AC 2012-3226: BEST PRACTICES IN K-12/UNIVERSITY PARTNERSHIPS

Dr. Christine Schnittka, University of Kentucky

Christine Schnittka is an Assistant Professor of STEM education at the University of Kentucky. She is the Chair of the 2012 Best Practices in K-12 and University Partnerships panel for the ASEE K-12 and Pre-college Engineering Division.

Elizabeth A. Parry, North Carolina State University

Elizabeth Parry is an engineer and consultant in K-12 STEM (science, technology, engineering, and mathematics) curriculum and professional development and the Coordinator of K-20 STEM Partnership Development at the College of Engineering at North Carolina State University. For the past 15 years, she has worked extensively with students from kindergarten to graduate school, parents, and pre-service and in service teachers to both educate and excite them about engineering. As the Co-PI and Project Director of a National Science Foundation GK-12 grant, Parry developed a highly effective tiered mentoring model for graduate and undergraduate engineering and education teams, as well as a popular family STEM event offering for both elementary and middle school communities. Projects include providing comprehensive professional development, coaching, and program consulting for multiple elementary engineering schools in several states, serving as a regional professional development partner for the Museum of Science, Boston's Engineering is Elementary curriculum program, and participating in the Family Engineering project. She currently serves as the chair of the American Society for Engineering Education K-12 and Pre-college Division and is on the executive board of the Triangle Coalition for STEM Education. Other professional affiliations include the International Technology Education Association, the National Council of Teachers of Mathematics, and the National Science Teachers Association. Prior to joining NCSU, Parry worked in engineering and management positions at IBM Corporation for 10 years and co-owned an informal science education business.

Mrs. Lizette D. Day, Rachel Freeman School of Engineering

Lizette Day is the STEM Coordinator at Rachel Freeman School of Engineering in Wilmington, N.C. She has more than 17 years of experience working with at-risk students in K-12 public education.

Dr. Augusto Z. Macalalag Jr., Stevens Institute of Technology

Augusto Macalalag, Jr., is the Assistant. Director of STEM Education Research at Stevens Institute of Technology's Center for Innovation in Engineering and Science Education (CIESE). He is responsible for developing and teaching courses, as well as conducting teacher workshops and research as part of the National Science Foundation's MSP Program. His research interests include enhancing K-12 science and engineering education through teacher pre-service and in-service programs. He received his Ed.D in science education from Rutgers University. Before joining CIESE, he taught different levels of high school physics and chemistry for seven years.

Mr. Albert Padilla Jr., Jersey City Public Schools

Albert Padilla, Jr., has been teaching for eight years middle school science. He has a B.S. in biology and an M.A. in biomedical science.

Dr. Malinda S. Zarske, University of Colorado, Boulder

Malinda Zarske is a is a former high school and middle school science and math teacher with advanced degrees in teaching secondary science from the Johns Hopkins University and in civil engineering from the University of Colorado, Boulder. She is a First-year Projects Instructor at CU, Boulder, on the development team as well as a content editor for the TeachEngineering.org digital library, and has co-created and co-taught engineering courses for both high school and undergraduate students through CU, Boulder's Integrated Teaching and Learning Program. Her primary research is on the impacts of project-based service-learning on student identity, recruitment, and retention in K-12 and undergraduate engineering.

Ms. Patty Ann Quinones, Skyline High School

Patty Quinones is the Principal of Skyline HS in the St. Vain Valley School District. She has a master's in education leadership and has been a business entrepreneur, consultant, Athletic Director, and a Division I Volleyball Head Coach. The STEM Academy focus began in 2009 and has a full curriculum focused on engineering/computer science.

Best Practices in K-12 and University Partnerships Panel Winners
ASEE K-12 and Pre-College Engineering Division

The **K-12 and Pre-College Engineering Division** of ASEE is recognizing exemplary K-12 – university partnerships in engineering education at the 2012 ASEE Annual Conference and Exposition in San Antonio, TX. To do this, the Division is sponsoring a panel session on Best Practices in K-12 and university partnerships. Submissions chosen for participation in this session demonstrate a true partnership between a K-12 school (or schools) and an engineering or engineering education school/college at a university.

Selected partnerships have *data to support proven success in the classroom* and demonstrate *engineering engagement and knowledge acquisition* by K-12 students through age appropriate activities and lessons. Best Practices Partnership Panel submissions are authored collaboratively between engineering and technology education faculty and K-12 teachers. Details on *the partnership's structure and goals,* the *strategies employed to overcome challenges and obstacles,* and *successes and lessons learned* are included.

One proposal winner was chosen at each of the following levels: pre-school or elementary school; middle school; high school. The three winning papers have been used to create a conference paper for this session.

At the elementary level, we describe a six year-long professional development partnership between Elizabeth Perry of NC State University and Lizette Day, a teacher at The Rachel Freeman School of Engineering, a public elementary school in Wilmington, NC.

At the middle school level, we describe a professional development partnership between Augusto Macalalag of Stevens Institute of Technology and Albert Padilla, a teacher at the Dr. Michael Conti School #5 in Jersey City, NJ.

At the high school level, we describe a STEM Academy partnership between the University of Colorado-Boulder's College of Engineering and Applied Science, Malinda Zarske and Patricia Quiñones, the principal of Skyline High School a part of the St. Vrain Valley School District in Longmont, CO.

PRE-SCHOOL / ELEMENTARY SCHOOL WINNER

Engineering an Elementary School: Rachel Freeman School of Engineering

Lizette Day, Rachel Freeman School of Engineering, Wilmington, NC
Elizabeth Parry, North Carolina State University, Raleigh, NC

Program overview and partnership structure

In 2007, our school was designated a magnet school by our local school board due to re-districting. The community was surveyed and a school with an engineering theme was overwhelmingly supported. The school's staff began researching and planning engineering in a K-5 setting and was contacted, through chance, by the university. Throughout the rest of the year, both parties worked together to develop and plan an engineering magnet school that would utilize the Engineering is Elementary curriculum as a primary tool. The plan addressed professional development, community/parent support, materials support and partnership support for the first three years initially.

During the 2007-2008 school year, our partner at the university provided significant professional development for the school. A five day workshop at the beginning of the year covered engineering as a problem solving process, project-based learning, understanding the components of STEM, STEM notebooks, science content, and specific engineering lessons and activities. Training and coaching continued throughout the year with monthly planning sessions with grade levels, quarterly science/engineering content training, and sessions on using STEM notebooks. Additional university faculty also visited the school for special in class lessons as well as school wide engineering activities. At the end of the school year, state mandated end of grade tests for third through fifth grade students measured students at 34% proficient in reading and 44% proficient in math.

During the 2008-2009 school year, the partnership between the university and the school continued but on a smaller scale as planned. The same activities took place, only less often. The beginning of the year training was three days and planning sessions were quarterly. Special in class lessons as well as school wide engineering activities continued. At the end of this school year, state mandated end of grade tests for third through fifth grade students measured students at 51% proficient in reading, 69% proficient in math, and 46% proficient in science; the only intervention was implementation of engineering as the pedagogical approach school wide.

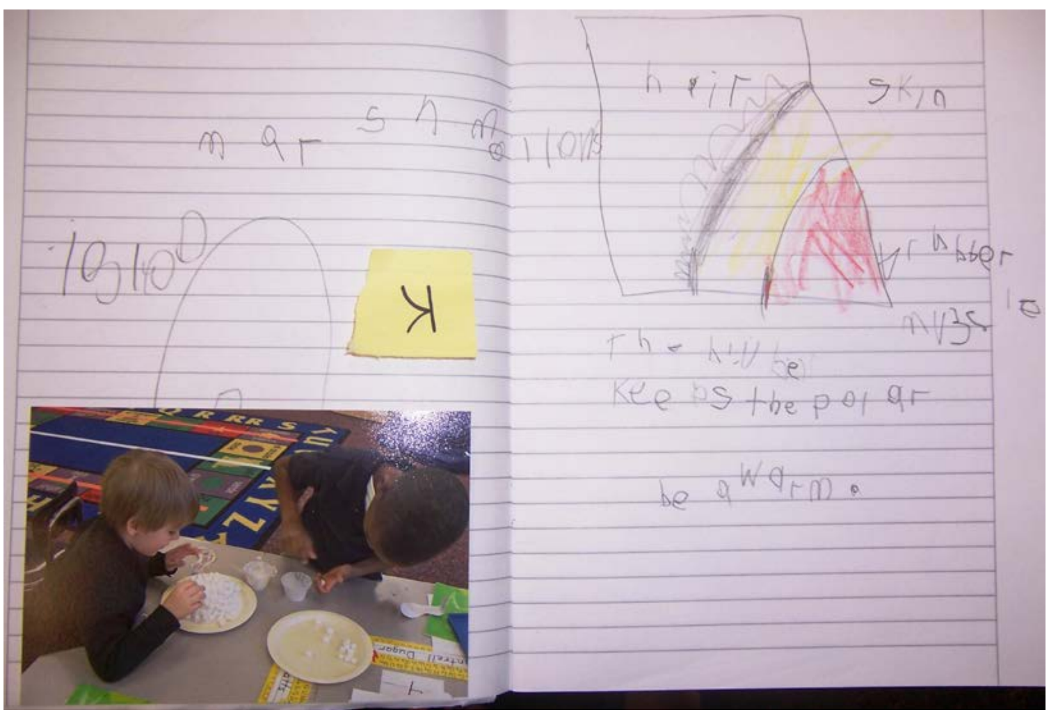
In year three, the need for widespread professional development and training continued to decrease, while the need for coaching and hands on help with lesson and activities increased. Quarterly coaching meetings with our university partner helped to pace and plan out the integration of engineering for kindergarten through fifth grades. Through a research grant funded by the National Institute of Health (NIH), the university funded and helped staff implement an after school program. University faculty, staff and graduate and undergraduate students rotated going to the school (about 115 miles away) weekly to help the school present hands on engineering and science activities to students during this program. At the end of the 2009-2010 school year, state mandated end of grade tests for third through fifth grade students measured students at 63% proficient in reading, 75% proficient in math and 83% proficient in science.

