A Companion to Interdisciplinary STEM Project-Based Learning

For Educators by Educators (Second Edition)

Mary Margaret Capraro, Jennifer G. Whitfield, Matthew J. Etchells and Robert M. Capraro (Eds.)

SensePublishers

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SENSE PUBLISHERS
ROTTERDAM/BOSTON/TAIPEI

A C.I.P. record for this book is available from the Library of Congress.

ISBN: 978-94-6300-484-8 (paperback)
ISBN: 978-94-6300-485-5 (e-book)

Published by: Sense Publishers,
P.O. Box 21858,
3001 AW Rotterdam,
The Netherlands
https://www.sensepublishers.com/

All chapters in this book have undergone peer review.

Printed on acid-free paper

We at Aggie STEM are glad you have an interest in this book and the work of the enthusiastic and very dedicated STEM educators who contributed to it. Everyone involved strives to improve STEM education to help others implement standards-based instruction that takes learning in isolation to greater accountability through integrated and meaningful tasks that answer the question every teachers dreads, "When am I going to use this?" This book was developed through the Aggie STEM mantra "Group Responsibility and Individual Accountability". The group assumed responsibility, but every author and each editor was individually accountable for the content and quality of his or her Project-Based Learning Activity. Of this, I am proud; the team could not have been a better embodiment of STEM Project-Based Learning nor a better model of how to develop a learning and teaching tool for today's teachers wanting to implement STEM instruction in their classrooms.

This book was the hard work of teachers who are currently graduate students working on their masters or doctoral degrees and preservice teachers who are learning about STEM project-based learning and planning to use it in their classrooms. My favorite analogy is that of a master chef. Consider yourself a teaching chef and this, a book of favorite family recipes. However, you are cooking, or teaching, for a different audience. There is no substitute for knowing your audience and teaching to its strengths and addressing its weaknesses. So consider each lesson as a tasty idea ready to be modified to meet your own style and the needs of your students. Feel free to teach it as is and try the lesson out or change it. And don't think it strange if when you teach it the following year you modify it again. The proof of a really great idea is that it can fit into so many new situations, and modifying a lesson is a tribute to yourself and the author.

Go teach something great! Make learning meaningful and use STEM Project-Based Learning to increase content retention, motivation, and to reinvigorate your teaching.

We dedicate this book to the numerous teachers who have participated in our professional developments, our colleagues, and our families.

Robert M. Capraro

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ASHLEY JENSEN, VICTORIA LANCE, JEFF JENSEN
AND MATTHEW J. ETCHELLS

1. ANTENNA DILEMMA

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5
Engagement and research	Begin working on presentations and journal	Demonstration, testing, research, and journal	Research, design, and journal	Presentation, demonstration, and journal

WELL-DEFINED OUTCOME

Students will demonstrate their knowledge of antenna properties by building an antenna out of common household objects. Students will then test their antennas, analyze power and efficiency in the designs, and present their findings in a well-designed PowerPoint® or Prezi presentation.

TEACHER INTRODUCTION

This project is designed for students in an on-level or AP physics class and who have a basic background in antenna properties. Students will learn how antenna properties and antenna design are connected to affect electromagnetic wave travel and frequency. They will then work in small groups to design an antenna from basic household materials. The antenna should transmit electromagnetic waves at the Wi-Fi frequency and should optimize power and distance of transmission. Students will test their antennas by connecting their designs to a router with a coax cable and copper tape. Using a BLE RSSI (Bluetooth Low Energy, Receive Signal Strength Indicator) smart phone application, students will measure the RSSI of their antennas and use this distance to judge their antennas' workability and strength. Finally, students will prepare presentations for the class that explain the factors that led them to choose their antenna designs, demonstrate the completed antennas' workability, and analyze the strengths and weaknesses of their designs. In order to successfully complete this project, students need a strong physics foundation, background in trigonometry, access to basic construction supplies, and access to technology including smart phones, Wi-Fi network, and PowerPoint® or Prezi.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- Develop understanding of antenna properties including power, efficiency, frequency, and radiation, and apply this knowledge to antenna construction.
- Research antenna shapes including, but not limited to, spiral, helix, ring, and bowtie.
- Develop understanding of how an antenna's shape affects its properties.
- Develop understanding of antenna radiation patterns and how radiation affects antenna strength and signal distance.

Mathematics – The student is expected to:

- (Trigonometry) learn how sine and cosine determine electromagnetic wave travel and frequency.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 3–9.

Technology – The student is expected to:

- Test the strength of their antenna by hooking it up to a router with a coax cable.
- Measure the RSSI (Receive Signal Strength Indicator) using a "Bluetooth Low Energy (BLE) RSSI" smartphone application and use this number to judge the performance of their antenna.
- Demonstrate proficient use of PowerPoint® or Prezi.

Language Arts – The student is expected to:

- Communicate effectively and professionally with team members to create a cohesive, successful group project.
- Demonstrate their finished antenna designs for the class in a clear, concise presentation.
- Keep a journal of their project designs and daily progress.

Life Skills – The student is expected to:

- Work through complex details to create a solution (working antenna).
- Analyze and assess information from different domains to create a high quality product.
- Collaborate effectively and professionally in small groups.
- Use effective time management skills to meet specific deadlines and due dates.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science:

- Students will use prior knowledge of speed of light, wavelength, frequency, and basic antenna properties.
- Nomenclature: students will understand the body of vocabulary in the electromagnetic field.

Technology:

- Students will learn about scientific applications of smart phones.

Mathematics:

- Students will utilize knowledge of sine and cosine wave patterns.

STUDENT INTRODUCTION

You depend on antennas everyday – television, Wi-Fi, radio, your smart phone, and even your dog's microchip transmit electromagnetic signals through antennas. Antennas come in various shapes and sizes and can be made out of various materials. During this project, you will learn about and research the basic properties of antennas including frequency, power, efficiency, and direction of radiation. You will then work in small groups to create your own working antenna out of commonly available materials. Be creative! Keep a journal of your antenna design and your daily progress. After building your antenna, you will use a BLE RSSI (Bluetooth Low Energy, Receive Signal Strength Indicator) smart phone application to test the RSSI number of your product to measure the strength of transmission. Finally, you will demonstrate your antenna for the class, as well as presenting a PowerPoint® or Prezi presentation that analyzes the strengths and weaknesses of your antenna design. What advantages do some designs have over others? Why are some designs suited for certain situations? In our technologically advanced world, why do we sometimes still struggle to get a signal? What can we do to change that?

MATERIALS USED

Research and Presentation:

- Computer with Internet access
- Calculator

– PowerPoint® or Prezi
– Journal

Building the antenna:

– Commonly found items including, (but not limited to):
– Wire clothes hangers
– Wire scraps
– Silverware
– Potatoes
– Pliers

Testing the antenna:

– Router
– Coax cable
– Copper tape
– BLE RSSI Meter app made by Arendi AG or similar.

SMART PHONE WITH BLE RSSI APPLICATION (ONE PER GROUP)

DAY 1 (50 MINUTES)

Introduce the topic of antennas to students as a class. Then divide them into groups of four or five. Each group needs to designate a recorder for research information, a designer to create the PowerPoint® or Prezi, and two or three researchers to look up the required information on antennas and decide what information about the group's antenna to include in the presentation. Have them research how to make a Wi-Fi antenna on YouTube (see references for support) and the Internet. Remind students that these videos show how to make a particular type of antenna, not necessarily the only method to create a homemade antenna that transmits electromagnetic waves at the Wi-Fi frequency; the goal in this project is to tap into their STEM ingenuity. Inform students that during the next lesson they will be given a materials bin including a calculator, pliers, a router, coax cable, copper tape, coat hangers, scrap wire, and a metal fork or spoon. Students should use the Material Supply Request Form to make a list, including cost, of extra material supplies they will need. Inform all groups that they may ask for additional supplies should they run out of a certain material they need; however, they should carefully plan ahead to cater for usage during the project. Remember to collect the Material Supply Request Form from each group.

DAY 2 (50 MINUTES)

Show students a dissected Wi-Fi antenna from a standard router, allowing students to see that antennas are not always as complex as they may seem. Once students have had a chance to view the dissected antenna, continue the session by distributing the material bins to each group. Allow them to break into their groups and have them turn to the presentation requirements and go over with students what their PowerPoint® or Prezi and presentation must include (see Presentation rubric). Allow students to work on their presentations for 30–35 minutes. Have students complete their journal entries by writing their antenna design ideas. Students should consider if they are staying on track and working on their antenna designs. The teacher should walk around and visit each group to discuss the positive and improvable attributes of their respective designs.

Presentations must include:

– Two antenna designs:
– What is each design best suited for?
– What materials are best suited for each antenna?
– Why do we still sometimes struggle to get a signal?
– What can we do to improve signal strength?

– Why did you choose your particular antenna designs?
– What are the strengths and weaknesses of your designs?

DAY 3 (50 MINUTES)

Open the class with a short presentation on the purpose of the BLE RSSI app test and how to use it. Allow each group to take a turn using the BLE RSSI app to test the antenna. The rest of the day should be a research day so that students can continue the background research portion of their presentations. Groups should have a clearer concept of what antenna designs will work best for their projects and what materials they want to use. Have students complete their journal entries by writing their understanding of how antennas work.

DAY 4 (50 MINUTES)

Today should be a design and construction day. Before students break into their groups, go over safety procedures for using the pliers, cutting wires, etc. If possible, bring in a teaching aide, student teacher, extra teacher, or classroom volunteer to watch over groups using tools and making their antennas. Allow groups to freely work between design and construction, but remind them that tomorrow will be the last day to design and construct. Have students complete their journal entries by writing their reflections on designing and constructing their antennas. They should pay close attention to their choices of shape and properties.

DAY 5 (50 MINUTES)

Each group should finish constructing their antenna. The rest of the lesson should be spent on adjustments and improvements to their antennas to try to increase the BLE RSSI score. Students should carefully document their adjustments and improvements. They should also clearly describe in their journals why they made these changes and what effect they had on the antennas' BLE RSSI score.

DAY 5 (50 MINUTES)

Each group should present their design, then connect their router and test their antenna with their respective smart phone. Throughout the presentations, students should take notes on the different designs, their effectiveness, and how they could be improved. After all the groups have presented, have a class discussion on which design worked best and why. The goal here is to tap into the class's ingenuity in order to keep improving the antenna designs if the project were to continue. Students should complete a final reflection of the success of their projects considering their presentation scores. Remember to collect student journals.

EXTENSION

For students who finish early:

– Have these students look into other types of homemade antennas and think up ideas to improve these designs.
– Allow students to create a booster antenna for the router to present with their main antenna design (homemade design videos can be found on various websites).

For advanced students:

– Give these groups a set amount of each material for their designs.
– Limit the types of material the groups can use to make their antennas.
– Allow students to create two antenna designs, explaining and testing each design in their presentation.

EVALUATION

Journal Rubric

	Exceeds Expectations 3 points	**Meets Expectations 2 points**	**Nearly meets expectations 1 point**	**Fails to meet expectations 0 points**
Research	The student shows synthesis and evaluation of scientific information through scholarly research from sources.	The student shows evaluation of scientific information through scholarly research from sources.	The student lacks evaluation of scientific information through scholarly research from sources.	The student does not provide any scholarly research from sources.
Analysis of Importance	The student analyzed the importance of shape and properties to make significant design decisions.	The student analyzed the importance of shape and properties to make some design decisions.	The student attempted to analyze the importance of shape and properties to make a few design decisions.	The student did not analyze the importance of shape and properties to make design decisions.
Scientific Process	The student displays an understanding of the scientific process by implementing a successful experiment where measurements are taken with precision and accuracy, data is appropriately recorded, and results are analyzed and implemented through a possible solution. The student thoughtfully monitors the progression of the scientific process and making appropriate adjustments along the way.	The student displays an understanding of the scientific process by implementing a successful experiment where measurements are taken with precision and accuracy, data is appropriately recorded, and results are analyzed and implemented through a possible solution.	The student displays an understanding of the scientific process by attempting an experiment; however, the student lacks measurements taken with precision and accuracy, data that is appropriately recorded, and/or results that are analyzed and implemented through a possible solution.	The student does not display an understanding of the scientific process.
Use of data	Student effectively used the BLE RSSI score to make decisions to greatly improve their antenna.	Student effectively used the BLE RSSI score to make decisions to moderately improve their antenna.	Student effectively used the BLE RSSI score to make decisions to make minor improvements to their antenna	Student did not make any changes to their antenna based on the BLE RSSI score.
			Total out of 12	

Presentation Rubric

	Exceeds expectations 3 points	**Meets expectations 2 points**	**Nearly meets expectations 1 point**	**Fails to meet expectations 0 points**
Work Ethic	The student presentation was broad in scope, well integrated with peers, and flowed seamlessly among peers.	The student portion of the presentation reflected required knowledge and showed a smooth transition of knowledge his or her peers.	The student portion of the presentation was limited in scope, depth or flow.	The student completed only a portion of the project, which resulted in an incomplete presentation.

Data and Visuals	The data, findings, visuals, and solutions are correctly represented, organized, and easily interpreted.	The essential data, findings, visuals, and solutions are included in the presentation.	Only a portion of the necessary data, findings, visuals, or solutions was included in the presentation.	The necessary data, findings, visuals, or solutions were absent from the presentation.
Organization	The presentation was logically organized and sequenced so there were no interruptions in the flow of the presentation and was easily understood and interpreted.	The presentation was sequenced and logically organized so that it was likely to be easily understood by the majority of the audience.	The presentation was sequenced but lacked clarity and at least some audience members of the audience had difficulty understanding.	The presentation was disorganized or not presented in a logical sequence. At least some audience members had difficulty understanding.
Presentation Skills	The student demonstrated exceptional professional and interpersonal communication skills when presenting and in all interactions with teammates.	The student was generally organized and professional; however, some comments or interpersonal communications could have been improved.	The student was organized but made some inappropriate comments, statements, or jokes. At least some of the audience or team might have felt uncomfortable.	The student was unprofessional, disorganized, impolite, or disrespectful while working with peers or presenting.

Specific Design Considerations (tick box)	**Requirement met 2 points**	**Requirement partially met 1 point**	**Requirement not met 0 points**
Two antenna designs presented			
Strengths and weaknesses of antenna design considered			
An understanding of the best suited purpose for the design			
An understanding of materials best suited for antenna			
An understanding of why signal strength might not be achieved			
An understanding of how to improve signal strength			
An understanding of particular antenna design choices			
		Total points out of 14	

Material Supplies Request Form

Material	**Source (website or store)**	**Cost $**	**Justification**	**Approved/ Denied**

REFERENCES

Do not buy wifi antenna from eBay –Build your own: https://www.youtube.com/watch?v=kUrN4aJM5P4 (03:05)
DIY Long Range Directional WIFI USB Antenna Tutorial (AKA Wok Fi): https://www.youtube.com/watch?v=WkXsS-kTtPo (12:45)
How to build a WiFi antenna: https://www.youtube.com/watch?v=FowqX_xysno (01:48)
How to make a high gain wireless antenna: https://www.youtube.com/watch?v=U6LkQ53vRJI (09:45)
The soup can wifi antenna: https://www.youtube.com/watch?v=ZHdiEPZ2OGk (07:19)

STEVE MCKISSICK AND JENNIFER G. WHITFIELD

2. BUILDING A BETTER CEREAL BOX

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5
Engagement activity and explore nets for cubes	Formulate formulas for surface area of given solids	Discussion and rubric development	Create prototype of cereal box	Create artwork for cereal box

Day 6	Day 7	Day 8	Day 9
Survey peers	Revise prototype	Create presentations	Give Presentations

WELL-DEFINED OUTCOME

Create a cereal box (other than a rectangular prism) using a 20-inch × 30-inch sheet of cardboard or poster board. The cereal box must be self-sealing, openable, and resealable. Students will present the product, including schematics and specifications, and survey findings to a panel of General Mills® engineers.

TEACHER INTRODUCTION

Students will apply principles of geometry, visual design, and marketing to design a cereal box given a fixed amount of material. The box must be completely self-sealing, openable, and able to be resealed. The final product must meet consumer needs while also meeting manufacturer requirements for advertising and required nutritional information. In addition to the development of the box, students must create a presentation for presenting the box to the manufacturer.

To be successful with this project, students must know how to find the area of two-dimensional shapes. Students must be familiar with developing and using formulas to find area and volume of shapes and solids. Students must be familiar with multiple representations of shapes and solids. This project is aimed at on-level high school students. Students should be grouped so each student's talents complement the talents of the other members.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Mathematics – The student is expected to:

- Use tools to determine measurements of geometric figures and extend measurement concepts to find perimeter, area, and volume in problem situations.
- Calculate surface areas and volumes of prisms, pyramids, spheres, cones, cylinders, and composites of these figures in problem situations.
- Calculate areas of regular polygons, circles, and composite figures.
- Analyze the relationship between three-dimensional geometric figures and related two-dimensional representations and use these representations to solve problems.
- Use nets to represent and construct three-dimensional geometric figures.
- Apply mathematical processes and mathematical models to analyze data as it applies to social sciences.
- Distinguish the purposes and differences among types of research, including surveys, experiments, and observational studies.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 11–18.

English – The student is expected to:

- Work productively with others in teams.
- Apply earlier standards with greater complexity.
- Participate productively in teams, building on the ideas of others, contributing relevant information, developing a plan for consensus-building, and setting ground rules for decision-making.
- Write expository and procedural or work-related texts to communicate ideas and information to specific audiences for specific purposes.
- Write procedural or work-related documents (e.g., instructions, e-mails, correspondence, memos, project plans) that include organized and accurately conveyed information.
- Write persuasive texts to influence the attitudes or actions of a specific audience on specific issues.
- Write an argumentative essay to the appropriate audience that includes an analysis of the relative value of specific data, facts, and ideas.

