerch using the engineering design process to add an arm capable of picking items from the pool bottom. The second goal is unique to the PEO STRI and NAWCTSD program and not part of the standard SeaPerch program: Supplemental targeted STEM skills developed were use of computer-aided-design (CAD - MakerBot) to develop the robotic “Arms/claws” and using Arduino microcontrollers to provide the rotational degrees-of-freedom for the robotic arms.

On average about 26 students every Summer from five local high schools completed the internship and participated in a post-assessment. Results of the post-assessment indicate that nine 21st century skills were rated high with teamwork, knowledge gained, time management, confidence and oral communication rated among the highest.

More interesting than the quantitative results were the comments received back as part of the open responses. Because these students self-selected for the internship it was clear that they had already developed an interest in STEM. Without exception, all respondents indicated they planned to attend college and major in a STEM discipline. Selected comments received back from the students that support the value of PBL as it pertained to “increased STEM knowledge” and “most rewarding part of the internship” are listed in Table 2.

Table 2. Comments Received from Students

Increased STEM Knowledge	Most Rewarding Part of the Internship
It gave me an idea of how solving real-world problems in a team oriented environment would be and I really enjoyed myself	Learned how to work with limited feedback, working on your own rather than having someone teach you step by step
Provided insight to the practical side of science and math	Final testing and retrieving the plastic block and keys
Introduced to computer code + access to a 3-D Printer	Using the 3-D Printer to print the claw
Allowed to work w/electronics (soldering and servos), a 3-D Printer and introduced to Arduino Computer Code	Helped introduce me to application engineering when we used the programming /electronics Arduino system
Helped me see a real life application and advantages of the knowledge we gained in school - especially the Arduino programming was new to me	An experienced mentor in Mr. Siddiqui, along with the multiple guests who came in to speak, provided real examples of successful engineers who could guide us in the right direction
Gave me the opportunity to have hands on experience in a field that I am interested in	Exposed to more of what engineering and computer programming really is
By teaching me the fundamentals that scientists and engineers use when designing and testing a product	Working with my friends on an interesting, fun and challenging problem
	Being able to be a part of a team and getting to do new things I normally wouldn't be able to do
	Being able to see the final testing and knowing that you created that
	Control the SeaPerch and see that it worked as designed
	Learning how to work with others in project management
	Getting a better understanding of how robots actually function

Effective Instructional Delivery of PBL

To improve student participation and learning, the first step in effectively implementing the curriculum was to share the value of the PBL goals. The mentors informed and emphasized to the students why it's important to gain the applied understanding of the engineering design process (see Figure 3) and the fundamental science involved with how the SeaPerch works.

Ideally, the classroom and teaching structure should be designed to facilitate small mixed teams. Having the teams composed of girls and boys together has been found to facilitate greater creativity and participation by all members.

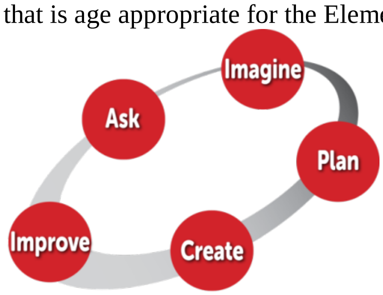
The S&Es utilize the I&D process (see Figures 2 & 3). Using this instructional process, the teachers and S&Es initially cover the subject fundamentals. This strengthens the base understanding of and brings all the students to an equal baseline understanding/knowledge/skill level (minimum required). The S&Es cover each of the subject domains using an iterative scaffolding approach. This gives the students an opportunity to experience different facets of the project and a better understanding of STEM interdependences.

The class weekly curriculum had a mix of learning and application activities scheduled. The I&D PBL process is ideal for refining the student's learning through engagement in related design activities that reinforce the learned STEM principles. The refinements used during the internship included teaching higher level STEM principles and toolsets to include the I&D process (see Figures 2 & 3), improvised design implementations using tradeoff analysis, special troubleshooting cases and the use of simulations. After the students had the foundational understanding of the STEM subject disciplines, they were then better prepared to engage in self-study and the design tasks based on using the STEM principles and toolsets mention above. These are vital STEM principles and toolsets to incorporate in the curriculum due to the fact that technology is constantly changing but these principles/toolsets are constant. Finally the S&Es guided the students on how to most effectively present their research study results to the other student teams to receive their feedback and share their design lessons learned.

Exemplar 3: Engineering Is Elementary® (EiE®)

The Executive Director of the National Center for STEM Elementary Education at St. Catherine University (2011), Mr. Anthony Murphy stated that by the time students reach fourth grade, a third of boys and girls have lost an interest in science. By eighth grade, almost 50 percent have lost interest or deemed it irrelevant. That means millions of students have dismissed these careers or lack the confidence to believe they can do science or math. By maintaining a child's interest in STEM, a community of problem solvers and innovators is created.