During the 2010-2011 school year, the founding principal retired, the assistant principal (relatively new to the school) was promoted and a new assistant principal with no engineering or STEM experience were hired. In addition, a local housing project where the majority of the school's students live began an extensive renovation, displacing students and resulting in changes in the student body. That year, the university funded an after school program which provided students with math and science tutoring as well as extra engineering activities. At the end of this last year, end of grade test scores fell slightly in all subject areas. Reading decreased by seven percentage points, math by five and science by 15 percentage points. These results are the focus of the school improvement team's focus for the 2011-12 year.

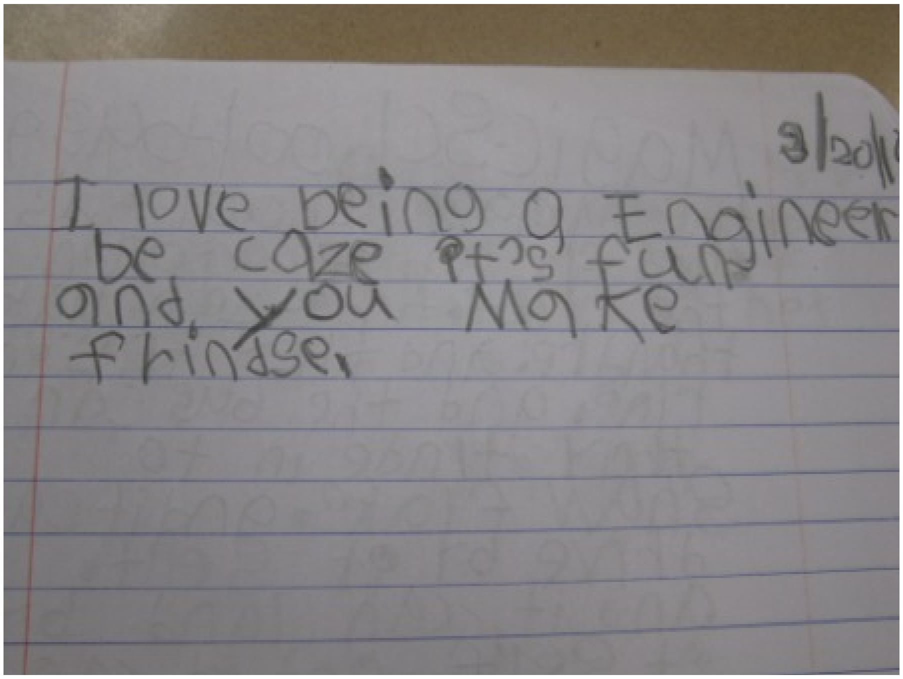
In addition to tracking the standardized test scores, the university partner and school have collaborated on ongoing research studying the efficacy of this approach. In the pilot year, the project investigation used data collected from the afterschool program students to assess science understanding, engineering and design understanding, identify STEM attitudes, engineering self-efficacy, and student assessment of teacher effectiveness. Additionally, teacher assessment of teacher effectiveness and classroom observation information was gathered. Student STEM notebooks were also evaluated. Pilot results have been disseminated through the publication and presentation of a paper at a national conference. Research results from year two are currently under analysis and will be available at time of conference.

The implementation plan developed under this partnership has been replicated at four other schools to date. The school serves as a model within and outside our state and draws visitors from around the country. The university partner and teachers and administrators from the school have collaborated on conference and workshop presentations. The partnership between the school and the university continues today. This relationship has evolved over six years and continues to be a vital part of both the school's success and provide further insight into research based approaches to elementary integrated STEM using engineering.

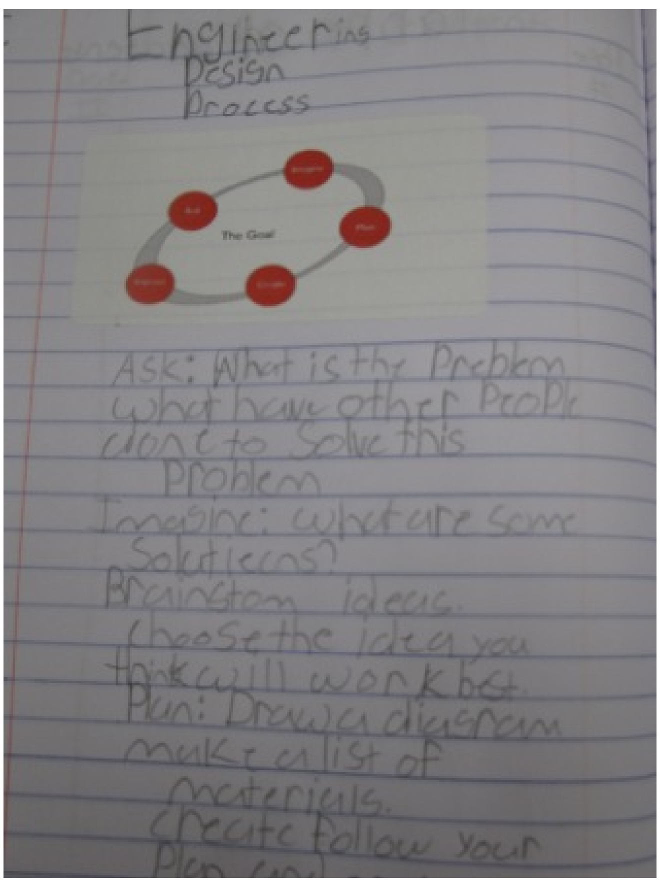
Samples of Student Work
STEM Notebooks



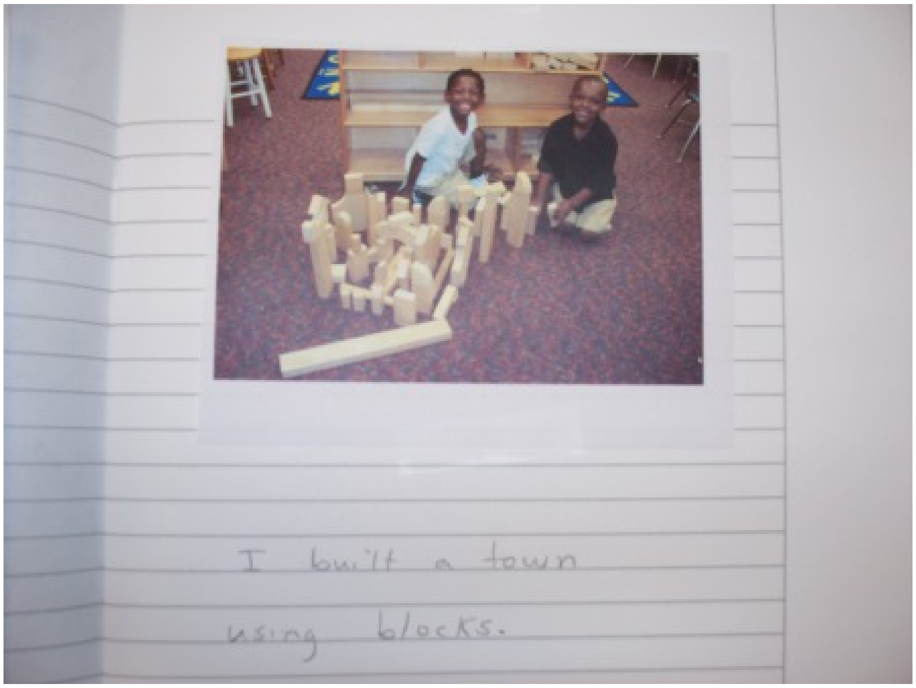
Kindergarten: Designing igloos



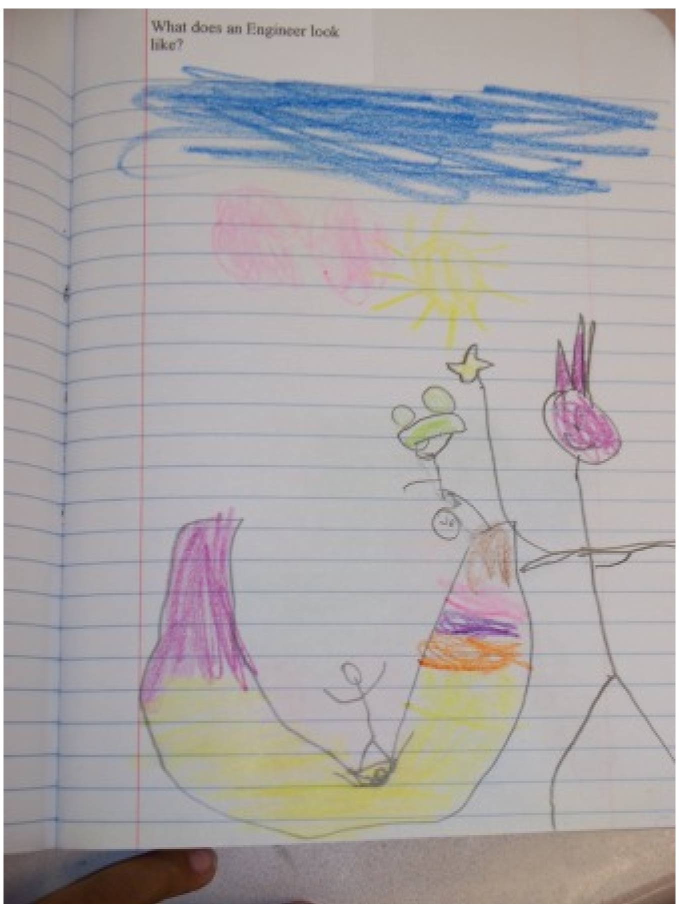
Second grade: Reflection after engineering activity