Visual Media Analysis and Production – The student is expected to:

- Produce visual representations that communicate with others.
- Use a range of techniques to create a media text and reflect critically on the work produced.

Physics – The student is expected to:

- Use a systematic approach to answer scientific laboratory and field investigative questions.
- Communicate valid conclusions supported by the data through various methods such as lab reports, labeled drawings, graphic organizers, journals, summaries, oral reports, and technology-based reports.

Art – The student is expected to:

- Communicate ideas through original artwork using a variety of media with appropriate skills.
- Express thoughts and ideas creatively while challenging the imagination, fostering reflective thinking, and developing disciplined effort and progressive problem-solving skills.
- Use visual solutions to create original artwork by problem solving through direct observation, original sources, experiences, narrations, and imagination.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Technology

- Use a variety of technology tools to gather data and information (e.g., Web-based resources, e-books, online communication tools, etc.).
- Use technology tools to present data and information.
- Execute the steps of a simple research process (three to four steps).

Engineering

- Discuss the purpose of teams, discuss the functions of different roles within the teams, and actively participate within one with a positive attitude.
- Incorporate engineering methodologies to solve a problem.
- Use consistent units for all measurements and computations.
- Engage in design and prototype development.
- Use teamwork to solve problems.
- Complete work according to established criteria.
- Develop a plan for implementation of an individual product.

Mathematics

- Calculate surface area, volume, and perimeter of shapes and solids.
- Use precise measurements.
- Use and construct nets for 3-D shapes.

STUDENT INTRODUCTION

General Mills® has recognized that millennials are looking for products that are new or interesting. They are hoping to rebrand their cereals to appeal to this demographic, and they intend to start with a redesign of the cereal box to avoid the traditional rectangular prism model. They want a box design that is both functional yet interesting. Cardboard for cereal boxes comes in sheets measuring 20 inches by 30 inches. Acceptable submissions will include only those in which a net of the final three-dimensional product, along with tabs to seal the box, will fit within the existing dimensions of the cardboard. Submission packages will include results of a field test of no less than 100 millennials demonstrating a preference for the design submitted. The submission should include box artwork to include required nutritional information as well as weight and volume specifications.

General Mills® has opened the design submission process to allow submissions from non-employee teams. Your teacher believes that students are uniquely poised to apply their geometric learning, developing artistry, and connection with the millennial generation to make significant contributions for General Mills® to consider. Student teams will therefore:

- Create a cereal box (other than a rectangular prism) using a 20-inch × 30-inch sheet of cardboard/posterboard to create a box that is sealed, openable, and resealable.
- Create artwork for the box that incorporates federal nutrition display guidelines and product trademarks.
- Conduct surveying and field-testing with no less than 100 millennials to identify desired elements of the re-designed box as well as preference for their final products.
- Present their products, including schematics and specifications, and their survey findings to a panel of General Mills® engineers.

MATERIALS USED

Students will need the following materials:

- 20” × 30” sheets of thin cardboard (allow 8 sheets per group)
- scissors
- glue
- markers and/or colored pencils
- computers, and access to color printers
- grid paper
- rulers

Optional Supplies

- JOVO Click ‘N Construct or Polydron pieces (snap-together polyhedra pieces; other options exist, including Poly-Snaps developed by a teacher and created using a 3-D printer)
- Polyhedral dice

DAY 1 (50 MINUTES)

Students begin by watching two videos and discussing the merits of the redesigned products illustrated. First, students watch a video of Sir James Dyson discussing how his bladeless fan works. The video can be found at http://www.youtube.com/watch?v=8he8afjQyd8 (05:49). In the video, Dyson contrasts his fan with traditional propeller fans while also providing principles of physics that explain how the machine works.

Second, students watch a video of Chris Curro and Henry Wang, two engineering students, who redesigned the shipping box. The video can be found at http://www.youtube.com/watch?v=xExVzADFeWo (02:49) and some background information can be found at http://www.cooper.edu/engineering/news/student-invented-rapid-packing-container-video-goes-viral (02:50). The discussions will move from a production of Venn diagrams, capturing similarities and differences between old and new designs, to a clustering of the areas of comparison. These areas should include both physical and aesthetic properties since both will be central to the project. Sample questions to be included at this stage of instruction are as follows:

– How are the new products in these videos like the old products they replace?
– What criteria do customers use to evaluate a product?

Following this, students should return to the redesigned shipping box to discover that the product is the net of a rectangular prism. We note how the sides of the solid are known geometric shapes, and we note how the net connects these shapes in ways that the rectangular prism can be built by folding the shapes at their edges. At this point the teacher should divide the class into teams of four or five. The challenge for each team is to find all the possible nets for a cube (ideation is used to generate multiple solutions). The exercise is timed (suggested time is 10 minutes), and manipulatives should be made available to support spatial thinking. As students work, if applicable, the teacher can challenge the students to formulate only unique nets; nets are unique if they cannot be rotated or reflected to make a previously identified net. After time has expired, group responses should be shared and evaluated by the audience (other groups) to determine accuracy and originality.

After all groups have shared their responses, conduct a discussion to extend the knowledge regarding the net of a cube. Sample questions for this discussion may include:

– Without drawing and cutting out a net, how can a person determine if it will make a cube when assembled?
– Which of the possible nets of a cube is most interesting?
– Which of the possible nets of a cube might fit best on a 20” × 30” sheet of paper to maximize the volume of the resultant cube? Why?
– Can a net be drawn for all three-dimensional shapes? (If needed, specifically ask about the net for a sphere – what would it look like?)

If time permits, assign students the task of drawing nets for the following shapes: square pyramid, triangular prism, cylinder, cone, tetrahedron, octahedron, and dodecahedron. If time expires, consider assigning this task for homework or complete it at the beginning of Day 2.

DAY 2 (50 MINUTES)

If complete, have students share their nets for the additional seven shapes they constructed on Day 1 with their group. If the students did not have an opportunity to draw nets for the seven shapes during Day 1, have them complete this task at the beginning of this day. Together, have the students determine formulas for finding the surface area of a rectangular prism, square pyramid, triangular prism, cylinder, and cone. During the discussion be sure to identify any areas where students may need clarification or direct instruction. Finally, each group should determine ways to measure the volume for these five shapes. Again, during the discussion, identify any areas where students may need direct instruction. End this exercise by having students construct a formula chart to use throughout the rest of the PBL.

Finally, students will return to the redesigned shipping box to see that tabs are needed to attach sides of the box. Students will transfer this concept to their nets, adding tabs to their designs. Groups will create (draw, cut out, and assemble) enlarged versions of several shapes, with tabs, to ensure that these schematics yield completely sealed products. During the next few days, students will work in their teams to complete the primary task of building a better cereal box.

DAY 3 (50 MINUTES)

The primary activities in the days that follow involve researching, brainstorming, and analyzing. Each day, as a microcosm of PBL, should involve iteration as students return to the drawing board.

During Day 3 each group will discuss the specific characteristics of a cereal box that are valued by the consumer. At this point students may need to interview people (teachers, students, administration, etc.) outside of class to generate enough data to settle on a list of specific characteristics. This activity should lead to the development of a rubric that students will use on Day 6. This activity is complete when the rubric has been submitted for review and approved by the teacher.

DAY 4 (50 MINUTES)

Each group will create prototype boxes from a sample piece of cardboard. Students should develop several possible nets of each shape to determine which will maximize volume given the available area. Students should determine the volume of the box that will be created with the 2-dimensional nets they construct. This activity is complete when the group has developed between 3 – 5 prototype boxes.

DAY 5 (50 MINUTES)

At this stage students will develop sample artwork that is appropriate for each prototype they created in Day 4. One day in the computer lab will be allotted for this. Students are encouraged to work on this before and after this lab day to prepare their artwork. This must include any required nutritional information as well as corporate logos. Otherwise, students are encouraged to develop packaging that attracts the targeted consumer group (millennials). This activity is complete when all artwork is finalized and ready to affix to the prototype boxes.

DAY 6 (50 MINUTES)

Students should explore public opinion by surveying their peers regarding box preference and other elements of their rubric. Per the guidelines, at least 100 millennials must be surveyed as part of this activity. This survey should provide respondents with a standard cereal box to be contrasted with the prototypes generated in steps 2 and 3. This activity will be complete when the group can provide confirmation that at least 100 survey responses have been received.

DAY 7 (50 MINUTES)

Students should revisit their prototypes and adjust them according to feedback received during the surveying activity. This will lead to the development of a final product for Day 9 activities. This activity is complete when final boxes are given to the teacher for storage and safekeeping.

DAY 8 (50 MINUTES)

Students should prepare their presentations, including product specifications (e.g., dimensions) and survey results. This activity will be judged as "in progress" until the final presentations are made. Though much of the initial constructions of the 3-dimensional figures will be simple and straightforward, objects with nonplanar surfaces present difficulty in visualization for some students. For example, students may have difficulty intuitively creating a net for a cone. As such, some direct instruction will be needed to ensure that students understand the formulas for surface area and volume, especially for the non-planar objects. Comparisons should be made between rectangular prisms and cylinders that will help as students move from pyramids to cones. At some point, all five Platonic solids need to be identified and built. Any of these not built by students may need to be discussed by the teacher.

Students may also need some assistance moving from nets of theoretical shapes to developing sealed boxes. Beyond the basic net, boxes require additional tabs that will allow the figure to be closed. While they do not affect the final volume, they must be accounted for in the surface area.

Some explanation may also be needed as students work through activities attempting to maximize volume or minimize surface area. This may take a bit more algebraic knowledge than some students possess, so problem-solving strategies may need to be developed. Likewise, statistical methods that will be used during the surveying phase may require some direct instruction. The teacher will need to fill in any gaps in student understanding.

The teacher should discuss with the class perspectives that exist regarding product effectiveness. The teacher may need to ask probing questions to ensure that the needs of both the manufacturer and consumer are identified. This will help students prepare for development of their field-testing rubrics.

At this point the teacher should explain research methods and ethical conduct of research. The teacher should put parameters regarding the way field-testing is conducted. The teacher should make sure permission for surveys and research was secured from school administrators; the expectations of the administrators need to be directly relayed to the students.

DAY 9 (50 MINUTES)

Students will present their projects to an expert panel. Ideally, professionals from the marketing or merchandising industries will be available to hear the student presentations. Students will present their product specifications, including a clear diagram (net) with appropriate tabs and any special assembly instructions. An overview of their chosen criteria for evaluation will be followed by an analysis of the survey results. A final pitch that emphasizes the uniqueness of the product design and artwork should conclude the presentation.

EXTENSION

A Platonic solid has faces that are congruent regular polygons with the same number of faces meeting at each vertex. In preparation for each activity listed below, define congruent, regular, face, and vertex as they pertain to polygons. The extension activities are listed below:

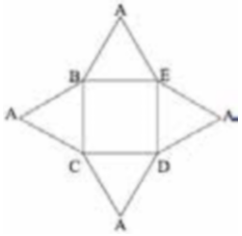
- Activity 1: Identify all five Platonic solids. Draw a net of each (no tabs needed).
- Activity 2: Create a table cataloguing the number of vertices, edges, and faces. Identify any patterns in your chart. Can you discover Euler's formula? What might "complementary solids" mean?
- Activity 3: Sketch (draw and/or narrate) a process by which you could find the surface area and volume of any Platonic solid. Assume that each edge has length x as you describe the process. Apply the process to any three solids, yielding formulas for surface area and volume for each of the three you select.

EVALUATION

Formative Assessment

1. Draw all nets of a cube.

2. Given the labeled pyramid below, what solid will this net construct?

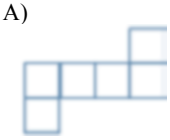


3. Complete the analogy and explain:
   Rectangular Prism : Pyramid :: Cylinder : _____

Correct Answers: 1-see http://www.onlinemathlearning.com/geometry-nets.html
2-square pyramid
3-Cone

Multiple Choice Questions

1. Which of the following nets could ***not*** be folded to create a cube?

A) 
B) 
C) 
D) 

2. A cube and a square pyramid share the same volume. What is the ratio of the height of the cube to the height of the pyramid?

   A) 2:1 B) 1:3 C) 3:2 D) π:1

3. Billy Joe intends to construct a simple outhouse. It will not have a foundation as he is building it over a pit he has already dug. The design will resemble a rectangular prism with a pyramid on top. Each wall will be 48 inches long. The tip of the roof will be 7 inches above the height of the walls, each of which stands 72 inches tall. Billy Joe will cut the door out of one wall, but it will be reattached and function as part of that wall. What is the surface area of this simple outhouse?

   A) 16,224 in^2 B) 18,528 in^2 C) 20,832 in^2 D) 16,128 in^2

4. A cylinder has the same height as the radius of its base. Both are equal to 8 cm. What is the surface area of this cylinder?

   A) 192π B) 256π C) 128π D) 512π

Correct Answers: 1-D 2-B 3-B 4-B

Project Rubric

Domain	Exemplary (5)	Proficient (3)	Lacking (1)	Unacceptable (0)
Maximized Space	Net uses as much space on cardboard as possible, margins less than 1”	All margins of cardboard greater than 1”	All margins of cardboard greater than 2”	Net does not fit on cardboard; multiple pieces cut out and secured together
Meets Assembly Criteria	Box can be sealed, opened, and resealed	Box is sealed and opened but is not resealable without outside support (e.g., clip or tape)	Box may not be completely sealed or easily opened	Box is not completely sealed and does not open without tool
Originality	Product and artwork are visually interesting, have exceptional creativity, and clearly stand out	Product or artwork is interesting and acceptable	Neither product nor artwork is particularly interesting	Traditional rectangular prism box
Net	Clearly drawn, tabs, measurements, and instructions for assembly	Some clarity lacking, but all elements present	Missing tabs, measurements, and/or instructions for assembly	Undecipherable net; may be missing tabs, measurements, and instructions
Required Labeling	Meets USDA packaging requirements AND General Mills® logos	Missing some required nutritional information OR poorly placed	Missing multiple elements of required labelling	Missing information; all required information located on bottom of product

Formative Assessment Rubric/Checklist

Day	Activities	Group Function	Work Production	Quality of Work	Total
1	Introduction Initial Discussion Nets of Cubes	/5	N/A	/5	/10
2	Development of Formulas Development of Rubric* Production of Prototypes	/5	Y/N	/5	/10
3	Production of Prototypes*	/5	Y/N	/5	/10
4	Development of Artwork* Surveying (during lunch)	/5	Y/N	/5	/10
5	Analysis of Survey Results*	/5	Y/N	/5	/10
6	Adjustments to Prototypes* Development of Presentation	/5	Y/N	/5	/10
7	Final Adjustments (Extension Activities)	/5	Y/N	/5	/10
8	Presentations	/5	N/A	/5	/10

Group Function – To what extent are the following characteristics demonstrated by your group: cooperative, respectful, communicative, shared workload, on-task

5 – All characteristics clearly identified
3 – Some issues, but group is working through them once identified
1 – Group is minimally cohesive; each person does their own thing

Work Production – Are tasks being completed? Activities identified with a star will be checked on the given day to ensure the group is keeping up with the project.

Quality of Work – Is the work being generated by your group demonstrating knowledge of the concepts and equipping the group for a good final presentation?

5 – Clear understanding of concepts; originality evident; thoroughness; precision
3 – Some issues, but group is working through them once identified
1 – Work is of poor quality; understanding of concepts is lacking; incomplete

Presentation Rubric

Domain	**Exemplary (5)**	**Proficient (3)**	**Lacking (1)**	**Unacceptable (0)**
Organization	Logical sequence, presentation between 5–6 minutes	All required information presented, though flow is problematic; less than 5 minutes	Missing information; jumps around sporadically; less than 3 minutes	Little more than a bulleted list of items; less than 3 minutes
Demonstrated Knowledge	Demonstrates clear understanding of nets, surface area, and volume; key vocabulary used; clear answers to any questions asked	Understands concepts as related to design chosen; some vocabulary used; decent answers provided	Limited understanding demonstrated; little/no vocabulary used; poor answers to questions asked	Factually incorrect information provided; incorrect use of vocabulary; wrong answers to questions asked
Group Participation	All members involved; evidence of rehearsal; seamless transitions	All members involved; transitions between presenters challenging	Limited participation by 1–2 group members; stilted presentation	More than 2 members do not speak; poor transitions
Presentation Aids	Effectively uses visual aids and executive summary for panel; may use technology for presentation	Either visual aids OR executive summary are lacking	Both visual aids AND executive summary are lacking	Either visual aids OR executive summary are missing
Non-Verbals	Good eye contact, voice, posture by all	Some issues; filler words are noticeable	Major issues; clarity suffers	Unintelligible; overuse of filler words

RESOURCES

Dyson Bladeless Fan Video
– http://www.youtube.com/watch?v=8he8afjQyd8.
Re-Engineered Shipping Box Video
– http://www.youtube.com/watch?v=xExVzADFeWo
Background for Shipping Box Video
– http://www.cooper.edu/engineering/news/student-invented-rapid-packing-container-video-goes-viral
Polydron supples
– http://www.mathartfun.com/shopsite_sc/store/html/Polydron.html
JOVO Click 'N Construct supplies
– http://www.jovotoys.com/

TANNER HILSABECK, JENNIFER G. WHITFIELD
AND MATTHEW J. ETCHELLS

3. BUILDING A BETTER TOMORROW

Designing the Home of the Future

SCHEDULE AT A GLANCE

Day 1	Day 2	Days 3–6	Day 7
Introduction of project and discuss the use of utilities in homes	Form small groups and create Gantt chart	Work in small groups to complete blueprints, concept drawings, and expense reports	Presentation Day

WELL-DEFINED OUTCOME

The class, as a whole, will formulate, design, and present concept drawings of a model home that consumes at least 10% less utilities (electricity, natural gas, and water) than a house of comparable size.