Like the MWM and SeaPerch exemplars discussed in the previous two sections, Engineering is Elementary® (EiE®) (National Center for Technological Literacy® (NCTL®), 2004) follows the I&D PBL instructional approach that targets the elementary school grade levels. This exemplar integrates lessons in engineering with science curricula already in place in public schools with two goals in mind: 1) Increase student technological literacy and 2) Increase elementary educators' abilities to teach engineering and technology to their students. EiE® materials make engineering fun and engaging for students by introducing them to real world problems. Using engineering principles, students work in teams to apply their knowledge of science and mathematics, and use their inquiry and problem-solving skills to design, create and improve possible solutions. This exemplar's engineering design challenges engage students in inquiry. As they analyze their team's data and make decisions about their design, students engage with content, hone their critical-thinking skills, and take ownership of their learning. Paralleling the engineering design processes that were shown in Figure 2, Figure 11 illustrates the EiE® engineering design process that is age appropriate for the Elementary school grade levels.



SHARE SOLUTIONS

- What's the best feature of your design? Why?
- What were the different steps you did to get your project to work?
- What was the hardest problem to solve?
- Did you have to do something a few times to get it to work? What?
- If you had more time, how would you improve your project?

Figure 11. EiE® Engineering Design

This exemplar includes 20 units covering challenges varying from the design of water filters and parachutes, to how to clean up an oil spill. Each unit follows a 4 part lesson plan: 1) an engineering story tied to a specific international geographic area, (e.g., Ghana, Japan, Egypt, etc.), 2) a broad view of an engineering field, 3) scientific data informing engineering design, and 4) an engineering design challenge. This exemplar describes its I&D PBL learning approach as the "Five E" learning cycle:

1) *Engagement*: Students are drawn to a challenge because it's interesting and captures the imagination.
2) *Exploration*: Students start to explore science and engineering principles through activities where they encounter problems or ask questions.
3) *Explanation*: Students describe what they think is happening. They're ready to learn from their teacher AND their peers.
4) *Elaboration*: Students apply what they've learned to the engineering design challenge.
5) *Evaluation*: Students reflect on what they have learned.

This "Five E" Model epitomizes inquiry when combined in the PBL context. Teachers are guided to use inquiry skills to engage students with question like those shown in Figure 11.

Like the other exemplars, program lesson units are mapped to national and state science curriculum standards and have been extensively evaluated and shown to produce reliable data that validates their approach. A 2010 study indicated that students who completed the EiE® curriculum were significantly more likely than their peers to report interest in being an engineer (Cunningham, Lachapelle, 2010). Students are not the only ones who benefit from this curriculum. A 2008 study showed that teachers also reported gains in STEM knowledge and skills (Faux, 2008). According to the report, participating teachers "grew significantly in their knowledge of engineering and their confidence in teaching engineering." (Faux, 2008). The study also found that these teachers exhibited "leaps in enthusiasm for engineering and even teaching in general, and had a strong commitment to continue." (Faux, 2008).

CONCLUSION AND CALL TO ACTION

This paper has discussed three exemplars that use the I&D PBL instructional model to effectively engage students in real-world STEM questions or problems. From these STEM education exemplars, schools can better decide with confidence how to adopt these or similar initiatives into their formal and informal STEM programs. The I&D PBL programs presented were shown to be a powerful learning method especially suited for building the essential 21st century skills and-knowledge (see Figure 12). Students in well-designed and managed I&D PBL projects produce reports, models, simulations, presentations, inventions, videos, etc. similar to the professional STEM domain. The activities can be evaluated for both understanding of content knowledge and the proficiency level of a range of 21st century skills. The 21st century workplace demands lifelong learners who understand how to learn and are proficient in both hard and soft skills. I&D PBL learning allows that two-sided mastery to emerge. Students are ready to learn in this new PBL environment; DOD and broader industry need employees that have the deeper thinking that these projects are seeing emerge.

Since teachers are our lifeline to students, we suggest a professional development model that is showing significant promise. Teachers are taught to create "research environments" in their classrooms. To teach in this integrated fashion, the I&D PBL instructional model, has been shown in this paper to be a highly effective approach to enhance STEM education into current academic curricula. Teachers explore STEM as a collaborative endeavor via the ultimate sharing and debating of ideas with a variety of STEM professionals (e.g., S&Es in the classroom). Instruction is focused on PBL with an emphasis on hands-on inquiry- and design-based processes. Another compounding factor to the STEM gap is inadequate teacher training. Better training for teachers in the I&D PBL instructional model is essential for stronger academic outcomes for our nation's K-12 students (Education Week, 2013). Teacher training to address the STEM gap requires STEM be taught in an integrated fashion: There are no dots between the letters in STEM.

21st Century Learner

- Creativity
- Innovation
- Problem Solving
- Data analysis /Modeling /Testing
- Communication (oral/written)
- Collaboration/Team Work
- Leadership
- Life skills (Organization, Time management, etc.)
- Negotiation/Persuasion
- Initiative/Motivation
- Perseverance
- Confidence
- Ability to Work under Pressure

Figure 12. 21st Century Learner Characteristics

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