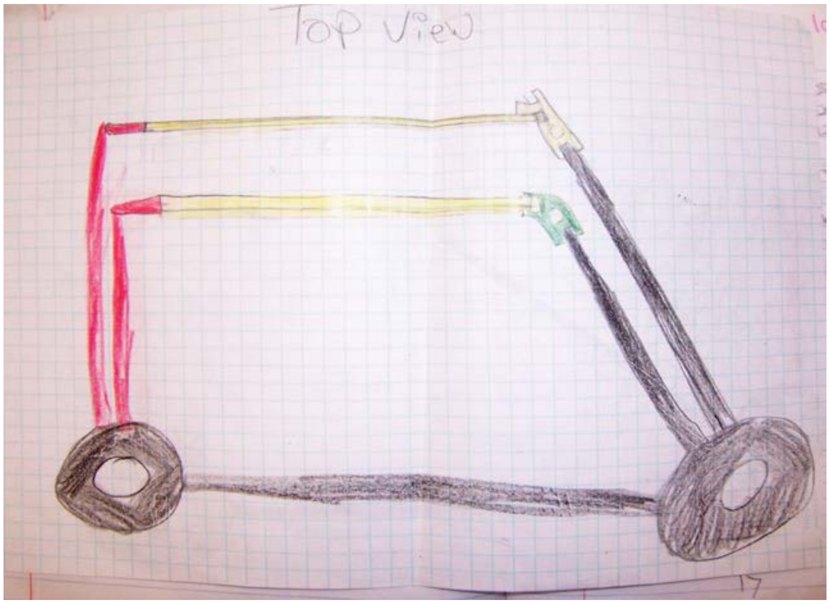
Third Grade: Design process



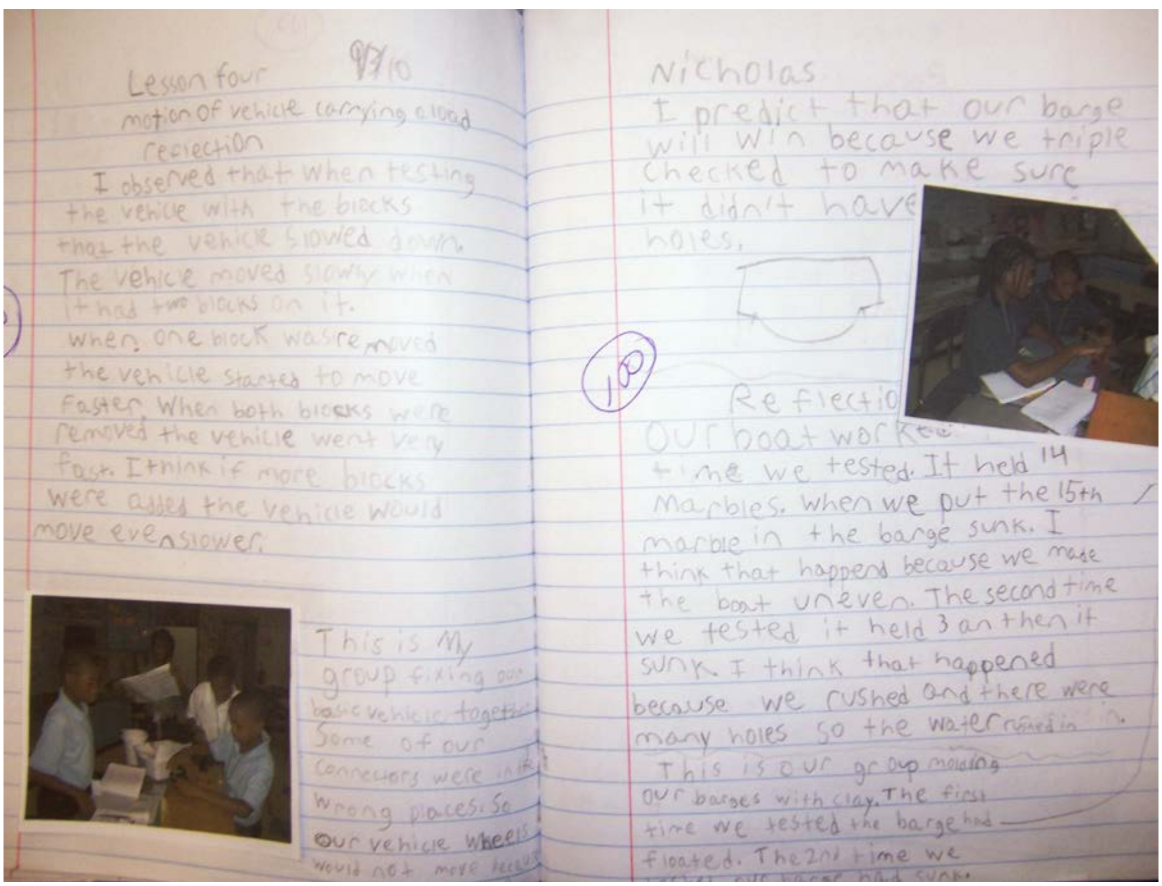
Kindergarten: Use the materials available to build a town.



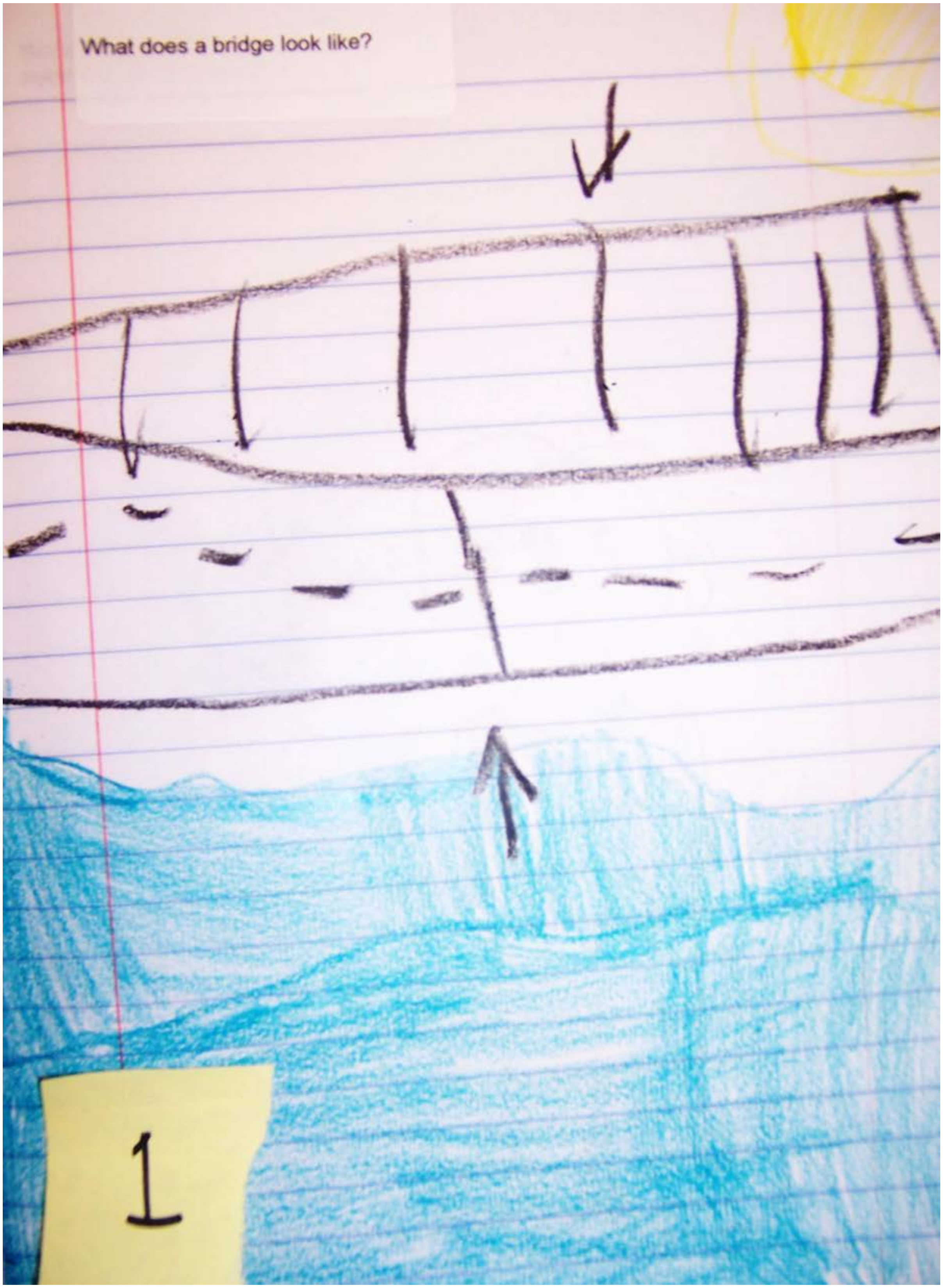
First Grade: What does an engineer look like?