TEACHER INTRODUCTION

This PBL is designed for on-level or above-level high school students. Rooted in a common topic discussed extensively by environmentalists today, students will be given the opportunity to apply their knowledge and skills across STEM-based subjects in an effort to help solve problems of energy conservation within private homes. Prior to introducing this assignment, students should have a firm grasp on spatial reasoning, basic trigonometric functions, surface area, and optimization. This PBL can be used as a major project to demonstrate the importance of problem solving, critical thinking, time management, cooperation, and time allocation.

In this PBL, the whole class will formulate, design, and present concept drawings of one model home that reduces the utilities (electricity, natural gas, and water) of a comparable-sized building by 10%. The class's final product should include blueprints as well as estimated costs for building the home. This model should be easily reproducible, and maintain the following features of a house:

- 2 Bedrooms
- 2 Bathrooms
- 1 Kitchen
- 1 Living Room
- 1 Dining Room
- 1 Utility Room/Closet
- 1 Garage or Car Port

The final house must meet a list of safety standards set by the U.S. Department of Housing and Urban Development (HUD), while maintaining its original purpose of a place for people to live comfortably. Students will research housing standards and current solutions for energy efficient homes. One good source, referred to frequently in this PBL, is the safety standards from the American Public Health Association (APHS). These can be found at http://www.nchh.org/Portals/0/Contents/NHHS_Full_Doc.pdf.

Each team of students – preferably groups of three or four – will act as sub-contractors and will be assigned a specialization. Ideas for the different specializations are: framers, roofers, electricians, drywall specialists, painters, climate control (air conditioning and heat), interior designers, plumbers, appliance specialists, and window/door specialists. Each team will collaborate to produce the deliverables required and to ensure that each team's solutions are compatible. The culmination of all teams' products must create a complete home that reduces the utilities by at least 10%. The presentation of concept drawings, blueprints, and estimated cost of building will take place in the form of a formal project proposal in front of a city housing official (if no such official is available, then the teacher can represent the housing official).

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 19–25.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Mathematics – The student is expected to:

- Apply mathematics to problems arising in modern society.
- Create a problem-solving model that analyzes data, develops a strategy, determines a solution, and evaluates the practicality of said solution.
- Express mathematical ideas and reasoning through the use of symbols, diagrams, and graphs.
- Apply optimization strategies with appropriate justification and reasoning.
- Explain rates in terms of electricity, natural gas, and water consumption.

Engineering – The student is expected to:

- Use engineering design methodology.
- Apply and use principles of ideation.
- Use rational and logical thinking to develop or improve a product.
- Apply decision-making strategies.
- Communicate ideas effectively in a team.
- Develop time management skills.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Identify the source and uses of electricity, natural gas, and water in a modern home.
- Learn the properties of electricity, natural gas, and water, as well as the by-products of their use.
- Explain key concepts of nonrenewable resource conservation.
- Identify the factors that can disrupt an ecosystem.
- Identify chemical reactants and products of processes relating to the home environment.

Technology

- Learn about existing technologies in the creation and consumption of electricity, natural gas, and water.

Mathematics

- Employ algebraic thinking to find unknown quantities.
- Graph function models in order to represent mathematical ideas.
- Calculate the surface area of basic shapes, including but not limited to: prisms, cylinders, and spheres.
- Apply geometric properties of shapes to real life structures.
- Use basic trigonometric functions to determine measurements.
- Apply properties of angles to real life structures.

STUDENT INTRODUCTION

Despite the fact numerous technologies having been invented over the last century, one thing has stayed constant: the Earth is finite. The current population of the United States is now three times the size it was in the 1900s. For the first time in history, we must consider the possibility of running out of natural resources such as electricity, natural gas, and water. The U.S. housing market is one of the largest markets using these valuable natural resources. Rethinking how resources are used in houses and designing houses that are more environmentally friendly is one solution to help the diminishing natural resource problem. Because of its use of a large amount of resources of varying types, as well as its commonality throughout developed countries, the house serves as a perfect platform to test the practicality of a range of resource-saving ideas.

In this PBL you will have the opportunity to be part of a team of sub-contractors that will design a house that consumes at least 10% less utilities of the average home. You will have the opportunity to be as creative and inventive as you like as you try to build a better home for the days of tomorrow.

MATERIALS USED

Research

– Internet Access

Designing Blueprints

– Computer-assisted Drafting Software
– Calculator (Scientific or Graphing)

Concept Drawings

– White Printer Paper
– Graphite Pencils
– Colored Pencils and/or Markers
– Ruler

Business Proposal

– Microsoft Office Excel®
– Microsoft Office PowerPoint®
– Scanner

Assessment

– Copies of Final Rubric
– List of Documents

DAY 1 (20 MINUTES)

Discuss with the class as a whole that they will be working together to start an architecture firm (more than one firm may be created for classes with a large amount of students). Instruct the class to agree upon a business name and a business executive committee that will be responsible for presenting the final product. Once the class has agreed upon a firm name, read aloud the memo found in the Appendix section of this PBL, and then conduct a discussion on how utilities in a home work. Some questions to help lead the discussion are:

– What type of activities within a home use utility?
– Which of these activities use the most utilities?
– What types of items are currently used to help reduce the use of home utilities?
– Are there any special protocols or devices you use in your own homes to reduce the utility bill?

DAY 2 (50 MINUTES)

Lead the students in a discussion to identify the task at hand. This discussion should begin with defining the deliverables, then lead into a method of production, and close with a brief overview of any potential problems that may occur. An example of a discussion outline is provided below. This information can be recorded in a variety of ways, including but not limited to idea clusters, flowcharts, and tree diagrams. Note: Some of the topics in the discussion outline below refer to some standards. These standards can be found on pages 5 to 22 from the document found at http://www.nchh.org/Portals/0/Contents/NHHS_Full_Doc.pdf.

Day 1 Discussion Outline Example:

- Concept Drawings
  - Must be completed after blueprints and furnishing
  - Should be drawn in proportion to blueprint
  - Should include both interior and exterior features
- Blueprints: must be the first product completed by each group.
- Bedroom: must comply with standards 2.6 and 4.3.
- Bathroom: must comply with standards 2.5, 2.6,1, 2.6.2, 4.3.2, and 4.4.
- Kitchen: must comply with standards 2.4, 4.3.2, and 4.4.
- Living Room: must comply with standards 2.6 and 4.3.
- Dining Room: must comply with standards 2.6.1-6 and 4.3.
- Utility Room/Closet: must be able to fit furnishing appliances.
- Garage or Car Park: must be able to fit at least one car.
- Estimated Cost to Build.
- Detailed Expense Report: should be recorded and updated constantly. Some prices may be hard to find, may have to determine alternative way to estimate cost.

DAY 3 (50 MINUTES)

On this day the whole class (i.e., architecture firm) will form smaller groups within the business to complete the required tasks. Each group should contain roughly an equal number of members. (If more than one business was formed during the engagement activity, each business should contain all 3 groups.) The groups should be as follows:

- Framers (Exterior Walls/Exterior Doors/Roof)
- Designers (Interior Walls/ Interior Doors/Climate Control)
- Furnishers (Appliances/Lighting/Plumbing)

Each group should contain at least one person from the business executive committee.

After groups are formed, the architecture firm should create a Gantt chart (timeline) of the required task. All the groups (of each firm, if more than one) should agree upon a time frame for tasks that require collaboration between groups (e.g. blueprints) before further breaking down the deliverables into their specific group's task. Figure 1 shows a sample Gantt chart.

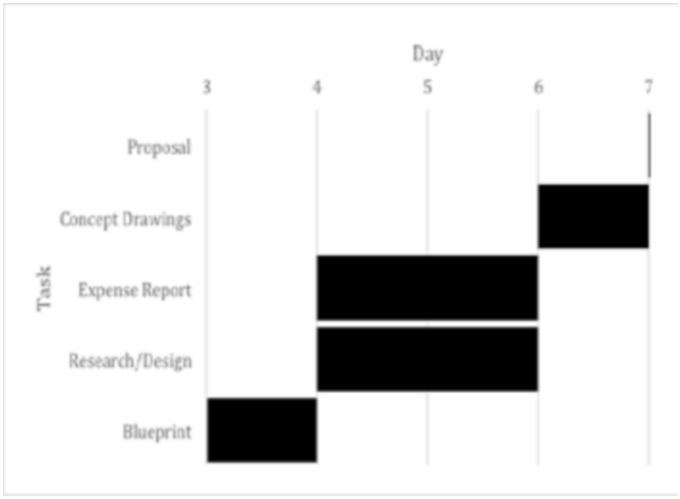


Figure 1. Day 2 Work Breakdown Structure Example

The teacher should check each group's Gantt chart to ensure the students have allotted the appropriate amount of time to each task. Gantt charts can be made by hand or using computer software like Microsoft Excel®.

Formative Assessment (optional): If you choose to do so, you may collect these charts for a grade. Complete charts should appropriately define the tasks, state the start/end date for each task, and minimize overlap between tasks.

DAYS 3–6 (50 MINUTES EACH)

Students should continue to work on the project according to their Gantt chart. You should monitor group progress, answer any questions, and assist struggling individuals/groups. At the beginning of each day the executive committee should meet to make sure all building standards are met and that each group is addressing the 10% reduction in utilities. Some resources for sample concept drawings, expenses reports, and blueprints can be found in the References section of this PBL. It is also helpful to refer to the rubrics in this PBL to help keep students on task and productive. The blueprints, concept drawings, and expense reports should all be complete by the end of day 6.

DAY 7 (50 MINUTES)

This is presentation day. If there is a city building and housing representative available, he or she should be available this day. For the presentation, have the executive committee present each group's product, the final blueprint, the final expense report, and how they calculated the final utility usage. Use the rubrics in the Evaluation section of this PBL to grade the final presentation and each group's product within the businesses.

EXTENSION

For students or groups who finish early, instruct them to brainstorm ideas about how the environmentally-friendly strategies used in their housing design can be modified to reduce the environmental impact of existing homes.

EVALUATION

Assessment of Deliverables

	Distinguished – 6	**Proficient – 4**	**Basic – 2**	**Unsatisfactory – 0**
Blueprint – Exterior Elevations	Blueprint shows all of the following: the front, rear and sides of the house, including exterior materials, details and measurements.	Blueprint shows all but one of the following: the front, rear and sides of the house, including exterior materials, details and measurements.	Blueprint shows all but two of the following: the front, rear and sides of the house, including exterior materials, details and measurements.	Blueprint is severely lacking in detail, measurements, and accuracy.
Blueprint – Detailed Floor Plans	Floor plans accurately and neatly show the placement of *all* the following: interior walls, the dimensions for rooms, doors, windows, stairways, etc. of each level of the house.	Floor plans accurately and neatly show the placement of *all but one* of the following: interior walls, the dimensions for rooms, doors, windows, stairways, etc. of each level of the house.	Floor plans show the placement of *all but two* of the following: interior walls, the dimensions for rooms, doors, windows, stairways, etc. of each level of the house.	Floor plan is incomplete and lacks three or more of the following: interior walls, the dimensions for rooms, doors, windows, stairways, etc. of each level of the house.
Blueprint – Following Standards	Blueprint followed *all* (100%) housing standards and met *all* (100%) requirements set by the client. Space was properly utilized and functional.	Blueprint followed *most* (80–99%) housing standards and met *all* (100%) requirements set by the client. Space was properly utilized and mostly functional.	Blueprint followed *most* (80–99%) housing standards and met *most* (80–99%) requirements set by the client. Space was mostly utilized properly and was functional.	Blueprint failed to meet most of the housing standards and/or requirements set by the client.
Concept Drawings	Concept drawings are detailed and well thought out. Effort to accurately display the final product is exceptional. Drawings are clean, accurate, and executed in a professional manner.	Concept drawings are detailed and well thought out. Effort to accurately display the final product is seen but not exceptional. There are some visual flaws in the drawing.	Concept drawings lack detail and are not well thought out. Effort and accuracy are lacking.	Concept drawings have no detail and are not well thought out. Effort is very poor and drawings are very inaccurate.

Overall Assessment

	Distinguished – 6	**Proficient – 4**	**Basic – 2**	**Unsatisfactory – 0**
Development of Ideas	Went above and beyond during the brainstorming process. Shows evidence of critical thinking and forethought. Is able to identify potential problems with the housing design before they occurred.	Contributed to the brainstorming process (~90% of time). Showed evidence of critical thinking and forethought.	Contributed somewhat (~70% of time) to the brainstorming process. There is some evidence of critical thought.	Failed to contribute to the brainstorming process.
Research	Synthesized information from numerous sources, as well as provided personal background knowledge about the topic of environmentally friendly housing. Resources were pulled from multiple sources (web, book, journal, database, etc.)	Synthesized information from numerous sources. Resources are mainly gathered from one type of resource.	Information was not well synthesized and information came from a select group of sources (~1–2).	Showed no evidence of research. Information was not at all synthesized and information did not contain any reliable resources.
Engineering Method/Collaboration	Shows ample evidence of problem solving strategies, as well as effective time management and collaboration skills.	Shows some evidence of problem solving strategies, as well as effective time management and collaboration skills.	Shows little evidence of either problem solving strategies or effective time management and collaboration skills.	Shows no evidence of problem solving strategies or effective time management and collaboration skills.

Overall Presentation

	Distinguished – 6	**Proficient – 4**	**Basic – 2**	**Unsatisfactory – 0**
Voice	Words were always clearly articulated with no mispronounced words.	Words were always clearly articulated with some mispronounced words.	Words were clearly articulated most of the time with some mispronounced words.	Words were not clearly articulated and words were often mispronounced.
Dress	Dressed professionally. Appearance was neat and clean.	Dress was casual. Appearance was neat and clean.	Dress was somewhat messy.	Dress was completely inappropriate.
Organization	Presentation was very well organized. There was clear evidence that thought and planning took place.	Presentation was somewhat organized. There was clear evidence that thought and planning took place.	Presentation was somewhat organized. There was little evidence that thought and planning took place.	Presentation was not organized and there was no evidence of forethought and prior planning.
Understanding	Shows 100% understanding of topic.	Shows between 80–99% understanding of topic.	Shows between 50–79% understanding of topic.	Shows less than 50% understanding of the topic.
Grammar, spelling, mechanical	Contains no grammatical, spelling, or mechanical errors.	Contains (1–2) grammatical, spelling, or mechanical errors.	Contains (3–4) grammatical, spelling, or mechanical errors.	Contains (5 or more) grammatical, spelling, or mechanical errors.

REFERENCES

Housing Standards
– http://www.nchh.org/Portals/0/Contents/NHHS_Full_Doc.pdf
Environmentally-Friendly Housing Ideas
– http://www.ecofriendlyhouses.net/
Gantt Chart
– http://www.gantt.com/
Concept Drawings
– http://gallery.conceptdraw.com/
Blue Prints
– https://www.thehouseplanshop.com/simple-house-plans.php
– https://houseplans.co/articles/whats-included-set-house-plans/

APPENDIX

Memo

To: Whom It May Concern
From: **(Insert Teacher's Name Here)**
Date: **(Insert Date Here)**
Subject: Business Proposition

Hello, my name is **(Insert Teacher's Name Here)**, Local Housing Committee Chairperson. Currently, we are seeking ideas for an upcoming residential neighborhood and are interested in partnering with local businesses like you to design an environmentally friendly house, which will serve as a model for the new development. If interested, please deliver to us concept drawings, blueprints, and estimated cost of your design by **(Insert Due Date Here)**. Listed below is a complete list of our requirements for your design.

Housing Design Requirements

The housing development is focused on providing affordable detached homes for middle class, single-families. Therefore we would like for your design to consist of the following features:

– 2 Bedrooms
– 2 Bathrooms
– 1 Kitchen
– 1 Living Room
– 1 Dining Room
– 1 Utility Room/Closet
– 1 Garage or Car Park

In addition to the requirements above, we would like for the new neighbourhood to serve as an example of the community's new "Save the Environment" campaign. As such, your design should also consume 10% less utilities than other houses of comparable size.

Average Local Utility Consumption (Per Household, Per Year):

Electricity: 10800 kWh.
Gas: 10500 kWh.
Water: 109500 Gallons.

ARIANE FAILLA

4. CELL COMMUNITIES

SCHEDULE AT A GLACE

Day 1	Days 2–3	Days 4–5	Days 6–7	Days 8–9
Show videos and introduce project	Research different websites of actual gated communities	Work on the designs for communities	Finishing touches and create presentations	Give presentations

WELL-DEFINED OUTCOME

Students will create a blueprint of a gated community, a list of amenities that the community offers, and a presentation that compares their gated community to the biology of an animal cell.

TEACHER INTRODUCTION

This PBL is intended for middle school students and may last for about a week and a half to two weeks depending on the length of each class period. It is designed to teach students about the components of animal cells (and their functions), in a creative manner using skills found in science, math, language arts, and social studies. In this PBL, students break into small groups to design a gated community. Each group will design a gated community and provide a list of amenities that the community offers. The structures and amenities represent the different organelles that are located within an animal cell. In addition to creating the communities, students will present their designs and effectively communicate what parts of their communities function like animal cell organelles. By comparing the roles of gated communities and amenities within the communities to those of cell organization and organelles, students will be able to differentiate between the structure and function of animal cell organelles.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Language Arts – The student is expected to:

- Spell correctly, using various resources to determine and check correct spellings.
- Determine, locate, and explore the full range of relevant sources addressing a research question and systematically record the information gathered.
- Differentiate between paraphrasing and plagiarism and identify the importance of citing valid and reliable sources.

Science – The student is expected to:

- Differentiate between structure and function in animal cell organelles, including cell membrane, cell wall, nucleus, cytoplasm, mitochondrion, chloroplast, and vacuole.
- Compare the functions, such as waste removal, of a cell to the functions of organisms.