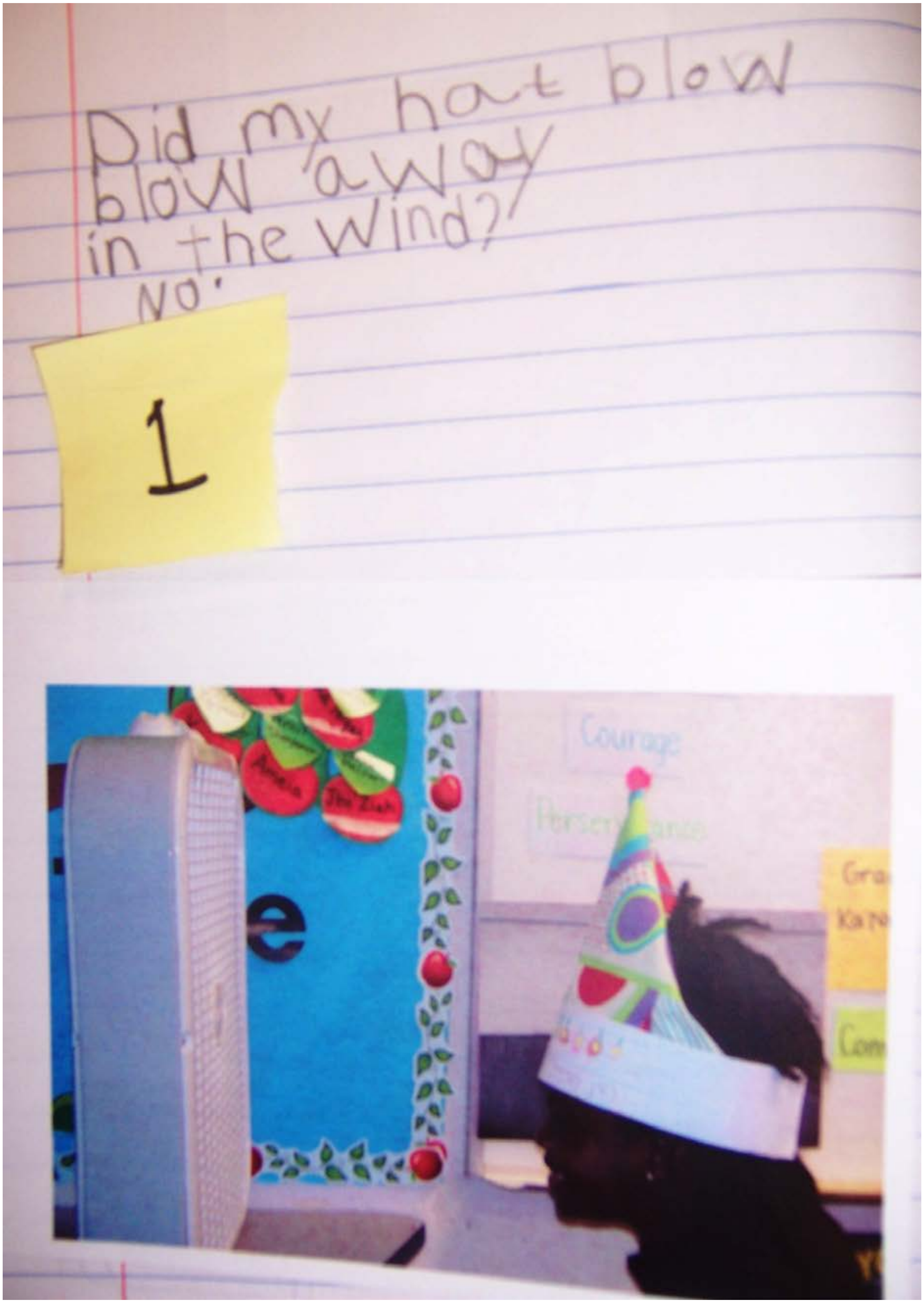


Fifth grade: Drawing of K-nex rubberband car

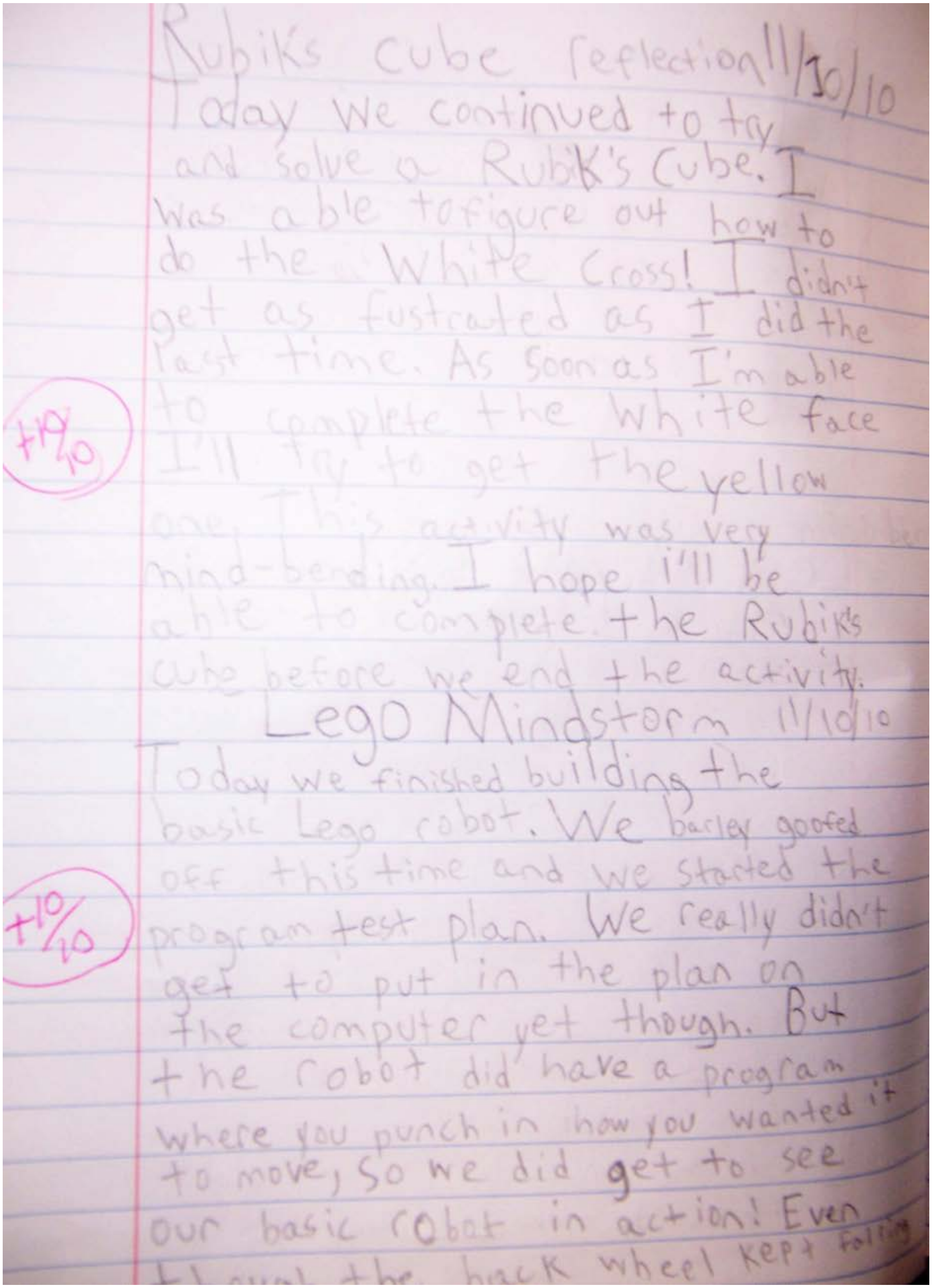


Fifth Grade: Engineering activity about motion and forces reflection


What does a bridge look like?
1


Did my hat blow
blow away
in the wind?
No.
1
Courage


What does an Engineer look like?
1



Rubiks cube reflection 11/10/10

Today we continued to try and solve a Rubik's Cube. I was able to figure out how to do the White Cross! I didn't get as fustrated as I did the last time. As soon as I'm able to complete the white face I'll try to get the yellow one. This activity was very mind-bending. I hope i'll be able to complete the Rubik's cube before we end the activity.

+10/10

Lego Mindstorm 11/10/10

Today we finished building the basic Lego robot. We barley goofed off this time and we started the program test plan. We really didn't get to put in the plan on the computer yet though. But the robot did have a program where you punch in how you wanted it to move, so we did get to see our basic robot in action! Even [illegible] the back wheel kept falling

+10/10

Fifth Grade Reflections

MIDDLE SCHOOL WINNER

Partnership to Improve Student Achievement in Physical Science: Integrating STEM Approaches (PISA^2)

Albert Padilla, Dr. Michael Conti School #5, Jersey City School District
Augusto Z. Macalalag, Jr., Stevens Institute of Technology, Hoboken, NJ

Program overview and partnership structure

Science and engineering education are seen as promising vehicles to promote 21st century skills in the classroom because they are not only a body of accepted knowledge, but also involve processes that lead to knowledge [1, 2]. For instance, the Science Teaching Standards encourages teachers to teach science through inquiry [3]. This includes engaging students in modeling and representation, learning investigations, and argumentation, which can foster critical thinking, problem solving strategies, collaboration, and communication.[4] Similarly, in the engineering design process (EDP), students are able to ask questions, propose possible solutions, construct and test prototypes, and present final products, which promote creativity, innovation, critical thinking, problem solving, communication, and collaboration (see Appendix A) [5]. Moreover, a study conducted by Kolodner et al. [6] showed that students in classes that used problem-based learning lessons performed better than those in traditional settings with respect to collaboration, metacognition, and science process skills. However, these work-related skills were found to be lacking in most high school and even college graduates [7]. Little is known regarding effective teacher professional development models of how to cultivate 21st century skills in K-12 science and engineering content and classroom activities [8]. Moreover, it is not clear what teachers know about 21st century skills and how to implement them in elementary classrooms [1].

To address some of these challenges, 42 Grade 3-8 science teachers in 11 elementary and middle schools throughout New Jersey are taking part in a professional development program that uses science inquiry and EDP to foster specific 21st century skills in their classrooms. The *Partnership to Improve Student Achievement in Physical Science: Integrating STEM Approaches (PISA^2)* includes three universities with specialization in the sciences, engineering, and education; the state's department of education; a national science education center; and twelve K-12 school districts throughout the state. Faculty members in the Stevens Schaefer School of Engineering & Sciences are working collaboratively with education specialists at the Center for Innovation in Engineering & Science Education (CIESE) to conceptualize and develop a new graduate certificate program. In this program, PISA^2 in-service teachers pursue five science courses to earn 15 graduate credits in science (see Appendix B). These courses, together with other requirements (passing the Praxis exam, taking a course in adolescent psychology) represent a critical component of the preparation necessary for teachers to earn the *Elementary School Endorsement with Science Specialization*. To date, four of the five courses were developed and offered in a hybrid (face-to-face and online coursework) mode during the 2010, 2011, and 2012 school years.

The goals of the PISA[2] are: (1) to increase teachers' content knowledge in physical and earth sciences, (2) to improve participating teachers' preparedness in creating, adapting, and delivering inquiry-based science and engineering lessons, and (3) to enhance teachers' ability to design learning environments that foster students' 21st century skills. We anticipate that by increasing teachers' content knowledge and pedagogical content knowledge in science and engineering, and by supporting teachers' implementation of science inquiry and EDP in their classrooms, we can improve students' creativity, innovation, critical thinking, problem solving, and ability to communicate and collaborate, which are essential 21st century skills [5].