Social Studies – The student is expected to:

- Apply critical thinking skills to organize and use information acquired through established research methodologies from a variety of valid sources, including electronic technology.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 27–31.

Mathematics – The student is expected to:

- Identify and apply mathematics to everyday experiences, to activities in and outside of school, with other disciplines, and with other mathematical topics.
- Use a problem-solving model that incorporates understanding the problem, making a plan, carrying out the plan, and evaluating the solution for reasonableness.
- Select tools such as real objects, manipulatives, paper/pencil, and technology or techniques such as mental math, estimation, and number sense to solve problems.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Recognize levels of organization in plants and animals.
- Explain the importance of cellular functions.

Technology

- Explore and research using technology.
- Create electronic presentations using technology.

Mathematics

- Use ratio and proportion to create scale drawings.
- Apply knowledge of area and perimeter.
- Apply knowledge of basic geometric shapes.
- Use rulers for precise measurement.

STUDENT INTRODUCTION

Anthropologists in Texas have teamed up with biologists to research the hypothesis that gated residential communities are designed and built to resemble the structure of an animal cell. They want to figure out if these communities can sustain themselves and how they might function. They have enlisted your help to design a gated community in a suburb just outside Houston, TX. If your designs show promise, then the anthropologists will continue the study by building your community and observing its activity over the next few months. The anthropologists have already bought and secured 60 acres of land on which you are to build. You do not need to build on all 60 acres, but all acreage must be accounted for and used in some manner. This community can also hold up to 150 houses. While the suburb is outside of Houston, it will still draw electricity and water from the city of Houston, as well as receive waste management and mail services. All the anthropologists need from you is a blueprint of a fully functioning gated community and a list of amenities the community will have. However, before your blueprint can be submitted for construction, you must present your community to the team of biologists explaining how every aspect of your community resembles an animal cell. If the biologists approve your presentation, work on your community may begin!

MATERIALS USED

- Newsprint or other large paper
- Rulers
- Pencils
- Access to computers
- Access to multimedia software like PowerPoint®, or Internet sites like Prezi
- Access to library or literature on cells
- Space to work in groups of three or four

DAY 1 (50 MINUTES)

The teacher begins the lesson by showing the class YouTube clips about the structure of cells such as the Parts of the Cell Rap, http://youtu.be/-zafJKbMPA8 (03:08). Afterwards the teacher can take some time to discuss the video and answer any questions students may have. Then the teacher presents the class with YouTube videos about gated communities such as the one featuring Ivy Estate in India, http://youtu.be/iNmkg73Jn24 (04:53). Then the teacher leads the class in a discussion about the similarities and differences the students notice about cells and gated communities. If the students are having a hard time finding connections, the teacher should ask about the specifics of the gated community and how those specifics relate to the cell (e.g., What could the gate in a gated community resemble in an animal cell?). After the discussion introduce the PBL by showing the students the student introduction.

DAYS 2–3 (50 MINUTES EACH)

Students will research different websites of actual gated communities in the Houston area. Because not all gated communities are built the same, students should be able to come up with a variety of options on which to model their own communities. It should be noted that students are not copying designs or blueprints from actual communities. They are merely researching ideas about what their communities might contain and what it might look like. As students are researching different communities, they should be keeping a journal of ideas that they want to use to incorporate in their own blueprints.

Students will also research animal cell anatomy. They will look up and describe the different parts of an animal cell and its functions. Because they will research these topics simultaneously, it is recommended that the students split up the research responsibilities between group members. Again, students will need to keep their findings in their science journals.

The teacher will check the students' journals throughout this process to clarify any misunderstandings and to check for understanding. A sample checklist is shown in Figure 1.

Criteria	**Done?**
Students are writing down gated community attributes.	
Students are listing community amenities that can be linked to cell organelles.	
Students are writing down cell organelles and their functions.	
Students are making connections about community design and biology.	
Students are brainstorming ideas and making connections on how cell biology can be linked to a gated community.	

Figure 1. Sample Checklist

DAYS 4–5 (50 MINUTES EACH)

Students will begin working on the designs for their communities. Using newsprint, or other large paper, groups can design their community blueprints. Students should also use this time to communicate with their group members about the research they have acquired so that the whole group may function coherently as a team. Students should research images of actual blueprints so that they can get an idea of how to create their own. Once they have their designs and procedures researched, they can actually create their blueprints. Note: blueprints need to be drawn to scale. If students need additional help on scaling, a mini-math lesson can be used at this time.

DAYS 6–7 (50 MINUTES EACH)

Students may use these days to finish any research, design elements, and create their final presentations for the "team of biologists." They must be ready to present a blueprint of their community, a list of amenities that the community offers, and a technology based presentation (i.e. PowerPoint®) that explains how their community functions like an animal cell.

DAYS 8–9 (50 MINUTES EACH)

During the final days of the PBL, students will present their final blueprints, list of amenities, and "presentation to the team of biologists" in front of the class. A sample presentation rubric is given in the Evaluation section of this PBL. This rubric can be altered to emphasize or de-emphasize any particular objectives.

EXTENSION

Students who wish to further their research or who need to be provided with extra criteria can expand their PBL in a couple of ways. They can create a new community that functions as a plant cell, or they can create a community that functions as both a plant *and* an animal cell. Students can also create different scenarios for their communities that they would need to solve. Some examples are:

– What if the gate for the gated community stopped working?
– How would people get in and out?
– What would happen to an animal cell if its membrane stopped working?

This extension can be used as an as needed basis or it can be applied to the whole class to add more rigor to the PBL.

EVALUATION

Presentation Rubric

	4 **Excellent**	**3** **Good**	**2** **Average**	**1** **Poor**
Research Skills	The presentation reflects above and beyond effort put into research of the material.	The presentation reflects good effort put into research of the material.	The presentation reflects adequate effort put into research of the material.	The presentation does not reflect much effort put into the research of the material.
Content Knowledge	Comparisons between amenities and organelles are accurate and tightly linked.	Comparisons between amenities and organelles are fairly accurate and closely linked.	There are comparisons between amenities and organelles.	Comparisons between amenities and organelles are not accurate.
Effective Communication	Communication is well thought out and conveys deep and thorough understanding of the material.	Communication is well thought out and conveys thorough understanding of the material.	Communication is thought out and clear. There is sufficient knowledge of the material.	Communication is not very well thought out or clear. There is little knowledge of the material present.
Visuals	The visuals are memorable and illustrate the main point clearly and effectively.	Visuals are neat and well organized. They illustrate the main point clearly.	Visuals illustrate and clarify the main point.	Visuals do not illustrate the main point clearly or effectively.

Multiple Choice Problems

1) What organelle within an animal cell is responsible for controlling all the functions and actions of the cell and all surrounding organelles?

A) Mitochondria
B) Nucleus
C) Ribosomes
D) Chloroplasts

2) What is the function of the vacuoles within an animal cell?

A) To send out messages to other parts of the cell
B) To protect the cell from outside intruders
C) To store food, water, and waste products
D) To break down large food molecules into smaller food molecules

3) All of the following are parts of an animal cell *except:*

A) Golgi complex
B) Nuclear membrane
C) Cell wall
D) Cell membrane

Correct Answers: 1-B 2-C 3-C

REFERENCES

YouTube videos:
– http://youtu.be/-zafJKbMPA8 – Cell Rap
– http://youtu.be/iNmkg73Jn24 – Ivy Estate concept plan

KEVIN KOLKER

5. CLASSROOMS THAT IMPROVE EDUCATION

SCHEDULE AT A GLANCE

Day 1	Days 2–3	Day 4	Day 5
Show video and discussion on what makes a "good" classroom.	Research possibilities for their classroom design and work on classroom design.	Finalize plans, draw schematics, and execute final calculations.	Presentations

WELL-DEFINED OUTCOME

Students will use geometric area and volume calculations as well as cost-calculation techniques as they formulate a design for a classroom. Students will also determine the factors important in educational settings, including technology and room layout.

TEACHER INTRODUCTION

In this PBL, students will have an opportunity to redesign their classroom. They will measure the current classroom and research ways in which they can improve the classroom aesthetically and educationally. The students will have to keep track of the costs incurred in designing the classroom, justify the decisions made within their designs, and give a presentation showing their final design.

This PBL is designed for high school students who have knowledge of area and volume formulas for rectangles and boxes. They must also be able to come up with a total cost of quantity Q of a material with price P by finding $Q \times P$. The students will synthesize many costs to formulate a total cost for all elements of the classroom. Additionally, it is important that the students minimize cost and use their own experiences to come up with learning-friendly classroom designs. These ideas, especially the principles intended to enhance learning, ought to be backed by research. Throughout the project, students will work in groups of 3.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Mathematics – The student is expected to:

- Collect and organize data based on research and estimation.
- Use geometric principles to determine area/volume of a surface/room.
- Use arithmetic to determine costs based on amount of material used and price of material.
- Understand and use relationships between prices and dimensions of materials used.
- Develop algebraic expressions representing geometric properties.

Engineering Design – The student is expected to:

- Learn about various considerations made when designing a structure.
- Optimize multiple factors simultaneously through consideration of different combinations of materials.

English – The student is expected to:

- Analyze factual, quantitative, or technical data presented online.
- Compare and contrast various design options.
- Present a PowerPoint® that conveys the decisions of the group and explain the thought-processes used throughout.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 33–38.

– Paraphrase, summarize, quote, and accurately cite all researched information according to a standard format.
– Participate productively in teams; build on the ideas of others, contribute relevant information, etc.
– Emphasize oral and written conventions and spelling.
– Brainstorm and develop a plan within a group setting.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Technology

– By researching the effectiveness of various classroom technologies, students will sharpen their computer and research skills as they learn about particular technology options for educational settings.

Engineering

– By looking at the pros and cons of using various layouts and materials in their classroom, the students get a sense of what considerations are made when designing the interior of a structure. They will also learn about the constant cost-benefit analyses that must be made in real-world designs.

Mathematics

– This project uses basic lessons about area, perimeter, and volume calculation for the size of the floor and walls. This PBL also connects to cost calculation, using costs given by unit multiplied by number of units to find the total cost for that object.

STUDENT INTRODUCTION

Two major ways to improve education are 1) to use technology to engage different learning styles and 2) to create an environment conducive to learning. Your school administrators have decided that the current classrooms could improve in both these areas. As the school looks into redesigning its classrooms in order to better integrate technology and learning-friendly design principles, they have turned to you, the students, for ideas. You will work in groups of 3 to create a classroom design that the school might purchase.

You will apply your knowledge of geometry and engineering design, in addition to practicing cost-calculation, as you work in groups to plan and design a cost-effective, learning-friendly classroom. You are responsible for considering cost, aesthetics, and educational benefit as you determine the layout and contents of the classroom, including seating, work spaces, and technology. Your group must justify each decision you make as you design this learning environment for 25 students who will be learning in both group and individual capacities. The justification for at least two of your decisions (regarding layout or materials) must be backed by research found online (possibly at first two websites listed in references). The rest of the justifications may be based on your experience as students or on hypothetical reasoning. As you create your classroom, always keep in mind the cost of your materials; if they are high, your group will need to justify why the benefit of your design would outweigh that cost. In addition, your final classroom design must have, at most, the same volume as the current classroom. Furthermore, you must calculate total work (desk) area and total open area and explain how each figure benefits education in the classroom. After you have determined your materials and layout, you will create a diagram of the classroom and present a PowerPoint® to school administrators to explain your design. This diagram of the classroom should include illustrations of any relevant technology (for instance a diagram of a wall with a Smart Board on it, with measurements shown), as well as a top-down view of the classroom floor plan, with desks/chairs drawn (approximately) to scale.

MATERIALS USED

– Tape Measures: students will use these to measure the dimensions of the classroom in order to determine volume.
– Journals/Word document: students will use these to keep track of ideas, decisions, justifications, cost-calculations, etc.

– Computers: students will need this in order to do the required research to come up with design ideas for their hypothetical classrooms. They will also need to use a computer to create their final PowerPoint® presentations.

DAY 1 (45 MINUTES)

Show a video summarizing construction of Kyle Field. http://kylefield.com/constructioncams (7:10). In 2014–2015 Texas A&M University renovated Kyle Field, the football stadium where the Aggies play. This project cost $450 million and allowed for over 102,000 people to be in the stadium at one time. In undertaking this project, the designers had to consider the purpose of the renovation and the intended use of the stadium. This included considering restroom placement, size of restrooms, size of walkways, capacity, etc., all while considering the cost of each aspect. This is an extreme example of a common problem – designing a structure by taking into account the purpose of that structure and attempting to minimize cost while maximizing aesthetics.

Students will now break into groups of three and brainstorm what kinds of considerations go into creating a new structure. Then they will brainstorm what considerations must be made when building a classroom in particular. They will begin thinking about what they would want in a classroom if they could design one themselves.

The first stage in exploration for this project is to research or brainstorm general considerations made when undertaking a construction project. These considerations could include intended use of the structure, capacity of the structure, and specific qualities desired by the owners of the structure. After creating this initial framework for construction design, the students will then explore these types of considerations with respect to classrooms. This will involve looking into trends in modern education, including the role of technology in the classroom, the ideal workstation for students, and the optimal layout of a classroom for engaging learning. Students should keep track of the ideas they find through their research, finding support for multiple different layouts and levels of technology integration. Each group should record all this information and their sources either in a word document or in a journal. This should include pros and cons of each option for the design of the classroom as well as sketches of the various layout possibilities. Students should use the costs given to determine the total costs of various options of desks, chairs, and technology. The information regarding costs of these objects can be found using the last two websites listed in references below. For example, if a group is considering selecting individual desks they found online priced at $49.95 each, the group needs to multiply that price by 25 (resulting in $1,248.75) to find the total cost of using these desks. The instructor may need to clarify that schools would normally be able to purchase desks and chairs in bulk at a discounted price, but for the sake of this project, students will act as if each item is being purchased at full price. Note: as groups explore various aspects of the classroom, they can split up the research however they like. For example, they may assign one person to research desks/chairs, one to research technology options, and the third person to research how the layout of a classroom impacts education.

DAYS 2–3 (45 MINUTES EACH DAY)

Once each group has a range of options for each element of classroom construction, the students should begin discussing, without judgment, the possibilities and combinations they think best. They should give reasons for their ideas and work together toward selecting all materials and a layout. Eventually, each group will decide on materials and layout, having reasons for all of their selections as well as costs of each component and total cost.

As students continue working in their groups, they should also come up with various possible sizes of their classroom, including the dimensions of the floor and walls. However, this size must not exceed the volume of the current classroom. In order to determine this, students will need to use their tape measure to determine the length, width, and height of the classroom and calculate the volume. If the classroom is not a perfect box, they will need to split the room up into perfect shapes to find the volume of each and add together to obtain the total volume. In order to ensure safety, the teacher will need to make it clear that students cannot stand on chairs or desks. Rather, to measure the height, the students will need to reach as high as possible and extend the tape measure toward the ceiling. If they cannot obtain a perfect number, an estimate will suffice. Students should record the volume of the classroom in their journals and list several possible layouts/dimensions for their classroom that stay within that volume. The teacher should ensure that no dimensions are absurd – for example, the height should be no less than 8 or 9 feet so that people can stand.

As groups refer to their research regarding the possibilities for their classroom designs, they should determine the most important considerations for the layout and contents of their classrooms. Furthermore,

students must understand the associated costs and pros/cons of various classroom materials. They should answer questions such as:

– What layout and types of desks are most conducive to learning?
– What technologies should be included to aid in learning?

If groups are not engaging in this type of discussion, the teacher should ask these questions to the group or to the class at large. The teacher should also be sure to emphasize justification of each decision – that is, why would having a certain technology or a certain type of desk benefit the students in the classroom? This justification could come from their experience, online research or both. Either way, the justification and each decision should be recorded in an organized manner in a journal or word document. Again, at least two decisions must be justified by some online research, which must be cited in the journal. As groups discuss all of these possibilities, their costs, and the pros/cons of each, they must begin to make final decisions for their designs.

DAY 4 (45 MINUTES)

After gathering information and discussing within groups, students should make final decisions for their own classrooms. Students need to draw schematics for the classroom and include the calculation of cost for each component of the room. This should all be recorded in the journal. They should also calculate the total area of desk space (by calculating the area of their chosen desk using the measurements found online and multiplying by the total number of desks). After calculating total desk space, they should find total open space in the classroom by the following formula (Open Area = Total Floor Area – Desk Space – Student Space) where student space is found by multiplying the space one seated student takes up by the total number of students. The space taken up by one seated student should be found by using the tape measure to determine how much space is occupied by one of the group members. This is something the teacher will likely need to explain so that the students know what is expected of them regarding work area and open area. After these calculations, students will record in their journals how the amount of desk space and open space will benefit classroom education (for instance: increased desk space allows students to be productive individually and increased open space allows for more interactive work, etc.).

By the end of the project, the journal should include the following: initial ideas with pros/cons of each, calculation of volume for current classroom, possible layouts that fit within that volume, final decisions, justification of each decision, cost calculations (of each material and total), and calculation of work/free area with an explanation of the benefit of each. Students can lay out this information in the journal however they like, as long as all information is displayed in some organized way. Justification for each element can come from personal experience or from research found online, or a combination of both. This journal can be used at any point for a formative assessment, with one possible rubric given in the Evaluation section of this PBL.

Finally, students will use all of this information to prepare a PowerPoint® presentation explaining their classroom designs and the reasons for their choices.

DAY 5 (45 MINUTES)

Each group will give a 7–8 minute presentation using their final PowerPoint® file, which should include their final design diagram, the materials they have selected and their respective costs, the total costs, and justification for each material. The slides should not be overly wordy, but the group should orally explain the reason for each choice made in their classroom. An example rubric for the student presentations is given in the Evaluation section of this PBL. In addition to the final presentation, the groups' journals will be graded (see rubric in Evaluation section). These will both contribute to a group's final grade.