Program content

Five three-credit graduate science content courses are being piloted for this program. These courses were based on the AAAS' Benchmarks for Science Literacy Clusters in the Physical Setting, the Designed World, and the Nature of Technology. Each of the five courses is introduced through the perspective of a contemporary issue in which science and engineering play a paramount role, such as energy consumption and climate change. Scientific inquiry and the engineering design process are embedded within each course as vehicles to promote 21st century skills, particularly critical thinking, problem-solving, innovation and creativity. For instance, as part of the Energy Production and Consumption Course, teachers created a plan for improving the energy efficiency of their homes. This project helped teachers gain a better understanding of the different energy sources by calculating and creating a plan for improving the energy proficiency of their homes. This included proposing an energy production scheme based on 50% fossil fuel and 50% on one of the alternative technologies that they learned from the course (PEM hydrogen fuel cells or solar photovoltaic). As part of their project, teachers also designed a lesson for their students to teach energy concepts (e.g. sources and forms of energy, energy transformations) (see Appendix C).

In addition to the courses, teachers are participating in four professional development workshops and monthly classroom support visits (planning, modeling and coaching) in 2010-2012 school years. The aim of these workshops is to enhance the teachers' repertoire of engineering lessons that are available for elementary and middle school teachers, and help them to adapt and implement these lessons in their classrooms. For instance, teachers used the *Design Squad's* lessons to learn the engineering design process. In the engineering design process, the learners engage in asking questions, imagining possible solutions, planning, creating, and improving designs to solve a problem (see Appendix D). Classroom support visits were another component of the program intended to ensure success of the teachers implementing what they learned from the courses into their classrooms. Site visits were also used to document and assess the needs of teachers and students.

Successes of the program and in the classroom

Our preliminary findings based on the pre- and post- tests administered to teachers in the Energy Production and Consumption Course suggest that teachers improved their knowledge in certain chemistry and related energy concepts- average by 18.4% (3.5 correct answers in the 19 questions). In particular, teachers improved their knowledge of the following: (a) properties of matter (density and states of matter), (b) chemical reactions (combustion and balancing equations), (c) elements (using the periodic table to predict properties), and (d) energy production and consumption (conservation and fossil fuels). In addition, teachers were able to design better lessons in their post-test that are student-centered and reflect appropriate scientific practices. In particular, we found a number of changes in the lessons designed by teachers from pre- to post- tests. Teachers were able to develop student-centered lessons at the end of the course. Specifically, their lessons considered students by eliciting students' prior knowledge at the beginning of the lesson, as well as active investigation and reflection of learning. In addition to student-centeredness of lessons, we found that teachers somewhat improved in their ability to design suitable and specific investigations and incorporate modeling in their lessons. Finally, teachers mentioned that they learned about the reform-based model of teaching and enjoyed the real-world application as context of the course- "The reform model was evident in your teaching. I particularly enjoyed the way chemistry was related in real-world application."

We also found a number of changes in the teachers' notions of 21st Century Skills and how to enhance their students' skills in the classroom after a year of the program (courses, workshops, and classroom visits). In particular, based on the pre- and post- interviews, we found there was a shift: (a) in using the engineering design process and science investigations to foster certain skills like critical thinking and problem solving, (b) from teacher-centered to student-centered lessons designed by teachers, and (c) in the view of the use of computer technology from passive tools (e.g. reading articles online) to productive tools (e.g. using Microsoft Office products to write reports).

In the next section, we will highlight the successes in the classroom of Albert Padilla. Albert teaches middle school students in an urban school in N.J. He is a model teacher whose work exemplifies how a classroom teacher can successfully integrate engineering activities into the existing curriculum. In his first lesson, he used the Design Squad's *Rubber Band Car* activity to teach and engage students in the engineering design process. While designing their cars, students reviewed the materials available to them, asked questions, considered science concepts (e.g. motion, forces and energy) to brainstorm ways in building their prototypes, tested their designs, and redesigned their cars to improve their speed (see Appendix E).

In addition to this pre-developed project, Albert developed his own engineering lesson. During the activity, *Designing Soda Can Holders*, Albert asked his students to brainstorm and design a device that can hold six cans of soda that are animal-safe, sturdy, convenient, and easy to carry. His lesson objectives are for his students to explain the impact of meeting human needs and wants (e.g. materials used to create bags) on the environment and to demonstrate how engineering can help solve problems. Students were grouped into teams of two and were given a number of materials such as copier paper, duct tape, wax paper, string, paint stirrers, and rubber bands. Students were also allowed to use other materials that were available in the classroom. As part of the design process, students engaged in a brainstorming activity in which they made drawings, sketches, and diagrams of their container designs. With regards to brainstorming, students had to decide what materials to use and how they were going to use them. They also discussed science concepts (e.g. forces) while designing their bags. Then, they built their prototypes and tested their designs. Each group collaborated and tested, evaluated, and redesigned prototypes to come-up with optimized designs (see Appendix D). This design challenge allowed students to apply skills such as critically thinking, problem solving, creativity, and innovation.

Strategies employed to overcome challenges and obstacles

Our assessments (pre- and post-tests, interviews, and surveys) revealed four major categories of concerns: (a) the teachers' limited content knowledge in science, engineering and mathematics, (b) insufficient pedagogical strategies of one of the course instructors to make the course content useful to elementary and middle school teachers, (c) time and test preparation issues that hinder implementation of engineering in their classrooms, (d) available resources in the classroom, and (e) limited science curriculum. Our first and main challenge is to engage elementary and middle school teachers, particularly those who lack knowledge and experience to teach science and engineering in the classroom. We found that teachers' lack of science background is a major limiting factor of our project, which affects teachers' experiences and abilities to benefit from the graduate courses as well as their abilities to translate course content into relevant classroom lessons. Moreover, it was difficult for a number of teachers to learn the quantitative aspects (mathematics) in the courses. To address this challenge, we instituted tutorial sessions to individually help teachers meet the demands of the graduate courses. We used our monthly classroom support visits to assist teachers in implementing engineering lessons in their classrooms. We are also redesigning the courses to meet the needs of elementary and middle school teachers. Second, according to our teachers, the insufficient pedagogical strategies of one of the instructors made it difficult for teachers to make connections between the concepts taught in the course and what they are teaching in their classrooms. To address this challenge, the education specialists are working with individual faculty members in redesigning the courses, to ensure that the course content is both meaningful and applicable to elementary and middle school classrooms. We also employed instructional activities such as lesson critique and design [9] and lesson study [10] to help teachers discuss and reflect on various aspects of teaching (lesson planning, analyzing students' work, assessments, etc.).

Third, in terms of time and test preparation issues, teachers mentioned that school time is devoted to subjects that are tested on state standardized tests, particularly, math and language arts. Teachers also mentioned that daily instructional time for science is often limited, sometimes to 30-40 minutes or less. This makes it difficult to do many labs or engineering design lessons. To address this concern, we worked with district administrators and teachers to allocate more time for science and give teachers time and support to implement more projects. Fourth, several teachers mentioned the lack of resources and materials in their classrooms to implement the activities in the project. Many of the teachers' resources for science are outdated and limited. Moreover, they mentioned lack of space, specifically, computer laboratory, or science laboratory scheduling issues. To address these needs, the instructors brought materials with them to the classroom to help the teachers. This encouraged teachers to share materials with other teachers and with other schools. Finally, teachers mentioned the limited science curriculum in their districts. We are working with our district partners to address this challenge. We are proud to say that, due to our encouragement, some of our district partners are currently revising their science curriculum to incorporate science and engineering.

References

1. National Research Council. (2010). *Exploring the Intersection of Science Education and 21st Century Skills.* Washington, DC:The National Academies.
2. Committee on Prospering in the Global Economy of the 21st Century. (2007). *Rising Above the Gathering Storm: Energizing and employing America for a brighter economic future.* Washington, D.C.: National Academies Press.
3. National Research Council. (1996). *National Science Education Standards.* Washington, DC: The National Academies Press.
4. National Research Council. (2011). *A Framework for K-12 Science Education: Practices,Crosscutting Concepts, and Core Ideas.* Washington, DC: National Academy Press.
5. Partnership for 21st Century Skills. Available: http://www.p21.org/ [retrieved January 18, 2011]
6. Kolodner, J.L., Camp, P.J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., and Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design™ Into Practice. *The Journal of the Learning Sciences*, *12*(4), 495-547.
7. Casner-Lotto & Barrington. (2006). Are they really ready to work? Employers' perspectives on the basic knowledge and applied skills of new entrants to the 21st century US workforce. The Conference Board, Corporate Voices for Working Families, Partnership for 21st Century Skills, and Society for Human Resource Management. Available: http://p21.org/documents/FINAL_REPORT_PDF09-29-06.pdf [Retrieved on July 16, 2010]
8. Bybee, R.W. & Fuchs, B. (2006). Preparing the 21st Century Workforce: A New Reform in Science and Technology Education (Editorial). *Journal of Research in Science Teaching, 43*(4), 349-352.
9. Duncan, R.G., Pilitsis, V., & Piegaro, M. (2010). Development of Preservice Teachers' Ability to Critique and Adapt Inquiry-based Instructional Materials. *Journal of Science Teacher Education, 21,* 81-102.
10. Macalalag, A.Z. (2012). *Changes in Preservice Teachers' Knowledge of Inquiry and Practice of Lesson Design*. Unpublished doctoral dissertation, Rutgers University, New Brunswick, N.J.

Appendix A: Possible Intersections of Engineering Design and 21st Century Skills

Appendix B: Graduate Courses

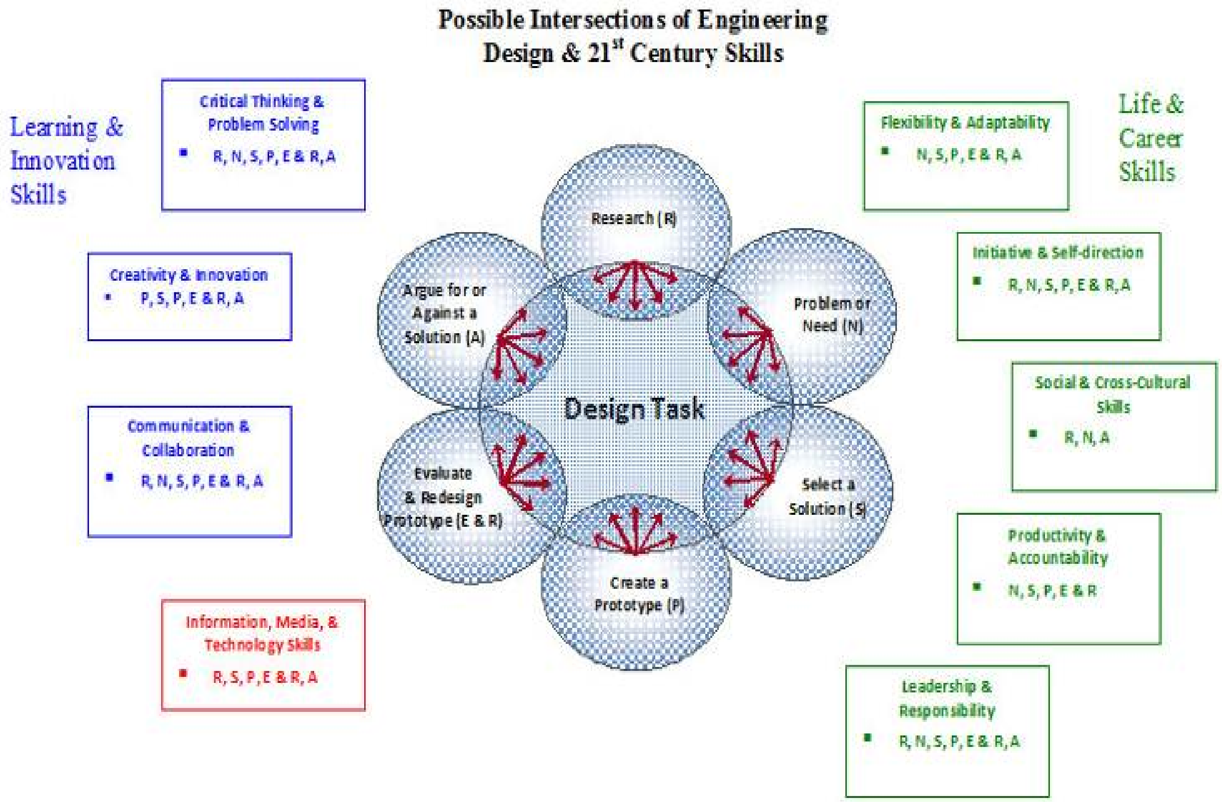
Appendix C: Energy Production and Consumption: Course Project Presentation

Appendix D: Design Squad's Engineering Lessons

Appendix E: Students Designing a Rubber Band Car

Appendix F: Students Designing a Holder for Soda Cans

Appendix A



Possible Intersections of Engineering Design & 21st Century Skills
Learning & Innovation Skills
Critical Thinking & Problem Solving
R, N, S, P, E & R, A
Creativity & Innovation
P, S, P, E & R, A
Communication & Collaboration
R, N, S, P, E & R, A
Information, Media, & Technology Skills
R, S, P, E & R, A
Life & Career Skills
Flexibility & Adaptability
N, S, P, E & R, A
Initiative & Self-direction
R, N, S, P, E & R, A
Social & Cross-Cultural Skills
R, N, A
Productivity & Accountability
N, S, P, E & R
Leadership & Responsibility
R, N, S, P, E & R, A
Design Task
Research (R)
Problem or Need (N)
Select a Solution (S)
Create a Prototype (P)
Evaluate & Redesign Prototype (E & R)
Argue for or Against a Solution (A)

Appendix B

Graduate Courses

Course 1: **Fundamental Principles of Physical Sciences:**
This course focuses on the fundamental principles of physical science necessary to develop a deep understanding of key issues in global energy production and consumption, global scale climate change and the engineering of solutions to problems arising from these phenomena. Concepts of energy and energy transformations are at the core of the course.

Course 2: **Fundamental Principles of Earth Sciences**:
The study of Earth as a complex, interacting system involving the large scale flow of energy and matter is the focus of this course. Building on concepts learned in Course 1, topics include historic and physical geology, oceanography, atmospheric science and natural energy. Methods used to collect and analyze earth scale data and indirect evidence is explored.

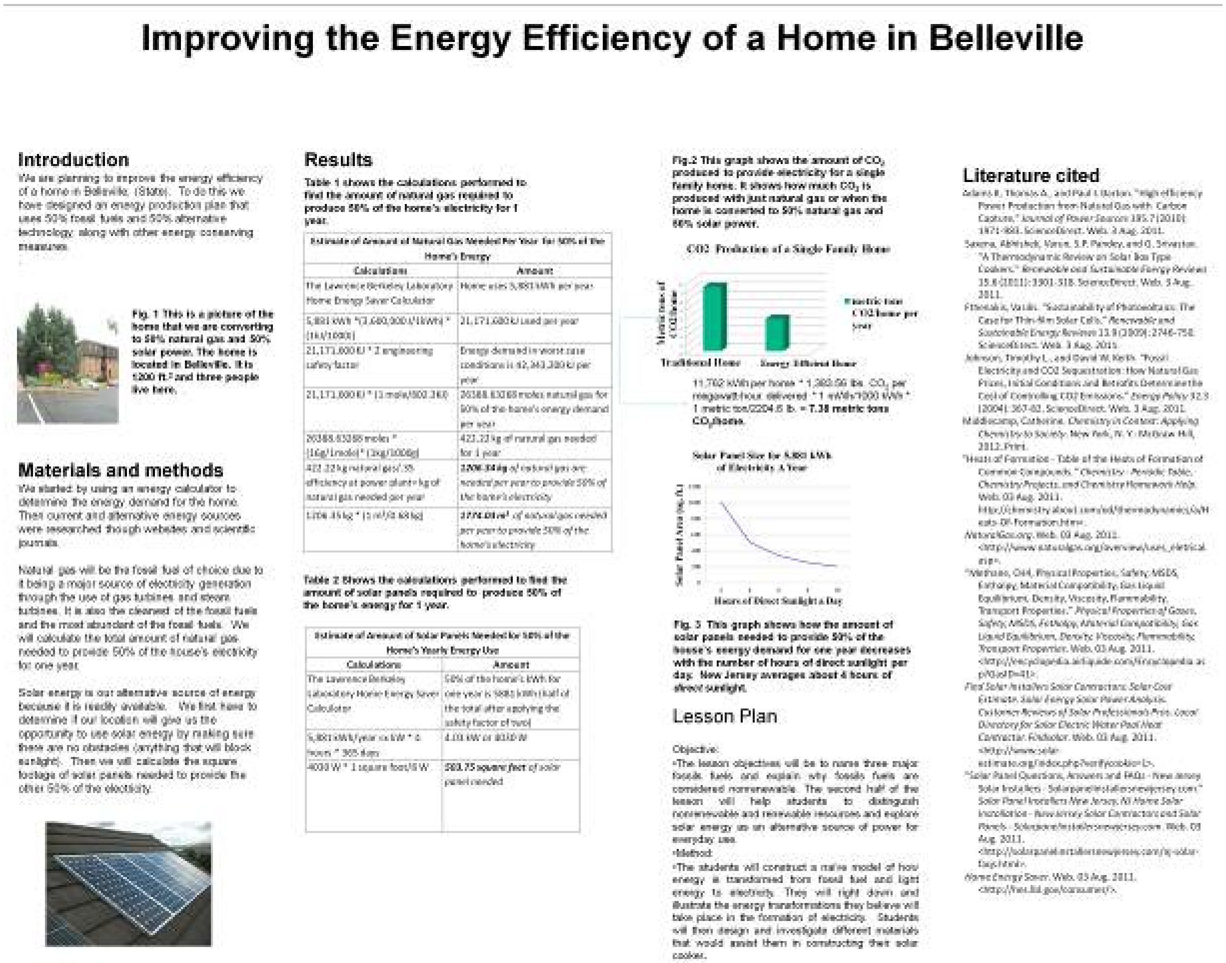
Course 3: **Energy Production and Consumption**:
This course focuses on the science and technology behind energy production, distribution and consumption. Concepts learned in the three previous courses are applied to the exploration of energy at the microscopic scale, ultimately leading to multiple energy production systems in use in the world today. Patterns of energy consumption that define the modern world and the global impact that energy use has on human society are explored.

Course 4: **Understanding Global Change**:
The phenomenon of global climate change and the impact of human activity on the Earth's large scale systems is covered in this course. Topics include energy flow in the Earth-Sun system, energy transformations that lead to the greenhouse effect and the scientific data that has been used to establish current viewpoints. Investigations of some socio-political issues in the discussion of global climate change are addressed.

Course 5: **Engineering Solutions to the Challenges of Energy and Global Change**:
This capstone course examines both the issues of energy production/consumption and global climate change from an engineering and innovation point of view. Using a case study approach, discussions focus on methods being investigated to move to a more sustainable world including the development of solar power, wind power and sustainable agriculture, as well as engineering solutions to reduce the effects of global climate change.

Appendix C

Energy Production and Consumption: Course 3 Project Presentation



Improving the Energy Efficiency of a Home in Belleville

Introduction

We are planning to improve the energy efficiency of a home in Belleville, (State). To do this we have designed an energy production plan that uses 50% fossil fuels and 50% alternative technology, along with other energy conserving measures.

Fig. 1 This is a picture of the home that we are converting to 50% natural gas and 50% solar power. The home is located in Belleville. It is 1200 ft.² and three people live here.

Materials and methods

We started by using an energy calculator to determine the energy demand for the home. Then current and alternative energy sources were researched though websites and scientific journals.

Natural gas will be the fossil fuel of choice due to it being a major source of electricity generation through the use of gas turbines and steam turbines. It is also the cleanest of the fossil fuels and the most abundant of the fossil fuels. We will calculate the total amount of natural gas needed to provide 50% of the house's electricity for one year.