EXTENSION

As an extension of this project, a group could redesign their classroom based on the budget of a particular school district. That way, the students would have to make more difficult decisions based on cost without completely sacrificing the educational benefits of their original classroom. This extension can be done within one day since the students will already have many possibilities for each element of the classroom from their research. Thus, the students will simply reselect from their previously constructed list some lower-cost options to ensure they fit under the budget. They will, however, still need to justify each selection and give the educational purpose of each one.

Another extension would be to constrain the students to the current classroom layout and have them make selections based on that. This would limit them to determining materials and technology and

deciding on the best way to layout these items within the current classroom structure. Again, students would need to justify each of these decisions.

EVALUATION

Presentation Rubric

Points	Research	Presentation
3–4	Students thoroughly researched classroom designs, including layout and technology.	Great visual and verbal presentation supported by a diagram of the classroom and pictures of materials included.
1–2	Mediocre research of possibilities for creating a classroom.	Some visuals included; students lack complete mastery of their project.
0	No attempt or mostly copy and paste. Unable to justify decisions made for their classroom.	Little visual aid; poor verbal presentation; little or no mastery of project.

Journal Rubric

	Exemplary (5 pts)	Proficient (3 pts)	Needs Improvement (1 pt)
Met Criteria	All or nearly all criteria for PBL have been met.	Significant criterion or multiple minor criteria omissions.	Many criteria not met by group.
Cost-Calculation	All or nearly all cost calculations are correct.	Several cost calculation errors.	Many cost calculation errors.
Factors Considered	Students gave significant thought to different factors – technology, layout, orientation, etc.	Students overlooked one or more important factors of design.	Students gave little thought to the various factors.
Justifications	All or nearly all decisions include reasonable justification.	Several decisions lack justification.	Few or no justifications of design decisions.

Multiple Choice Questions

1. All of the following are benefits of using technology in the classroom EXCEPT:
   A) Decreases student interaction
   B) Allows students to research to solve problems
   C) Increases forms of learning (video, audio, etc.)
   D) Allows teacher easier ways of showing concepts to the class

2. Which of the following are ways to improve learning in the classroom?
   A) Design an effective layout for the classroom
   B) Ensure students are separated from each other
   C) Include technology to aid in learning
   D) A and C

3. The area of the figure below is ___

   A) 10 ft^2
   B) 8 ft^2
   C) 8 ft^3
   D) 10 ft^3

Correct Answers: 1-A 2-D 3-B

REFERENCES

http://eric.ed.gov/
http://www.ebscohost.com/academic/education-research-complete
https://www.schooloutfitters.com/catalog/default/cPath/CAT202
http://www.bizchair.com/school-furniture.html

RAMIRO NICOLAS LOPEZ AND JENNIFER G. WHITFIELD

6. DESIGN YOUR OWN HIGH TECH HIGH SCHOOL

SCHEDULE AT A GLANCE

Day 1	Days 2–4	Days 4–5	Day 6
Discussion about overcrowded schools	Distribute property plans, begin research, and draft 2-dimensional plans.	Prepare presentation	Presentation to board of principals

WELL-DEFINED OUTCOME

Students will design a two-dimensional model of a high-tech high school and describe the intricate parts of their models (location and relative size) to a panel of experts.

TEACHER INTRODUCTION

For this project-based learning exercise, teams of four will work over five, 50-minute, class periods inside a traditional classroom setting to create a unique solution to a real life problem: the construction of a new high school that incorporates technology in an innovative and unique way. In this project, high school students will demonstrate an understanding of geometry, technology, environmental science, and language arts skills. Before attempting this PBL, students should have solid knowledge of the properties of geometric figures, including the calculation of area, perimeter, and surface area. Relevancy is provided by the inclusion of technologic and environmental aspects of the project. Technological advancement explored by students could include digital libraries, outdoor classrooms, renewable energy, building automation, incorporation of robots, or growing local produce to become self-sufficient. The project will require graph paper and construction materials to create a scale model representation of the team design. At the end of the project, students will have a two-dimensional scale model of their new high-tech high schools and will be able to describe the intricate parts of their models (location and relative size) to a panel of experts.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Mathematics – The student is expected to:

- Use a variety of representations to describe geometric relationships and solve problems.
- Select appropriate representations (concrete, pictorial, graphical, verbal, or symbolic) in order to solve problems.

Science – The student is expected to:

- Determine the interrelationships among the resources within the local environmental system.
- Summarize methods of land use and management.
- Convert between units of measurement and select appropriate scale representations.

English – The student is expected to:

- Write expository and procedural or work-related texts to communicate ideas and information to specific audiences for specific purposes.
- Produce a presentation that conveys a distinctive point of view and appeals to a specific audience.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 39–45.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Identify and document the use and conservation of renewable and non-renewable resources.
- Evaluate the impact of waste management methods such as reduction, reuse, recycle, and composting on resource availability.

Engineering

- Participate in team projects in various roles.
- Use teamwork to solve problems.
- Use time-management techniques to develop and maintain work schedules and meet deadlines.
- Develop a plan for production of a product.
- Apply concepts of sketching and skills associated with computer-aided drafting and design.
- Prepare a project budget.
- Think critically and make fact-based decisions.

Mathematics

- Calculate area and perimeter of various shapes.
- Classify geometric shapes.
- Use special reasoning to design the school.
- Add, subtract, multiply, and divide decimals.
- Use proportional reasoning.
- Use proportions to determine scale of drawing.

STUDENT INTRODUCTION

Schools in your area are crowded and outdated. There is a proposed site for the construction of a new high-tech high school but no building plans. Your team (~4 members) has been charged with designing plans for an environmentally friendly, technology driven, and space saving high school. Your plans must be drawn to scale with precise and accurate measurements displayed on the drawing and include a proposed budget for the construction of the new building. Your plans must be easily readable and include a legend so readers know the proportions of your scale drawing. You will present your final design to a board of principals for approval and the board will choose the high school that best fits their needs and budget. Your design will have to stay within space limitations while accommodating a daily attendance of 2,400 students. Your team is required to provide at least one improvement, or advancement, that includes new, innovative, and cutting-edge technology. Some ideas for the advancement are: save space, dramatically improve the students' daily activities, improve the educational experience for the students, lower building maintenance, or make the operations of the building more efficient. You will need to research and design a way to improve the school in a way that makes sense for 21st century education. Your design will be graded based upon thoughtful use of the proposed property space and the innovativeness of your technological advancement. Additionally, you will be graded upon your ability to verbally articulate your design to a board of principals and how well your design communicates your ideas. Your final project must meet the following criteria or features:

- Maximum usable area is 87,1200 square feet (20 acres). You will be provided a property line specific to your building site.
- Classrooms at the secondary level shall have a minimum of 700 square feet per room accommodating 25 students. Larger classrooms will meet a minimum of 28 square feet per student. All classrooms must collectively accommodate a total of 2,400 students.
- A computer center used for the teaching of computer skills shall have a minimum of 900 square feet per room. The minimum room size is ideal for 25 students; 36 square feet per student should be added to the minimum square footage for each student in excess of 25.
- Primary gymnasiums or physical education spaces shall have a minimum of 7,500 square feet at the high school level. Must have room for one regulation size basketball court or volleyball court.

- Administrator offices (900 square feet with at least 3 reasonably sized offices)
- Nurse's office (170 square feet)
- Bathrooms
- Library
- Parking lot (with at least 580 spaces)
- Additional items that may be included in your project are:
  - 400 meter track
  - Regulation size football field
  - Regulation size soccer field

MATERIALS USED

- Computers
- Printer
- Internet access
- Protractors
- Rulers
- Enlarged Graph Paper (17in × 22in or larger)
- Pencils
- Calculators
- Scissors

DAY 1 (50 MINUTES)

The teacher can begin by viewing the news story about crowded schools, the Dallas News story about coping with crowding, or the Agency for Instructional Technology article about student sourced solutions to overcrowded schools (links to these articles are provided below). The decision should be made based upon the maturity and achievement level of the students in the classroom. The key points to discuss in the classroom are identifying problems with overcrowded schools, technology's role in improving schools, and the environmental and safety aspects of schools. Students should be encouraged to discuss personal experiences and ideas for improvement. Ideas for improvement should be examined for their use of technology and environmental impact.

Below is a list of possible articles to use for the class discussion.

- Dallas News Story: http://www.dallasnews.com/news/community-news/park-cities/headlines/20140203-highland-park-isd-leaders-brainstorm-ways-to-cope-with-school-crowding.ece
- Agency for Instructional Technology article: http://www.ait.net/technos/tq_11/1pearlman.php
- Austin Independent School District Overcrowding: http://kxan.com/2014/03/24/austin-isd-looks-for-help-solving-overcrowding-problems-aging-facilities/

DAYS 2–4 (50 MINUTES EACH DAY)

At this point the teacher should pass out building site plans that outline the available property for the school and other irregular areas to represent limiting factors like ditches, streams, rock-beds or other non-building areas. A Google search for key words "images for high school building site design plans" will help generate ideas of the types of site plans teachers can create and give to the students. After students have correctly identified the problem and have some initial background information, they are ready to begin the exploration phase. Teachers can begin this phase by allowing students to research space saving strategies or innovative school designs. Students will need to find and understand minimum space requirements per classroom as well as the minimum number of classrooms for the school. Teachers can direct students to research digital libraries or interdisciplinary classrooms to reduce quantity of rooms. Ecological or environmental concerns can be addressed through solar power, garden centers that grow school food, or other creative solutions. Once students have at least one innovation in mind they can begin to plan the two-dimensional layout of their schools.

A list of mandatory structures should also be provided with perimeter, area, or exact dimensions. For instance, a football field has specific dimensions, a 400m track has perimeter, and a classroom has only area requirements. For more advanced students, you can include mandatory structures (parking lots, football stadium, tennis courts, etc.) with no given dimensions and require the students to figure out the standard dimensions of the structures. To begin, students must decide on an origin, or focal point, of the building. This will be the spot in the school where the design starts and from which the rest of the

building is constructed. The students can then adjust their school plans to save space, lower environmental impact, or to make the structures more accessible. The teacher will have to closely monitor students during this iterative process to ensure reasonable and thoughtful criteria are used to adjust building plans.

During these days, it is important for the teacher to guide students through transforming their true sized proportions down to the scale model with correct proportions. The teacher should facilitate students while they approximate their building site areas and the amount of structures they can fit inside the building spaces. The two dimensional representations should be labeled so that a casual observer can read and interpret the plans to use the allotted space. This is a good time for the teacher to point out safety concerns such as high traffic areas, academic building distances to roadways or even potential future security measures.

DAYS 5–6 (50 MINUTES EACH DAY)

Give student groups an opportunity to refine their two-dimensional drawings and prepare their presentations to the board of principals. Students who have technology advancements in mind can annotate them. Students who have not identified a technological advancement can brainstorm how to improve their models by acting out scenarios or brainstorming with the scale representation. Once the models are finalized the teacher can offer feedback prior to judging.

DAY 7 (50 MINUTES)

Students present their drawings to the board of principals and justify why the board should choose their schools.

EXTENSION

Extensions to this activity can either be reflective or forward thinking. Reflective exercises can focus on effective land usage with an emphasis on building in three dimensions. Once students receive feedback on two-dimensional representations, the students can turn to 3D software like Sketchup©. The teacher can also provide other high school building plans to the students for examination and critique. Students can also be directed to www.discoverdesign.org to observe national competition results and solutions to similar problems. Students who opt to construct the three-dimensional model should maintain the original scale and location requirements as depicted in the two-dimensional plan.

Forward thinking extension activities focus more on innovations and advancements. Students can discuss the role of technology, modernization of existing structures, renewable energy, and high efficiency schools. Ideas can be generated from magazines like *Science*, *Popular Science*, *Popular Mechanics*, *Scientific American*, *Tech & Learning*, and *Education Magazine*.

EVALUATION

Multiple Choice Questions

1. You have been handed a map with a 1mm:250m scale. A school on this map occupies 2mm by 1.7mm. What is the approximate area of the school?

   A) 42,500 m^2 B) 85,000 m^2 C) 212,500 m^2 D) 250,000 m^2

2. Find the scale measurement of a 250m × 250m storage shed on a 1mm:100m map.

   A) 1 mm × 1 mm B) 2.5mm × 2.5 mm C) 5mm × 5mm D) 10mm × 10mm

Correct Answers: 1-C 2-B

Checklist for Teacher to Track Group Progress

Use: To be used with the High Tech High School PBL. Teachers can place checks or tally marks to indicate completion of a task.
Purpose: Use indicators to assess individual and group engagement. This should allow the teacher to identify successful students and groups.

Date:		Group 1				Group 2				Group 3				Group 4				Group 5				Group 6				Group 7			
	Observed Behavior	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**
Days 1 & 2	Group researches current assignment																												
	Group explores related previous material																												
	Group requests clarification on problem statement																												
	Group asks teacher for clarification																												
	Group has discussed ecological concerns																												
	Group has agreed on at leach one tech advancement																												
	Group sets goals/deadlines for completion																												
	Other																												
Day 3	Group has developed a scale for its 2D model																												
	Students have discussed location of key structures																												
	Students have identified usable area of assigned land																												
	All buildings/rooms are clearly identified																												
	Students can articulate reasons for layout																												
	All buildings/rooms are correct scale																												
	A legend or key explaining symbols is present																												
	Other																												
Day 4	The group has an ordered presentation plan																												
	Visual representation is visible from across the classroom																												
	Visual representation has professional appearance																												
	All required elements are clearly identified																												
	Group can explain technological advancement and impact																												
	Other																												

Rubric for Two-Dimensional Plan

	Excellent	Good	Fair	Poor
Maximum usable area	Plan uses all 871,200 square feet (20 acres) of the allowable area.	Plan uses between 80%–99% of the allowable area.	Plan uses between 60%–79% of the allowable area.	Plan uses less than 60% of the allowable area OR more than the 871,200 square feet of allowable area.
Classrooms	All classrooms contain minimum size of 700 square feet per room accommodating 25 students. All larger classrooms meet a minimum of 28 square feet per student.	All classrooms contain minimum size of 700 square feet per room accommodating 25 students. Some (but not all) of the larger classrooms do meet a minimum of 28 square feet per student.	Some classrooms contain minimum size of 700 square feet and some of the larger classrooms have minimum of 28 square feet per students.	Most of the classrooms (large or small) do not meet minimum size requirements.
Total Accommodation	Collectively, the classrooms will accommodate all 2,400 students enrolled in the school.	Collectively, the classrooms will accommodate 80-99% of the 2,400 students enrolled in the school.	Collectively, the classrooms will accommodate 60-79% of the 2,400 students enrolled in the school.	Collectively, the classrooms will accommodate less than 60% of the 2,400 students enrolled in the school.
Computer Center	Contains a minimum of 900 square feet (per computer room). If room accommodates more than 25 students, 36 square feet were added for each additional student.	Contains between 720 and 899 square feet (per computer room). If room accommodates more than 25 students, 36 square feet were added for each additional student.	Contains between 540 and 719 square feet (per computer room). If room accommodates more than 25 students, 36 square feet were added for each additional student.	Contains less than 540 square feet (per computer room). 36 square feet (for each additional student) were NOT added to the rooms that accommodated more than 25 students.
Gymnasium	Contains a minimum of 7,500 square feet and contains a basketball and/or volleyball court.	Contains a minimum of 7,500 square feet but does not contains a basketball and/or volleyball court.	Contains less than 7,500 square feet and contains a basketball and/or volleyball court.	Contains less than 7,500 square feet and does not contain a basketball and/or volleyball court.
Administrator Offices	Has an area of 900 square feet with at least 3 reasonably sized offices.	Has an area of 900 square feet with only 2 reasonably sized offices.	Has an area of 900 square feet with only 1 office.	Does not have an area of 900 square feet.
Nurses office	Has an area of 170 square feet.	Has an area ~10% over or under 170 square feet.	Has an area ~20% over or under 170 square feet.	Has an area more than 20% over or under 170 square feet.
Bathrooms	Contains enough bathrooms to accommodate 2,400 students and are strategically placed.	Contains bathrooms but does not accommodate 2,400 students. Bathrooms are strategically placed.	Contains bathrooms but does not accommodate 2,400 students and bathrooms are not strategically placed.	Does not contain bathrooms.
Library	Plan has a library, is a reasonable size, and is logically placed.	Plan has a library, is logically placed, but is not a reasonable size.	Plan has a library, but is not logically placed nor is it a reasonable size.	Plan does not have a library.
Parking Lot	Contains at least 580 spaces.	Contains between 430-379 spaces.	Contains between 340-379 spaces.	Contains less than 340 spaces.

Presentation Rubric

	Unsatisfactory (1 point)	**Proficient (3 points)**	**Advanced (5 points)**
Proposal	Presentation seems to contain no prior coordination; no organization; design is not explained.	Presentation has logical sequence; problem and solution explained.	Presentation shows signs of rehearsal; all key elements briefed; professional presentation.
Visual Representation	Does not contains required objects; no legend/key present; improper use of shapes.	Contains required objects but uses approximate proportions in model; all objects labeled.	Contains required objects; all objects drawn to scale; legend/key explains key elements; precision in layout/space used.
Technological Advancement	Technology is unrealistic; improvement is poorly connected to problem.	Technology is mostly realistic. Visual/spatial representation appropriate; improve is logical.	Technology is realistic and is backed by research; improvement is logical.
Innovativeness	Technology contains no innovation.	Technology used is interesting, but can be found in current high schools.	Technology used is very innovative and cutting edge. Definitely unique.
Site Plan	No logical organization to facility layout.	Reasonable and thoughtful approach to facility layout.	Facility layout is ecologically driven; thoughtful use of space.
Total Points			
Notes/Comments:			

REFERENCE

http://ritter.tea.state.tx.us/rules/tac/chapter130/ch130o.html

ALI BICER AND SANDRA NITE

7. EGG DROP PARACHUTE

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4
Engagement and research	Exploration and research	Develop hypothesis regarding construction of the parachute	Design parachute shape and dimension
Day 5	Day 6	Day 7	Day 8
Finish constructing parachute model	Field trip to have an egg drop parachute performance	Create presentations with revised hypothesis	Conduct presentations

WELL-DEFINED OUTCOME

Students will design and construct a parachute with diverse polygons and a circumscribed circle. With the area of the parachute and length of segment of polygons, students will a make a parachute and try to drop an egg from the second floor of a building to the ground without breaking.