Solar energy is our alternative source of energy because it is readily available. We first have to determine if our location will give us the opportunity to use solar energy by making sure there are no obstacles (anything that will block sunlight). Then we will calculate the square footage of solar panels needed to provide the other 50% of the electricity.

Results

Table 1 shows the calculations performed to find the amount of natural gas required to produce 50% of the home's electricity for 1 year.

Estimate of Amount of Natural Gas Needed Per Year for 50% of the Home's Energy	
Calculations	Amount
The Lawrence Berkeley Laboratory Home Energy Saver Calculator	Home uses 5,881 kWh per year
5,881 kWh *(3,600,000 J/1kWh) * (1kJ/1000J)	21,171,600 kJ used per year
21,171,600 kJ * 2 engineering safety factor	Energy demand in worst case conditions is 42,343,200 kJ per year
21,171,600 kJ * (1 mole/802.3kJ)	26388.63268 moles natural gas for 50% of the home's energy demand per year
26388.63268 moles * (16g/1mole) * (1kg/1000g)	422.22 kg of natural gas needed for 1 year
422.22 kg natural gas/.35 efficiency at power plant= kg of natural gas needed per year	**1206.34 kg** of natural gas are needed per year to provide 50% of the home's electricity
1206.35 kg * (1 m³/0.68 kg)	**1774.03 m³** of natural gas needed per year to provide 50% of the home's electricity

Table 2 Shows the calculations performed to find the amount of solar panels required to produce 50% of the home's energy for 1 year.

Estimate of Amount of Solar Panels Needed for 50% of the Home's Yearly Energy Use	
Calculations	Amount
The Lawrence Berkeley Laboratory Home Energy Saver Calculator	50% of the home's kWh for one year is 5881 kWh (half of the total after applying the safety factor of two)
5,881 kWh/year = kW * 4 hours * 365 days	4.03 kW or 4030 W
4030 W * 1 square foot/6 W	**503.75 square feet** of solar panel needed

Fig.2 This graph shows the amount of CO_2 produced to provide electricity for a single family home. It shows how much CO_2 is produced with just natural gas or when the home is converted to 50% natural gas and 50% solar power.

11,702 kWh per home * 1,360.56 lbs. CO_2 per megawatt-hour delivered * 1 mWh/1000 kWh * 1 metric ton/2204.6 lb. = **7.38 metric tons CO_2/home.**

Fig. 3 This graph shows how the amount of solar panels needed to provide 50% of the house's energy demand for one year decreases with the number of hours of direct sunlight per day. New Jersey averages about 4 hours of direct sunlight.

Lesson Plan

Objective:

•The lesson objectives will be to name three major fossils fuels and explain why fossils fuels are considered nonrenewable. The second half of the lesson will help students to distinguish nonrenewable and renewable resources and explore solar energy as an alternative source of power for everyday use.

•Method:

•The students will construct a naïve model of how energy is transformed from fossil fuel and light energy to electricity. They will right down and illustrate the energy transformations they believe will take place in the formation of electricity. Students will then design and investigate different materials that would assist them in constructing their solar cooker.

Literature cited

Adams II, Thomas A., and Paul I. Barton. "High-efficiency Power Production from Natural Gas with Carbon Capture." *Journal of Power Sources* 195.7 (2010): 1971-983. ScienceDirect. Web. 3 Aug. 2011.

Saxena, Abhishek, Varun, S.P. Pandey, and G. Srivastav. "A Thermodynamic Review on Solar Box Type Cookers." *Renewable and Sustainable Energy Reviews* 15.6 (2011): 3301-318. ScienceDirect. Web. 3 Aug. 2011.

Fthenakis, Vasilis. "Sustainability of Photovoltaics: The Case for Thin-film Solar Cells." *Renewable and Sustainable Energy Reviews* 13.9 (2009): 2746-750. ScienceDirect. Web. 3 Aug. 2011.

Johnson, Timothy L., and David W. Keith. "Fossil Electricity and CO2 Sequestration: How Natural Gas Prices, Initial Conditions and Retrofits Determine the Cost of Controlling CO2 Emissions." *Energy Policy* 32.3 (2004): 367-82. ScienceDirect. Web. 3 Aug. 2011.

Middlecamp, Catherine. *Chemistry in Context: Applying Chemistry to Society*. New York, N.Y.: McGraw-Hill, 2012. Print.

"Heats of Formation - Table of the Heats of Formation of Common Compounds." *Chemistry - Periodic Table, Chemistry Projects, and Chemistry Homework Help*. Web. 03 Aug. 2011. http://chemistry.about.com/od/thermodynamics/a/Heats-Of-Formation.htm>.

NaturalGas.org. Web. 03 Aug. 2011. <http://www.naturalgas.org/overview/uses_eletrical.asp>.

"Methane, CH4, Physical Properties, Safety, MSDS, Enthalpy, Material Compatibility, Gas Liquid Equilibrium, Density, Viscosity, Flammability, Transport Properties." *Physical Properties of Gases, Safety, MSDS, Enthalpy, Material Compatibility, Gas Liquid Equilibrium, Density, Viscosity, Flammability, Transport Properties*. Web. 03 Aug. 2011. <http://encyclopedia.airliquide.com/Encyclopedia.asp?GasID=41>.

Find Solar Installers Solar Contractors Solar Cost Estimate. Solar Energy Solar Power Analysis. Customer Reviews of Solar Professionals Pros. Local Directory for Solar Electric Water Pool Heat Contractor. Findsolar. Web. 03 Aug. 2011. <http://www.solar-estimate.org/index.php?verifycookie=1>.

"Solar Panel Questions, Answers and FAQs - New Jersey Solar Installers - Solarpanelinstallersnewjersey.com." *Solar Panel Installers New Jersey, NJ Home Solar Installation - New Jersey Solar Contractors and Solar Panels - Solarpanelinstallersnewjersey.com*. Web. 03 Aug. 2011. <http://solarpanelinstallersnewjersey.com/nj-solar-faqs.html>.

Home Energy Saver. Web. 03 Aug. 2011. <http://hes.lbl.gov/consumer/>.

Appendix D

Design Squad's Engineering Design Lessons

Teachers designed space crafts with shock absorbers that will protect marshmallow astronauts when they land. (Design Squad's *Touch Down*)

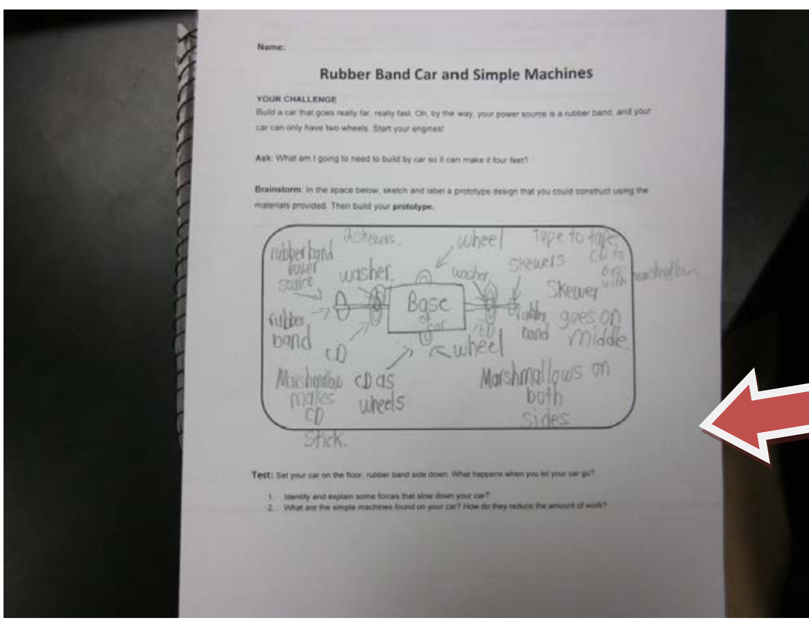
Students designed roller coaster rides.

Appendix E

Students Designing Rubber Band Powered Cars

The purpose of this lesson was to create a vehicle, made out of a piece of cardboard and compact disks (wheels), that is powered by rubber bands). Students used the engineering design process to solve the challenge.

Students reviewed their materials and asked questions.



Name:

Rubber Band Car and Simple Machines

YOUR CHALLENGE

Build a car that goes really far, really fast. Oh, by the way, your power source is a rubber band, and your car can only have two wheels. Start your engines!

Ask: What am I going to need to build by car so it can make it four feet?

Brainstorm: In the space below, sketch and label a prototype design that you could construct using the materials provided. Then build your **prototype.**

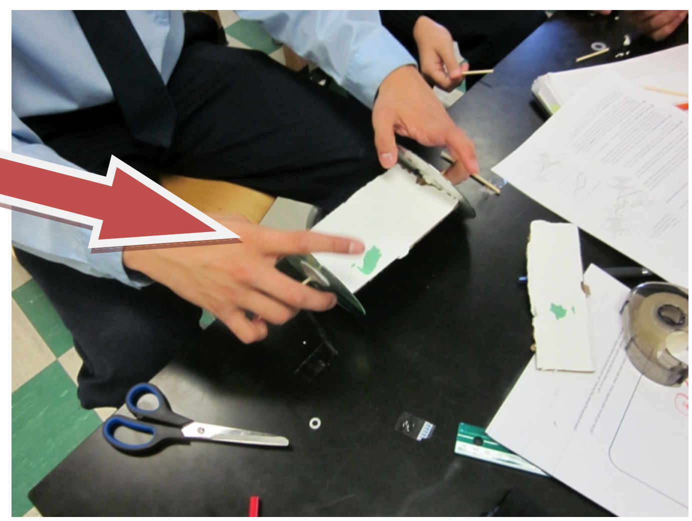
Test: Set your car on the floor, rubber band side down. What happens when you let your car go?

1. Identify and explain some forces that slow down your car?
2. What are the simple machines found on your car? How do they reduce the amount of work?

Brainstorming: students sketched and labeled their designs using materials that were available to them. Students used science concepts (forces, friction) during this stage of the EDP.

Students tested their designs. During testing, students saw energy transformation from elastic potential energy (of the rubber band) to kinetic energy (car in motion).

Students made improvements to their prototypes.

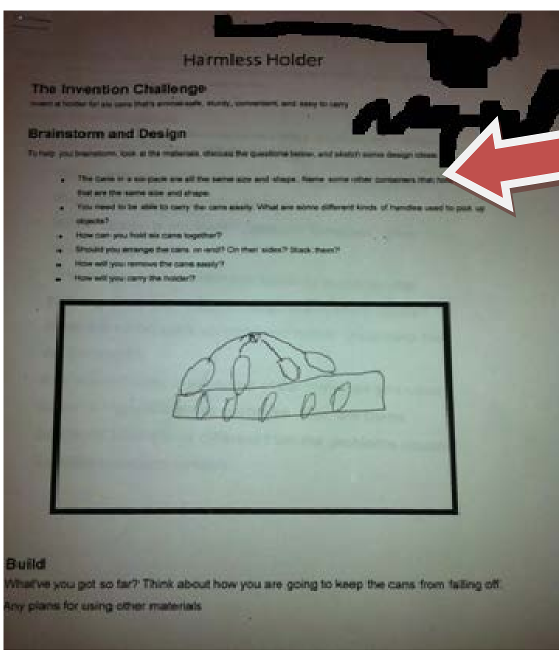


Appendix F

Students Designing a Holder for Soda Cans

The purpose of this engineering design challenge is to design and create a device that can hold six cans and at the same time be more environmentally friendly compared to plastic holders. Students learned about the harmful effects of plastic holders to the environment. Moreover, they learned that engineers are constantly looking to improve their products such as to enhance packaging materials and techniques.

Students reviewed their materials and asked questions: What materials should I use for my bag? What design should I make? How can I remove the cans from the bag? How can I carry the bag?



Students sketched and labeled their designs using the materials available to them. During the design process, students used the science concepts (forces, properties of materials) that they learned in class.

Students tested their bags and made improvements.

HIGH SCHOOL WINNER

The Skyline High School TEAMS Program: An Engineering-Focused High School Feeder System Designed to Broaden Participation in Post-Secondary STEM Studies

Patricia A. Quiñones, Skyline High School, Longmont, CO

Malinda S. Zarske, University of Colorado, Boulder, CO

Program overview and partnership structure

Skyline High School appears at first glance to be a below average American high school. It is a diverse school with 1,230 students across grades 9-12. Recent composite ACT test scores, required by state mandate to be taken by all 11^{th} grade students, are below the 2011 district wide and statewide averages. Likewise, 45% of the students are from economically disadvantaged families (free and reduced lunch eligible), compared to a high school average in the district of 20% and state of 40%.

However, a closer look shows that Skyline High School is not average at all. To help reduce the high number of students, particularly white students, who would leave the school (as predicted by district officials), open enroll into a different high school, or drop out of high school completely, the Skyline High School STEM Academy program was created in 2009, in partnership with the long-established K-12 TEAMS Program at the University of Colorado Boulder. The overarching goal of this K-12 and University partnership is to prepare students for career opportunities of the future as well as develop students' 21^{st} century skills.

One of the objectives of the STEM Academy is to mirror the demographics of the school, ensuring that the program is serving their whole population—including minority youth and girls, both underrepresented in STEM-related fields, and low-income youth from all backgrounds. The STEM Academy opened in fall 2009 with 80 freshman and 12 sophomores. By fall 2011, the Academy had grown to 249 students, comprised of 35% female, 35% minority, and 23% free and reduced lunch students across grades 9-12.

The combined Skyline High School and CU-Boulder TEAMS (Tomorrow's Engineers... creAte. iMagine. Succeed.) leadership team has developed a comprehensive education plan for the STEM Academy, with the overarching goal of students pursuing post-secondary STEM degrees. In order to receive a STEM Certificate upon graduation, students are required to take 28 total high school credits (minimum district graduation requirement is 24.5 credits) and follow a challenging education plan during all four years in the STEM Academy. Students must attain grades of C or better in each of their core and STEM courses, and graduate with at least a 2.5 unweighted GPA to receive the STEM certificate. Additionally, students must still meet all of the graduation requirements mandated by the school district.

Each of the courses has been developed in collaboration with CU-Boulder's College of Engineering and Applied Science—modified from their *First-Year Engineering Projects* course curricula—and provides students with fundamental engineering design principles and experiences. The classes are taught by the high school's experienced science teachers, trained in engineering design through the TEAMS's professional development program. Students begin the engineering sequence with exploring the engineering design process and the importance of teamwork in engineering. As students move through the sequence of courses, they are engaged in increasingly complex hands-on design projects that peer into a variety of engineering disciplines. The focus on the iterative design process allows students choose the topic that interests them most and learn about engineering disciplines through those choices. Through the Academy, students are engaged during the school day, making science, technology, engineering, and math part of their world *every day.*

The first four-year STEM Academy cohort to graduate will do so in 2013. Evidence that the STEM Academy is moving students beyond the average level of academic preparation are the 2011 school wide state NCLB assessment test results, which reveal that while the majority of 9th and 10th grade students scored only *partially proficient* in math, writing and science, the average STEM Academy student scored *proficient* in every one of these content areas—success by any measure. And, this achieved so early in the program's tenure is also remarkable.

Student perceptions of engineering, including engineering identity and engineering self-efficacy are also changing for students in the STEM Academy. The CU-Boulder TEAMS program has taken the lead in assessment, surveying students every semester during their tenure in the Academy, in order to specifically answer how student perceptions are evolving, both by grade and demographics. This research is poised to inform the engineering education research community on the value of early and frequent exposure to engineering. Several early indications of success include:

- An 11% increase in the number of students enrolling in the school from charter schools or middle schools *outside* of Skyline High School's two feeder middle schools.
- A stable year-to-year retention in the program of 77% for current 11th graders and 99% for current 10th graders.
- A change in the Likert-style survey responses indicate a significant increase in knowledge gain, engineering identity, and self efficacy. Although interest in engineering is also increasing, it is not considered statistically significant. With the exception of engineering identify, these gains are greater for females.
- Steady improvement in attendance and decrease in suspensions at Skyline High School. The school leadership attributes this increase in attendance and decrease in suspensions to the active engagement of students in the STEM Academy, as students take responsibility for learning and have pride in themselves and their school.
- Increasing successful partnerships with several post-secondary groups, including local companies, offering skills to help students succeed as they pursue undergraduate STEM degrees.
- Preliminary indication of more students enrolling into engineering colleges. From the first "quasi cohort" (i.e., seniors who had only 3 possible years of engineering through the STEM Academy), 8 out of 10 current seniors applied directly to the College of Engineering and Applied Science at the University of Colorado Boulder.

Even though this program is very promising, there are still lessons to be learned that help drive improvements in the program and increase student learning and success. For example, Skyline has increased the quality of their application process from their first round of fall 2009 applicants in order to increase the quality and buy-in of the Academy students. Also, the current Academy teachers are enthusiastic and flexible, but more teachers who share these characteristics will be needed as the Academy grows.

Skyline High School's six feeder elementary and two middle schools have similar demographic patterns and are a key component in the recruitment and retention of underrepresented populations to the Academy. Thus, the TEAMS partnership program has been introduced into all eight feeder school's curriculum, developing shared learning goals between the nine schools. Overall, the Skyline STEM Academy and feeder program is becoming successful because it employs a focused curriculum and a vision for accomplishment that was established and is maintained through collaboration with the CU-Boulder TEAMS program. The nine-school engineering continuum allows students to explore engineering and engages them in enriching projects, while learning that engineering is meaningful work that benefits humanity and our planet.

The Skyline and CU-Boulder TEAMS leadership team believes that all students can achieve success at a high level no matter their status, race, ethnicity or gender. Engineering requires upper-level critical thinking, and girls and boys are learning that all students can be engineers. The STEM Academy provides a venue for students to understand what engineers do, explore engineering design, and gain the confidence to pursue post-secondary engineering or other STEM fields. The Skyline High School STEM Academy students are starting to recognize the needs in the world around them and thinking like engineers; they are beginning to seek out problems and think about how to solve new challenges. This K-12/ University partnership model demonstrates the benefits of pre-college engineering exposure and is replicable in other "average" high schools across the nation. Other universities and high schools who wish to offer their students a similar comprehensive STEM experience should consider incorporating hands-on engineering design experiences throughout every year in the high school curriculum, coupled with early and regular exposure to its feeder elementary schools. This model, combined with high expectations for challenging, concurrent core courses for their high school students, can provide schools with opportunities to create a similar engineering pipeline in their area.

Examples of student work:

There are many examples of the innovative design work that is accomplished by high school students in the Skyline STEM Academy. Two of these examples are described below:
During the 2011-2012 academic year, 10^{th} grade students enrolled in the school's *Creative Engineering* sequence, chose either a biomedical engineering or civil engineering section of the course. Those who chose the biomedical track designed an assistive technology product for a local client—a young girl from the nearby elementary school who has arthrogryposis, a condition that limits the movement of her joints at the wrists, elbows, and knees. The high school students designed original products to help their client more independently access a drinking water fountain. They met with their client several times throughout the semester to fully design to their client's needs. This real-life context, combined with high team expectations of the course

demonstrated how engineering can impact the local community with real-world engineering solutions.

Students who chose the civil engineering track focused on the design of energy technologies for developing communities. In this case, student teams specifically designed simple, yet well-engineered, solar water heaters to allow communities lacking electricity the capability to heat water for cooking, medicinal, and hygienic purposes, among other uses. Student teams came up with very creative solutions to a need: a third-world community struggling to thrive and stay healthy with their current lack of available technology. In both sections, the engineering design process, as well as teamwork and building within constraints, were stressed to student teams. At the end of each project, teams had to present to the class and outside experts (university engineering graduate students and faculty) the engineering and design criteria behind their decisions. Much to our delight, these high school projects were not too dissimilar in quality than those created by first-year college students.

10th grade students enrolled in the school's *biomedical engineering option* presenting their ideas to the local elementary client (left) and client testing of the final product (right).

10th grade students enrolled in the school's *civil engineering option* testing simple solar water heaters for communities lacking electricity (left) and final testing of the finished product (right).