TEACHER INTRODUCTION

The new egg drop project is different from previous egg drop projects because it requires a more accurate hypothesis, higher-level mathematics, and science knowledge (i.e. quadrilateral and circle's dimensions, gravity, density of air, velocity, resistance force), and application on a real world situation.

The teacher introduces a story that can give students motivation and interest in the project. By reading the story, students can follow up with what they are going to do, why they should do it, and what they need to consider while implementing the project. The story is that the parachute company wants mathematics and science researchers (students in the classroom) to develop parachute models with scientific hypotheses to apply them on practical situations.

The teacher can help students understand the big picture on the egg drop project through some video clips or online games. For example, there are many available video clips that show previous egg drop projects online. Some students may already know what the egg drop project is, but others may not. Students who do not know what the egg drop project is can imagine a big picture in their heads to plan what they are going to do. Furthermore, online games including parachutes can stimulate students' interest and spark ideas on parachute shapes and areas/sizes.

The teacher should explain and review prior knowledge even though students have already covered that topic. For the present project, some science and mathematics content should be taught before students explore the project. Content related to gravity, density of air, and velocity in physics is necessary for students to find solutions for this project. The following formula is one example:

$$A_p = \frac{2gm}{\rho C_d V^2}$$

In this formula, g is the acceleration due to gravity, m is the mass, ρ is the density of air, C_d is the coefficient drag of the parachute, and V is the velocity.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 47–52.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- State the nature of forces in the physical world.
- Investigate the historical development of the concepts of gravitational, electromagnetic, weak nuclear, and strong nuclear forces.
- Explain how the magnitude of the gravitational force between two objects depends on their masses and the distance between their centers.
- Demonstrate how changes occur within a physical system, and apply the laws of conservation of energy and momentum.
- Investigate and calculate quantities using the work-energy theorem in various situations.
- Investigate examples of kinetic and potential energy and their transformations.
- Display and understanding the momentum of a physical system.
- Demonstrate and apply the laws of conservation of energy and conservation of momentum in one dimension.
- Describe how the macroscopic properties of a thermodynamic system such as temperature, specific heat, and pressure are related to the molecular level of matter, including kinetic or potential energy of atoms.
- Give examples of different processes of thermal energy transfer.
- Analyze and explain everyday examples that illustrate the laws of thermodynamics, including the law of conservation of energy and the law of entropy.

Mathematics – The student is expected to:

- Demonstrate a variety of representations to describe geometric relationships and solve problems.
- Use numeric and geometric patterns to develop algebraic expressions representing geometric properties.
- Apply numeric and geometric patterns to make generalizations about geometric properties, including properties of polygons, ratios in similar figures and solids, and angle relationships in polygons and circles.
- Use properties of transformations and their compositions to make connections between mathematics and the real world, such as tessellations.
- Identify and apply patterns from right triangles to solve meaningful problems, including special right triangles (45-45-90 and 30-60-90) and triangles whose sides are Pythagorean triples.
- Use tools to determine measurements of geometric figures and extend measurement concepts to find perimeter, area, and volume in problem situations.
- Calculate areas of regular polygons, circles, and composite figures.
- Calculate areas of sectors and arc lengths of circles using proportional reasoning.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Apply principles of relationships between force and motion.
- Plan and implement investigations.

Technology

- Conduct effective internet searches; recognize reliable internet sources.
- Select appropriate technology to help solve the problem.

Engineering

- Use an iterative problem-solving process.
- Select appropriate tools to solve the problem.

Mathematics

- Solve literal equations; proportions and scaling.
- Use the Pythagorean Theorem.

STUDENT INTRODUCTION

Students are young researchers looking for funding on a project. The parachute company would like for the student's research team to design a parachute that can hold a maximum of 1,500 pounds and fall from a height of 20,000 feet (6,096 meters). They would also like for the cargo to fall as slowly as possible without breaking the fragile contents inside. The task will be to create a parachute model, using the egg drop experiment, that can later be built to scale and has an accurate time measurement of drop time. The parachute company wants a thorough analysis because they have limited supplies and funding for the project. Students will present the process including the physical equation related to gravity and resistance, and the calculation of the parachute area required to safely deliver the egg. It is very important that the parachute models are not tinkered with constantly and are not subject to trial and error testing. The company requests that the researchers design their models in one iteration if possible. Students, as a team, will contact a company that is interested in helping the next wave of scientists receive their start.

MATERIALS USED

- Cups (paper or plastic)
- String
- Fabric
- Knife
- Ruler
- Scissor
- Stop watch
- Wood sticks
- Egg
- Plastic film
- Spring gauge

DAY 1 (50 MINUTES)

In presenting to the class, it is important that teachers foster within students the enthusiasm, encouragement, and confidence to create a parachute that will safely land an egg. A key factor in presenting the problem is to show students how to calculate and create a parachute without giving them the "answers" to how it can successfully be done. The project introduction begins with presenting the story in order to engage students and show them why they should care about the problem. Students will be able to understand what they will learn and how it will benefit them in the future. After explaining to the students why the project is important, the teacher then provides them with the constrained materials necessary to complete the project. Before giving students the equations necessary to design the parachute, teachers will present an interactive online game, which offers some guidance on how drag force affects the time the parachute takes to land and reduces the force of the impact when landing.

DAY 2 (50 MINUTES)

Students review the physics and geometry content provided by the teacher in the class and search for more information using textbooks or the Internet. Teachers may also suggest that students view video clips to see how other egg drop projects have been designed and implemented. Students can discuss and try to design the parachutes using the provided materials.

DAY 3 (50 MINUTES)

Scaffolding is defined as "a process that helps a child or a novice to solve a problem, carry out a task, or achieve a goal which would be beyond his unassisted efforts" (Wood, Bruner, & Ross, 1976, p. 90, cited by Barron et al., 1998, p. 276). Barron et al. (1998) used three types of scaffolds that were defined by Collins, Brown, and Newman (1989); those that function to communicate process, those that provide coaching, and those that elicit articulation. Scaffolding tools such as video formats and problem materials

were provided for students to see how they could approach to the problem. Barron et al. suggested that pairing problem and project-based learning could positively impact students' learning. In this regard, students in the community could share knowledge and motivate each other. This project has three kinds of scaffolds based on Barron et al.'s (1998) study. First of all, the appropriate goal will be clearly defined. A clearly defined goal provides students with direction for the project rather than just enjoyment of the activities. The second scaffold skill is to offer picture models and equations related to making parachutes or any devices to deliver the egg safely without breaking. Because the egg drop project has been implemented for a long time, many pictures of models are available.

DAY 4 (50 MINUTES)

Students need to consider diverse components to design parachutes or other devices such as gravity, density of air, velocity, height, and dimension of the parachute. The relation among these can be represented by the equation below;

$$A_p = \frac{2gm}{\rho C_d V^2}$$

where, g is the acceleration due to gravity, m is the mass, ρ is the density of air, C_d is the coefficient of drag of the parachute, and V is the velocity.

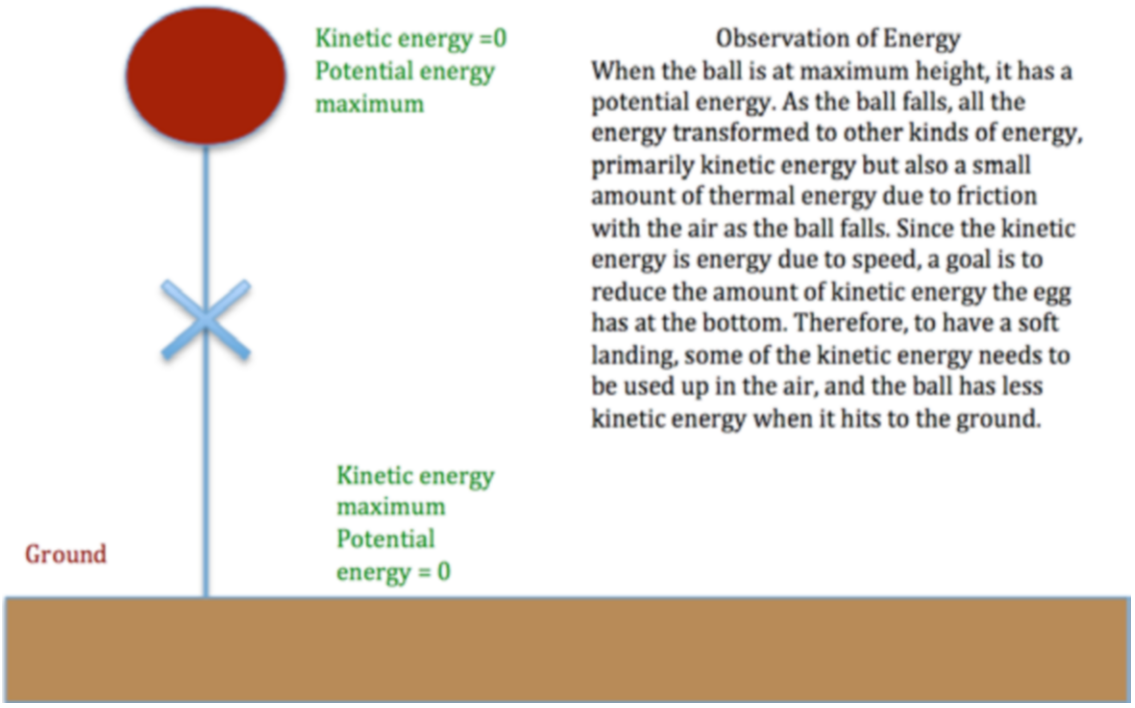
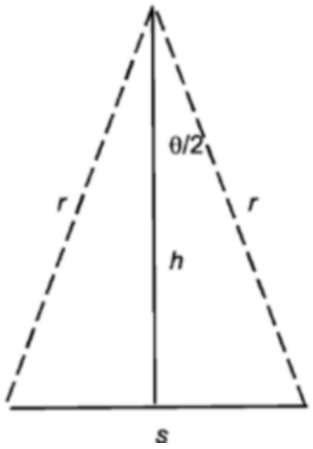


Figure 1. Observation of energy transformation

Furthermore, students will be given geometry knowledge to utilize in designing the parachute shape and dimension. The last scaffold is to assign students to three groups. Each group has students who are experts in different fields. This strategy facilitates sharing of knowledge and continuing to explore the project.



$$A_p = n \cdot A_T$$

$$A_T = \tfrac{1}{2} \cdot s \cdot h$$

$$* \cos\left(\frac{\theta}{2}\right) = \frac{h}{r}$$

$$\therefore h = r \cdot \cos\left(\frac{\theta}{2}\right)$$

$$* \sin\left(\frac{\theta}{2}\right) = \frac{s/2}{r}$$

$$\therefore s = 2r \cdot \sin\left(\frac{\theta}{2}\right)$$

$$\therefore A_T = \tfrac{1}{2}\ 2r \cdot \sin\left(\frac{\theta}{2}\right) r \cdot \cos\left(\frac{\theta}{2}\right)$$

Figure 2. Basic trigonometry formulas

DAY 5 (50 MINUTES)

Students can evaluate their first hypothesis based on their results. In the mathematics aspect, students can generalize geometric formulas related to polygons.

DAY 6 (50 MINUTES)

All groups are encouraged to make calculations and observations to write their hypothesis. The groups are allowed to develop their hypothesis until the day before they begin the design and construction of the parachute. For a week-long period, students receive scaffolding from the project designers whenever they face challenges or need assistance, by using cyber-learning technologies such as: Skype, Messenger, Share Point, and other communication tools. All of the group hypotheses will be collected to see the groups' mathematical, physical backgrounds, and how much effort they spent.

DAY 7 (50 MINUTES)

All groups will be allowed to perform at least two times. This provides the groups with the opportunity to see the results of the first egg drop and have a chance to make any necessary modifications for the second drop.

DAY 8 (50 MINUTES)

After the whole group presentations, the egg drop parachute designer will make a small presentation to compare the development of the group hypothesis. The groups' hypotheses will be evaluated in terms of scientific progress.

EXTENSION

How the scientific hypothesis should have been written and what it includes is reviewed to help students see their weaknesses and strengths in their conceptual parachute model. After the groups compare their parachute models' arrival time to their hypotheses, they realize what they need to work on in order to design a more aerodynamic and safe parachute model. For an extension, they may use an iterative engineering design process to redesign and test. Or, they may write up a report about what they learned and what they would do if they had the opportunity to continue the iterative process.

EVALUATION

When formative assessment is not used in the classroom, teachers miss an opportunity for learning and increasing student engagement. The key to formative assessment is to allow students to revise, edit, communicate with others, and redesign through small steps in a project or by providing feedback.

The Oral Presentation Rubric can be used to assess students' participation and presentation skills.

Oral Presentation Rubric

Category	4	3	2	1
Comprehension	Student group is able to accurately answer almost all questions posed by classmates about the basic physical and mathematical knowledge and the hypothesis. (20 points)	Student group is able to accurately answer most questions posed by classmates about the basic physical and mathematical knowledge and the hypothesis. (16 points)	Student group is able to accurately answer a few questions posed by classmates about the basic physical and mathematical knowledge and the hypothesis. (14 points)	Student group is unable to accurately answer questions posed by classmates about the basic physical and mathematical knowledge and the hypothesis. (10 points)
Preparedness	Student group is completely prepared and has obviously rehearsed the presentation. (20 points)	Student group seems mostly prepared but might have needed a couple more rehearsals. (16 points)	Student group is somewhat prepared, but it is clear that rehearsal was lacking. (14 points)	Student group does not seem at all prepared to present. (10 points)
Collaboration with Peers	Almost always listens to, shares with, and supports the efforts of others in the group. Tries to keep people working well together. (20 points)	Usually listens to, shares with, and supports the efforts of others in the group. Does not cause "waves" in the group. (16 points)	Often listens to, shares with, and supports the efforts of others in the group but sometimes is not a good team member. (14 points)	Rarely listens to, shares with, and supports the efforts of others in the group. Often is not a good team member. (10 points)
Evaluates Peers	Completes peer evaluation completely and always gives scores based on the presentation rather than other factors (e.g., person is a close friend). (20 points)	Completes almost all of the peer evaluation and always gives scores based on the presentation rather than other factors (e.g., person is a close friend). (16 points)	Completes most of the peer evaluation and always gives scores based on the presentation rather than other factors (e.g., person is a close friend). (14 points)	Completes most of the peer evaluation but scoring appears to be biased. (10 points)
Content	Shows a full understanding of the building project. (20 points)	Shows a good understanding of the building project. (16 points)	Shows a good understanding of parts of the building project. (14 points)	Does not seem to understand the building project very well. (10 points)

REFERENCES

Barron, B. J., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem-and project-based learning. *Journal of the Learning Sciences*, *7*(3–4), 271–311.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. *Knowing, learning, and instruction: Essays in honor of Robert Glaser*, *18*, 32–42.

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JENNIFER RIEGER

8. FUZZY DECISIONS

How Control Systems Are Developed

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Days 4–5	Day 6	Day 7
Read scenario and introduce the project	Designing and constructing the robot	Draft of code to program the robot	Use code to program robot and modify code through testing process	Presentations	Demonstration of Robots

WELL-DEFINED OUTCOME

Students will construct a robot using LEGO® MINDSTORMS® robotics and will create a program that receives signals from input sensors to direct the robot towards a predetermined location.

TEACHER INTRODUCTION

Students will gain knowledge about types of control systems as well as be able to develop their own control system that receives input from the environment and has the robot respond as a result of the input. The students will gain knowledge of programming and robotics while using LEGO® MINDSTORMS® robotics and LabVIEW™.

This PBL uses LEGO® MINDSTORMS® robots and LabVIEW™ technology to engage students in the process of product development and collaboration with a team. Students will apply their knowledge of velocity, acceleration, and mechanical physics to make decisions about the best way to design a robot to complete a desired task. Prior to beginning this project, students should understand basic logic rules, the construction of if-then statements, and the construction of for-each loops. This will prepare students to use LabVIEW™ software – a user-friendly, drag and drop programming language. This PBL can be used for students to demonstrate their ability to apply their knowledge of physics and logic to make decisions, problem solve, and present ideas to others about how to build a robot that will complete a desired task.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skill in each of the areas identified below.

Physics – The student is expected to:

- Apply knowledge of mechanical physics to make decisions about the design of a robot.
- Use knowledge of speed, velocity, acceleration, and vectors to determine how fast to spin each wheel (servo) of the robot so the robot will move forward, move backward, turn left, and turn right at a desired speed.

Technology – The student is expected to:

- Create a program in LabVIEW™ that uses information given by the input sensors that are connected to the robot.
- Apply the knowledge of control systems to create a program that uses the information from the input sensors to change the speed and/or the direction of the robot to arrive at a desired location.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 53–59.

Mathematics – The student is expected to:

– Use logic rules to aid in the development of the algorithm used for the robot to interact with its surroundings.

English – The student is expected to:

– Use detailed and clear communication to share ideas about how to best build and program the robot with other team members.
– Demonstrate the functionality of the robot and justify reasons behind the design of the robot.

STEM CONNECTIONS

This PBL will allow students to develop the following knowledge and skills in each of the identified areas.

Technology

– Students will learn how to develop their own algorithms that will direct a robot towards a desired location.
– Students will learn how to implement their algorithms in LabVIEW™.

Engineering

– Students will use the engineering design process to develop their robots.
– Students will brainstorm and collaborate ideas with team members.
– Students will implement ideas by building and coding a robot.
– Students will engage in the test and redesign process to improve the performance of the robots.
– Students will present the design and demonstrate the functioning of the robots.
– Students will improve upon their skills for working in a team to complete a project.

Mathematics

– Use knowledge of addition of vectors to determine the speed of each wheel.

STUDENT INTRODUCTION

The ability of technology to respond to the information it receives allows us to do many things like live in a properly air conditioned home, have factories that remain on task, and have cars that respond to the turn of a wheel. Every day, Americans rely on devices that have the ability to make decisions based on the information they receive. These devices are called control systems. In robotics, control systems are used to allow robots to make decisions based on various inputs they receive. In this project, you will be the engineer and create a robot that will respond to input signals and navigate obstacles to arrive at a desired location using a control system.

MATERIALS USED

– LEGO® MINDSTORMS® Robotics Kit
– Computer with software to program in LabVIEW™

Materials will vary for the construction of the maze the robot will follow. Some possibilities are:

– Color tape (put on ground for robot to follow)
– Light
– Boxes or some obstacle that blocks the robot

DAY 1 (50 MINUTES)

Read the following scenario to the class: Imagine you all have been hired by the government to develop a robot that can be sent into enemy territory to retrieve information about the enemy's plans to attack. You

find out from a very reliable source there are wires running underground that will allow you to track where information is received and where information is sent. It is your robot's job to collect as much information as possible regarding the location of the wires using its input sensors to move as quickly as possible to the station transmitting the information to protect the country from attack. However, the large variety of wires running underground make it difficult to identify the main wire that transmits the information. Your robot must decide which wire is the correct one to follow. The robot must also be careful to navigate obstacles that might lie in its way such as buildings, forts, people, or anything else that could cross its path during the trek. The government has hired other groups of people to also work on this task. At the end of the project, the government will conduct a simulation and have each group demonstrate how its robot navigates the terrain. The government will choose the group whose robot best navigated the conditions and successfully tracked the enemy's path.

At this point, have the students split into groups of 3 or 4 (the teacher may want to construct the groups to maintain similar group dynamics) and move their desks to the outside corners of the room to create an open area in the middle of the room. Give each team a different color of tape. Tell the students that this tape represents their wire that transmits information. Have each group use a minimum amount of the tape (depending on size of classroom, you may want to determine a maximum size as well) and put the tape on the floor in the group's current location (this is the information center that the enemy would want to find to know the group's plans) and leads to a specific location inside the room that we will call the power station (where all wires must come from to have the energy to transmit information). Also tell them that the tape cannot pass back over itself. Next, randomly assign each group another color tape that they must follow to retrieve their enemy's information. Figure 1 gives an example of what the room configuration may look like.

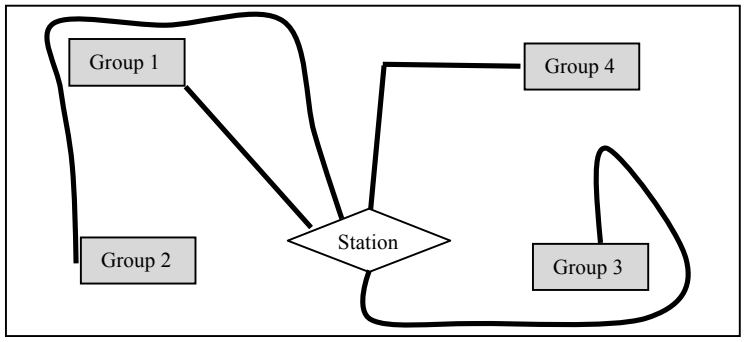


Figure 1. Sample room configuration

Tell the students that their goal is to send a robot to the "power station" where they know that the all wires must begin. The robot must then determine which wire is the one it should follow and follow the wire to the location where information is transmitted. Pass out the LEGO® MINDSTORMS® Robot Kits to the teams and tell the students the kits are the only objects they have to build their robots. It is up to each group's creativity to determine how the objects are used. Have each group look through its kit and begin discussing ideas on how all objects can be used in the project. It's an exploration day! Let the students explore and discover for themselves what each part could be used for in their mission.

DAY 2 (50 MINUTES)

Assign each group another group's tape to locate. Tell the students that they must determine how to construct their robots such that it can best follow the path depicted by the color tape. There might be different considerations based on how each team placed their path of tape. Ask students the following questions:

- What values will the sensor read when it sees this color tape?
- Does it matter how close or far away the sensor is to the tape?
- When will you have to consider angles?
- How will the value change as the sensor is only partially on the color tape and partially on the ground?
- What are other items you should consider? Some possible responses by the students are lighting, using more than one sensor, overlapping tape, the degree of turns (e.g., 90 degree turn).

Tell the students that based on the information their robots receives from the sensor and by keeping mobility in mind, they must determine how to best construct their robot. Let them use this time to further explore how the sensors work and design a plan for constructing their robots.

DAY 3 (50 MINUTES)

In Day 2 students created a plan for the mechanics and construction of the robot. Today students will construct their own plan or algorithm for coding the robot. They will think about the challenges of accurately following a line as well as handling obstacles. Tell the students to think about the last time they were on a computer and, though they knew the page number they needed, they had to scroll through a long document to find the desired page. Ask them the following questions:

– Were you at the same scrolling pace for the entire search?
– When were you scrolling faster or slower?
– How do you think this relates to the construction of code that will tell the robot to follow a line?

Tell the students that the idea of having to adjust speed based on how close the robot is to the target is the basic understanding of control systems. Remind the students that today they will be researching types of control systems to help them better understand how control systems work and how they will implement their own in the code for their robot. Some ideas of control systems to research are PID, Fuzzy Logic, and Closed Loop Control Systems. Help the students understand that proper and thorough research will help to make their robots follow the tape more smoothly, accurately, and quickly and help in avoiding obstacles. By the end of this class students should have an outline of the code that they will implement for their robots.

DAYS 4–5 (50 MINUTES EACH DAY)

Students will use their design plans and outlines of their code to build the robots and implement code. Allow students enough time to complete their robot construction. Remind them that there will be changes that will have to be made. Encourage them to test their robots and make adjustments accordingly.

A challenge for the students will be determining how to adjust the robots' speed and how to make turns. Remind the students that each wheel has its own speed vector and that all of the wheels must work together to determine the overall speed vector of the robot.

DAY 6 (50 MINUTES)

Today is presentation and demonstration day. Have all of the students imagine that they are presenting their ideas to the government and have each group present robot to the class. Have the students present the reasons for their robots' design to the class, including but not limited to:

– The research they used to help them decide how to structure their control systems.
– The considerations they made in the mechanical construction of the robot.
– Changes the group made to the original design plan.
– Challenges the group faced during the design process.

Tell the students that they must take notes from the other groups on things like the following:

– What were the presenting team's design considerations?
– Why did the presenting team decide to build their robot the way that they did?
– How did the presenting team implement their control system? What was their reasoning?

Following all of the teams' presentations, have each team share something that they learned from another team's project and how they would enhance their robot after listening to all the presentations.

DAY 7 (50 MINUTES)

Today is judgement day – the day of the final demonstration. To make the judging process more difficult, place boxes throughout the room. Note: This may or may not be done depending upon the students' progress on their projects. Leave this as an extra challenge if some teams finish more quickly. Some obstacles could lie right over the tape in which case the robot must be programmed to make its way around the obstacle to get back on track.

The goal of each team is to have the robot follow the designated color of tape to its final location as quickly as possible. All robots will begin in the power station box. Using the code the students have downloaded, the robots will then continue on their own to their enemy's location. When the robot arrives, the team has completed their task and is ready to send its robot into the field!

EXTENSION

Teams that are able to follow their partner's line will be given the extra challenge of how to navigate the robot around an obstacle.

EVALUATION

Teamwork Rubric for Individual Group Members

Category	**4**	**3**	**2**	**1**
Quality of Work	Provides work of the highest quality. The work is clearly outstanding.	Provides high quality work. The work is acceptable and respectable.	Provides work that occasionally needs to be checked/redone by other group members to ensure quality.	Provides work that needs heavy modification by others to ensure quality.
Working with Others	Always listens to, shares with, and supports the efforts of others. Always keeps people working well together and on task.	Most always listens to, shares, with, and supports the efforts of others. No problems were found with group dynamics.	Often listens to, shares with, and supports the efforts of others, but sometimes is not a good team member.	Rarely listens to, shares with, and supports the efforts of others; not a good team player.
Problem-solving	Actively looks for, suggests, and implements solutions to problems without aid from other groups. Actively contributed to solutions of own group.	Finds and refines solutions suggested by their own groups and occasionally offered solutions to own group.	Does not suggest or refine solutions, but is willing to try out solutions suggested by others.	Does not try to solve problems or help others solve problems. Lets others do the work.
Contributions	Routinely provides useful ideas when participating in the group and in classroom discussion. A definite leader who contributes a lot of effort.	Usually provides useful ideas when participating in the group and in classroom discussion. A strong group member who tries hard.	Sometimes provides useful ideas when participating in the group and in classroom discussion. A satisfactory group member who does what is required.	Rarely provides useful ideas when participating in the group and in classroom discussion. May refuse to participate.

Final Presentation Rubric

Category	4	3	2	1
Content	Shows a full understanding of the topic.	Shows a good understanding of the topic.	Shows some understanding of parts of the topic. There were definite parts where understanding was not demonstrated.	Does not seem to understand the topic very well.
Comprehension	Student is able to accurately answer all questions (100%) posed by classmates about the topic.	Student is able to accurately answer most questions (80–99%) posed by classmates about the topic.	Student is able to accurately answer some questions (50–79%) posed by classmates about the topic.	Student is unable to accurately answer less than half the questions posed by classmates about the topic.
Organization	The presentation is easy to follow and presented in a coherent and logical manner. All criteria are addressed to their full extent.	For the most part the presentation is easy to follow; however, there are some rough transitions in which it is evident that the student cannot logically develop and explain his or her reasoning.	It is evident that the ideas are not fully developed and the presentation lacks considerations of logical reasons for the way that the robot was designed.	The ideas presented lack reasoning and explanation.
Research	Students have found at least 4 reliable sources that have information that aided in the development of their algorithm.	Students have found at most 3 reliable sources that have information that aided in the development of their algorithm.	Students have not found an adequate amount (at most 2) of reliable resources to aid them in the development of their algorithm.	Students have not conducted research to back their ideas.

Design Rubric

Category	4	3	2	1
Modification/ Testing	Clear evidence of troubleshooting, testing, and refinements based on data or scientific principles.	Clear evidence of troubleshooting, testing, and refinements. Limited on data or scientific principles.	Some evidence of troubleshooting, testing, and refinements. No data or scientific principles.	Little evidence of troubleshooting, testing, or refinement. No data or scientific principles.
Program Efficiency/ Accuracy	The robot was able to navigate its way to the desired location. Robot was capable of navigating around boxes to continue on the desired path. Control system that was implemented allowed for robot to make smooth turns to follow the path.	The robot was able to navigate along the proper color tape. However, it might have needed help to find its way back on course. Robot was unable to navigate around obstacles.	Robot showed little ability to follow the desired path.	Fatal flaws in function with complete failure.
Robot Design	Placement of light sensor and wheels were creatively and strategically placed for effective mobility and functionality of the robot.	Placement of light sensor and wheels were effective yet could have been improved upon for more efficiency.	Placement of light sensor and wheels is somewhat effective. However, the robot might seem fragile or require frequent adjustments to keep items in place.	Construction of robot is without a clear purpose and contributed to a product that performed poorly.

Multiple Choice Questions

1. What is a control system?
   A) A device that manages, commands, directs or regulates the behavior of other devices
   B) A device that allows a human to control the behavior of another device
   C) A device that is under control

2. Which of the following is NOT a common control system?
   A) PID (Proportional, Integral, Derivative)
   B) Fuzzy Logic
   C) Close loop control system
   D) Circular

3. What is troubleshooting?
   A) Removing areas of code that seem to be causing problems.
   B) Logical, systematic search for the source of a problem so that it can be solved.
   C) Completely starting from scratch since the design was no good

Correct Answers: 1-A 2-B 3-D

REFERENCES

To order the LEGO® MINDSTORMS® robot kits
– https://shop.education.lego.com/legoed/en-US/search/navSearchResults.jsp?categoryId=EDU_PRD_LINE_107
To download LabVIEW
– http://www.ni.com/download-labview/

MARGARET KENDRICK

9. MARS

The First Frontier

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5
Engagement – Movie clips and discussion	Discussion comparing Earth and Mars	Discuss on basic survival needs	Break into teams and research	Research
Day 6	Day 7	Day 8	Day 9	Days 10–11
Design base	Improve the design of base	Improve the design of base	Finalize design	Group Presentations

WELL-DEFINED OUTCOME

Students will design and present a nearly self-sustaining operations base on the surface of Mars. The operations base must be capable of supporting a small settlement of human life.

TEACHER INTRODUCTION

This PBL is designed for high school students who are completing or have already completed basic biology and physics courses. In this project, students will apply their knowledge of the different disciplines into an engineering style project. It will cover aspects of science such as physics, biology, and environmental science. Through research of Martian conditions and current engineering advancements, students will develop an understanding of the basic conditions necessary for human survival on another planet and the new and emerging technology that makes survival on another planet possible. Students will begin the project by designing a base of operations on Mars. Because of Mars' large distance from the Earth, the number of supply trips from Earth to Mars must be limited and thus, the base will need to be almost completely self-sufficient. Therefore, students will design a nearly self-sustaining base of operations on Mars capable of supporting a small settlement of human life. Students will brainstorm the necessary conditions of the base such as heat, energy, etc. From there, the students will split into groups to focus on each identified condition. The project will take nine or ten 50-minute class periods and some out of class research on the students' behalf. Each group will develop its idea within its own group to solidify their design and converse with other groups to make sure all conditions will work together. Finally, the students will present their design to the class and explain their reasoning for elements in their design. Students may use various design programs and presentation programs to present their completed projects. By the end of this project, students will have an understanding of scientific and engineering methodologies, the necessity of research, new and emerging technologies, a greater understanding of the connections between the different classifications of science, the purpose and functionality of teamwork, and the necessary communication skills to present their completed design.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas:

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 61–72.

Science – The student is expected to:

- State the environmental factors necessary for survival of an organism.
- Research the environment of Mars and compare and contrast it with that of the Earth's.
- Adhere to scientific processes in order to analyze and solve a problem with logical reasoning.
- Discuss the necessity for scientific research and the factors that contribute to an engineering design.
- Discuss the importance of resource conservation and the management of those resources.
- Discuss the difference between open and closed systems.
- Identify and apply various energy sources and their advantages/disadvantages.

Engineering – The student is expected to:

- Discuss the purpose of teams, discuss the functions of different roles within the teams, and actively participate within one with positive attitudes.
- Incorporate engineering methodologies to solve a problem.
- Develop and adhere to their created timeline.
- Determine how different technological systems can serve a common goal.
- Research and apply new innovative technology to other real world purposes.
- Describe how different technological systems interact to serve a common goal.

English – The student is expected to:

- Use clear and concise communication strategies to present their ideas to their peers.
- Use appropriate communication strategies with their co-workers, teachers, and outside resources in a professional context.
- Research and decipher important technological innovations through various media outlets.
- Implement visual, verbal, and written techniques to convey and explain their design.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the students.

Science

- Critical thinking, scientific reasoning, and problem solving skills to make informed and logical decisions.
- Analyze, evaluate, and apply scientific research.
- Recognize how environmental changes affect ecosystem stability.
- Identify environmental factors hazardous to organic life.
- Identify the various energy sources and their viability in different environments.
- Apply knowledge of management and conservation of various resources to an isolated environmental system.
- Identify and apply the necessary factors conducive to human survival.
- Communicate and apply the scientific research gathered from various sources.

Technology

- Present their conclusions, research findings, and designs using a variety of technology and media.
- Identify new and emerging technologies then apply them in other fields.
- Predict possible changes in society through technology based on student's research.
- Use of variety of media sources to effectively research.

Engineering

- Identify and discuss the principles of ideation.
- Identify system constraints and make decisions.
- Use rational thinking to develop or improve a system.
- Apply decision-making strategies to develop a solution.

– Use time-management techniques to develop and maintain deadlines.
– Complete work according to established criteria.
– Participate in the organization and operation of an engineering project.
– Employ research skills to investigate new and emerging technology.

STUDENT INTRODUCTION

Who is a fan of Star Wars? Interstellar? Guardians of the Galaxy? The Martian? Who here knows of the science fiction series Star Trek? Now, let me ask you this question: What do all of these movies all have in common? Space travel, intergalactic empires, and even other forms of intelligent life are some of the few main ideas of these tales, but the core concept is clear: the human race is extended to the far reaches of the universe. Now, this may seem like a fantasy or a notion that should remain in stories, but look at what young scientists and engineers are doing today. We have 3-D printers, proto-types of invisibility cloaks, laser guns, computers that fit in the palm of your hand, and more. All of this technology has been developed within the last one hundred years, and the development and use of these technologies has grown at an exponential rate. As astrophysicist Dr. Jane Foster in the movie THOR put, "[Science fiction] is a precursor to science fact!" Nothing is impossible. But as the saying goes, "Rome was not built in a day;" we cannot expect to immediately explore the entire universe. We must start small.

The Red Planet, Mars, named after the Roman God of War, is our first stepping-stone on the path of space exploration. It is one of the closet planets to Earth and the most similar to Earth in our solar system. Now, I am not saying one could take a shuttle to Mars, land, and live with ease. Living on Mars will not be easy. But in comparison to Jupiter, which has gravity that is 2.5 times that of Earth's and is a gas giant, or to Venus, whose atmosphere rains acid rather than water, Mars colonization will be relatively simple. Notice how I said relatively, because living in a hostile and foreign environment is in no way simple. Life on Mars will be hard. There will be numerous factors you need to account for and solve, but with modern and advancing technology, a little ingenuity and a lot of brains, anything is possible.

Your mission, should you choose to accept, will be to design a small scientific base of operations on Mars. You may choose the location that best suits the needs for the base. Because of your distance to Earth, your base design must be able to operate with very little help from Earth. Now what does that mean? You must be semi-self sufficient. Ask yourselves these questions: What will I eat? How will I get water? How will I breathe? What factors on Mars will kill me? Who and what will you bring? Who are essential personnel? As a team, you will identify the challenges that you will experience on Mars, research modern and emerging technology that can solve these problems, and use this information to design a nearly self-sustaining base of operations that will allow humans to survive and thrive in a Martian habitat. No detail can be left unnoticed. On other planets, anything and everything can kill you, even a loose screw. To complete this project, you will need to be thorough. As a team, you will need to prioritize the different challenges and divide the workload within the team. You will need to record and maintain all sources in an organized fashion. You will need to document what happens at meetings, decisions made, and tentative designs as they progress. At the end, your team will present your comprehensive design including blueprints, system specifications, and the reasoning behind the design components to the class using visual, written, and oral communication methods.

MATERIALS USED

For Research Purposes: Students will need to obtain and maintain research for their design

– Technology Magazines
– 2 notebooks (research and design, see Appendix for example page layout)
– Folders
– School Library
– Internet
– Any valid research source the students wish to apply
– Graph Paper
– Pen/Pencil
– Colored pencils/markers
– Computers
– Computer software such as Microsoft Power Point®, Excel®, Word®, Windows Movie Maker®, etc.
– Internet Applications

– Engineering Software (if available)
– Scanner

DAY 1 (20 MINUTES)

Today, you need to gain the interest of the students. Grab their attention and make them take an interest in what this project is about. Begin the engagement section by showing the students a series of clips from the Star Wars trilogy and the 2014 movie *Interstellar*. You can find website suggestions on these movies in the Resource section at the end of this PBL. The Star Wars movies portray numerous human settlements on different planets. From *Star Wars Episode IV: A New Hope*, show the students the clip of Luke's farm. Here, discuss moisture farms where machines would pull water out of the air to survive the arid climate of Tatooine. From *Star Wars Episode V: The Empire Strikes Back*, show them the Hoth Base (the ice planet) and the Cloud Base. For each clip, prompt the students to discuss what things or systems are helping the humans survive. For example, the humans would need heaters and electric power to survive on the icy Hoth, and the humans constructed a flying settlement above the toxic gases of the Cloud base. Lastly, you can either show the clip from Interstellar where Matt Damon and Matthew McConaughey's characters discuss the viability of Matt Damon's planet or an earlier clip where the small crew of the Endurance discuss which of the identified planets holds the most opportunity for the human race. Let the students identify the factors that are detrimental to human survival and the technologies that the movies explicitly or implicitly show to survive. If you as the teacher believe that you have a more beneficial movie clip or short story, feel free to use it, but the scenario must show humans surviving in otherwise lethal environments and allow the students to discuss the things that ensure human survival.

After the movie clips and discussion, introduce the students to the project. Let them read through the student introduction and discuss what will be happening over the next week or two. Explain to them that instead of planets like Hoth or Tatooine, they will be designing a base of operations on Mars. But, before they can design anything, they must understand the challenges and conditions they will face. Thus, give them a small homework assignment to research the differences between the environment of Mars and that of Earth. This will allow your discussion on Day 2 to be more productive.

DAY 2 (50 MINUTES) – ALL ABOUT MARS

As the teacher, you will start with an informative discussion on the differences between Mars and Earth. The NASA website has a comprehensive yet easily viewed database on the comparisons between Mars and Earth (http://www.nasa.gov/audience/foreducators/5-8/features/F_JASON_Expedition.html). NASA also has a visually appealing factual page that goes into a bit more depth of Martian conditions (http://quest.nasa.gov/aero/planetary/mars.html). After showing the students some of the facts and comparisons, you should prompt the students to discern what those similarities and differences could entail. Let the students head the discussion, but pose guiding questions. For example, "Mars has a smaller diameter than Earth; what does that mean?" The students should then be able to discern that with a smaller planetary diameter comes a smaller gravitational constant. Thus, gravity of Mars is less than that of Earth. A harder example would be "Given that the Martian atmosphere is 100 times less dense than our own, what does that mean?" Students would then determine that there would be less atmospheric pressure on the surface and thus decompression would be a major factor. During the discussion, you should have the students record the similarities and differences of Mars. This will be helpful during the brainstorming and researching sessions.

This project will require some research into Mars on the teacher's behalf. For more ideas, I recommend reading "The Martian" by Andy Weir. It is science fiction, but it relies heavily on science fact and portrays the scientific process and thinking processes fairly well. For some good links to assist in the research see the Resources section of this PBL.

DAY 3 (50 MINUTES) – I WILL SURVIVE

"During the trip I'll need to breathe, eat, and drink." – Andy Weir, *The Martian*

What conditions do humans need to survive? You will prompt a discussion about the basic needs humans will need to survive. This should include water, temperature, air conditions, pressure conditions, energy, an atmosphere that protects against radiation, etc. Make the students think a bit deeper than beyond the obvious.

For the second half of the class, you should break the students into teams of six. Each team will need a project notebook so they can organize their work. The project notebook may be a three ring binder or a folder. As the project progresses, the students will store research, design drafts, daily logs, and other items related to the project within the notebook in an organized manner. Each group will be turning in the notebook at the end of the project, and a sample rubric for grading the notebook is given in the Evaluation section of this PBL. Have the students use the notes they took from the Day 1 discussion to identify all needs to be met. You should have the students identify the needs and potential problems. Have the students form possible ideas to satisfy the needs and combat the problems. For example: Problem: Need Electricity for System (such as a heater) Ideas for Solution: Nuclear generator, Solar Panels, Geothermal Power, Wind Power etc. Before the discussion, emphasize to the students that their base will have little contact with Earth and thus the base needs to be somewhat self-sufficient. They cannot rely on Earth for pressing needs. The groups should record their brainstorming ideas within the project notebook using the format shown in the Appendix section of this PBL (see Brainstorming page). A link for the most basic environmental needs of human survival is provided in the Resources section of this PBL.

DAY 4 (50 MIN) – ASSEMBLE

"We are not a Team. We're a Time Bomb." – Dr. Bruce Banner, *Avengers*

Teamwork is one of the most crucial elements to any project. If a team does not cooperate and collaborate successfully, the entire project can fail. Engineering projects of this magnitude often have multiple teams working towards the same goal. No one person is responsible for every tiny detail in the project. You will give the students a brief discussion over team dynamics and roles within the team such as leader, timekeeper, devil's advocate, recorder, researcher, presenter, liaison to other groups etc. The teams should also divide the workload within different functions of the base design. For example, one part of the team should focus on the electricity element while another part focuses on the water aspect. You should have students determine the different functions and responsibilities within group and have the students divide the workload. A sample rubric for Teamwork is given in the Evaluation section of this PBL. Be sure to introduce the students to the rubric so they know how they will be evaluated. Students should design moderate deadlines and expectations for one another for steps within project. Once this is completed, students may begin research on computer labs. At the end of the class, the students should prepare a summary of the day's events documenting decisions made, roles within the team, and progress made. Have the students use the Daily Meeting and Decision Log (located in the Appendix section of this PBL) and have every team member sign the form. The daily logs should be stored within the project notebook.

DAY 5 (50 MIN) – RESEARCH AND DEVELOPMENT

Research is what I'm doing when I don't know what I'm doing. – Wernher von Braun

Knowledge is power. Students will research their identified challenges and formulate a solution within their teams. You should give a brief discussion over what sources are acceptable and what are not. For example, research sources from newspapers with a long-time tradition of being accurate are acceptable, as are scientific journals. The resources found by Google Scholar are very helpful. The research sources and information must be able to be verified. Gossip columns or websites are not acceptable. Wikipedia is not an acceptable resource either because it can be edited by anyone. Students may use Internet sources, magazine articles, scientific journals, documentaries and other reputable sources. Their ideas for the base design must come from a modern or developing technology. For example, the students may not use "beam me up Scotty" technology because teleportation technology does not exist and there have been no successful attempts at the technology. If the technology is not well known, have the students find multiple sources of the technology to reinforce its validity. You should have the students collect and record their sources within the notebook. By the end of the project, the students will need to complete a bibliography of their sources. At the end of the day, you should have the students record another Daily Meeting and Decision Log (see Appendix) about what they did and decisions made. Stress to the students that outside of class research is crucial. If you feel that it is necessary, you may add another day dedicated to the research portion of this project.

DAY 6 (50 MIN) – COLLECT, COLLABORATE, AND CREATE

Team time! Have the teams discuss their research and begin forming a tentative design of their base. Team members should present their research on their subtopic and subsequent ideas to the rest of their team. Using these ideas and research, the students should begin to create a tentative design of their bases. At this point, the students should be answering their own questions on topics such as power, food, air, shelter, what supplies are we bringing, who and how many should we be bringing for operation, what does the layout look like, etc. Students can refer back to the brainstorming section (see Day 3) to make sure they formulated solutions to the problems they identified. You should have the students record their design decisions and initial blueprints for the base on another Daily Meeting and Decision Log. As the project progresses, the logs should become longer and more detailed.

DAY 7 (50 MIN) – ANYTHING THAT CAN GO WRONG WILL GO WRONG

> "I guess you could call it a 'failure,' but I prefer the term 'learning experience.'" – Andy Weir, *The Martian*

Mistakes are the key to success, especially in the design process. It took Thomas Edison 1,000 tries to create a working light bulb. Mistakes in the lab are crucial, but mistakes in the field are deadly. You should have the students critique their designs. Have the students ask themselves: What could go wrong? What if this happened? How would we prevent it? You should have the students point out flaws, oversights, and what could go wrong. Have the groups appoint members of their teams to interact and collaborate with other teams to critique their ideas and be critiqued themselves. You should emphasize to the students that this is all part of the design process. You should make sure the students give constructive criticism rather than unproductive criticism. Engineering firms consult with experts about their designs to prevent mistakes in the field. Today, have the groups simulate consultations between firms and experts. Have each team pick two to three members to send to the other teams as consultants. At each consultation, the remaining members will present their tentative design and reasoning to the consultants. It is the consultants' job to provide constructive criticism to the design. It is better to find the oversight in the design process rather than after the finished product. In pairs, consultants will rotate until they have met every team. Each consultation should take about 10 to 15 minutes. The teams should record the problems and complications with their designs during each consultation on the Consultation Form located in the Appendix of this PBL. If there is time at the end of class, have the teams reconvene with one another. Before students leave the classroom, have the students record the day's events, decisions, and insights on the Daily Meeting and Decisions Log (see Appendix) and attach the consultation notes at the end within their notebooks.

DAY 8 (50 MIN) – BACK TO THE DRAWING BOARD

> "No plan survives first contact with the enemy." – Andy Weir, *The Martian*

Today will be very similar to Day 7. Using the information collected from the consultations, the teams will improve their designs. They should research, when needed, to improve their designs and make final design decisions. You should have the students record their finalized decisions within their notebooks and have blueprints of their design. End the class with another Daily Meeting and Decisions Log form.

DAY 9 (50 MIN) – IT'S ALIVVEEEEE!

At this point, students should be finalizing their designs. In the engineering world, though, the design is only part of the work. Presentation to investors and explanation of the design is just as important. Have the students use different modes of communication to present their project designs. Allow them to use options such as PowerPoint®, 3-D models, engineering programs, etc. Stress to the students to be as creative as possible. Not only are the students trying to convey their designs, they should promote their designs as the best choice. In the scientific community, this is best done with information and logical reasoning. During their presentations, the students must clearly convey their designs, ideas, and reasoning to the rest of the class. At the presentation, each team must have a clear schematic or model, written summary of its design and reasoning for the components, (may be done in presentation such as PowerPoint® or written in a technological brief) and be able to orally present its ideas to the class. Stress to the students that having visual components to a presentation can allow outsiders and investors to be able to understand their projects and ideas with more clarity. Introduce the students to the Presentation Rubric located in the Evaluation section of this PBL.

Allow the students to once again divide the projects amongst themselves and work on the presentations. Some out of class work will be required to complete this portion of the project. Introduce the students to Google Docs or Dropbox where students can collaborate and interact without actually having to meet. Once again, have students document the day's events with a Daily Meeting and Decision Log form.

DAYS 10 AND 11 (50 MIN EACH) – SPACE…THE FINAL FRONTIER

These days will be presentation days. If possible, invite experts such as local engineers or scientists to observe the presentations. This will give more gravitas to the students' projects and presentations. It will also provide the opportunity for learning and constructive criticism. Randomly select teams to present the projects to the rest of the class. These presentations should have input from every student in the groups, visual representation, and a sound final design. Students can have entertaining and creative openings and explanations. Make sure their decisions are logical and based on scientific evidence. The students' presentations should be between 8 to 12 minutes long and followed by a Q&A session with the rest of the class. At the end of the presentation, have the team's members turn in their project notebooks. Within their notebooks, they should have their research sources, daily logs, brainstorming notes, consultation forms, design drafts, etc. Lastly, have the students fill out the team member evaluations for each member in the Evaluation section of this PBL.

EXTENSION

Wheel of misfortune – For students who finish early or who need an extra challenge

If students finish early, they may have not been critical enough of their design. Thus, they may face the wheel of misfortune. This may also be used on Day 6, if the students are not critical enough. The wheel of misfortune has many different scenarios that the students may face. For example: How would you handle:

- Air leak in base
- Broken tools
- Crazy Dust Storms
- Communication Systems
- Volcanic Eruption
- Someone getting sick
- Food Shortage/ how are you growing food
- Solar Wind
- Meteor
- Fire
- Etc.

Introduce "doomsday" scenarios to the students and spark ideas for designs they can have to meet these demands. Remember, anything that goes wrong can have dire consequences. NASA stopped all operations with the rover Curiosity when they thought they saw a loose screw in one of its pictures. (It was a plastic chip). In engineering and space, a loose screw can be the difference between a failure and a success.

Secondary Mission – For more Advanced Students or Students Who Pass the Wheel of Misfortune:

Add a secondary mission objective. The overall objective is to design a scientific base of operations on Mars, so place more of an emphasis on the "scientific" part. You can have them design a laboratory, a means of travel on Mars, and landing sites for Earth shuttles. You could also put more constraints on each topic: energy consumption, space travel, more in depth presentation, etc.

EVALUATION

Project Notebook Rubric

Category	**1**	**2**	**3**	**4**
Research	Research does not come from reputable sources, is inadequate, does not reflect scientific accuracy and does not relate to necessary content.	Research comes from a mix of reputable and unreliable sources. Research may address content matter but not directly relate.	Most research sources are reputable and relate to subject material. There is adequate research.	Research sources are valid, current, and directly relate to content material and specific topics. Research material is reinforced with a variety of different sources.
Design Process *(Most of this should be evident through the students' memos and required content or observed during the process)*	Students may use design methodology as a guideline but do not identify all problems nor address problems discovered later in the process. The time is not used effectively, and the students do not effectively collaborate.	Students attempt to follow design methodology, but do not fully explore each step. They identify and research some of the problems and develop a solution but do not address complications later in process. Time is not efficiently used and there is moderate collaboration.	Students seem to adequately model the design methodology by identifying and researching problems, addressing constraints, and developing a solution, but not with an effective use of time or an underbalanced responsibility.	Students clearly follow design methodology by finding problems, researching ideas, addressing constraints, and using fact based thinking to develop a solution. They use their time efficiently and effectively collaborate.
Required Content	Less than half of the required material is present, and it does not adequately meet the requirements of the content.	At least half of the required content is present.	At least 75% of the memos, consultations, blueprints, and research sources are present and adequate.	All memos, consultations, blueprints, research sources, and required content are present and completed beyond requirements.
Writing/Clarity	The writing is difficult to follow with little to no main ideas presented or developed. There are multiple grammar mistakes.	Ideas are presented, but not well developed or particularly clear. There are many grammar mistakes.	Ideas are clearly presented with most of the main ideas developed to understanding. There are few grammar mistakes.	Ideas are clearly organized, developed, and conveyed in a clear and concise fashion. There are few or no grammar mistakes.

Presentation Rubric (Page 1)

Category	1	2	3	4
Visual	There are little to no visuals in the presentation.	Visuals are presented, but they are difficult to understand and distract from the main idea.	Visuals are presented and are used to develop further understanding.	Visuals are clearly presented and use highly developed visual representations to convey the main idea in an effective and appealing fashion.
Communication	The students do not clearly express the main ideas for the design and are unsure of what to say.	The students are nervous and stumble over words, but most of the main points are covered.	The students rarely stumble over words or use filler words. The main points of the design are presented and explained.	The students are articulate and show confidence throughout the presentation. The main ideas and reasoning for the design are expressed and clearly explained.
Contribution	Less than half of the team contributes to the presentation of the design.	About half of the team contributes to the presentation.	Most of the project members contribute to the presentation.	All project members contribute to the presentation of the design and ideas.
Understanding	The students fail to show an understanding about their design and its components. They are unable to field questions from other students.	The students show a basic understanding of their design and reasoning but fail to be able to respond logically to questions about the design.	The students understand their design and reasoning for their design. They adequately answer questions from other students.	The students demonstrate a clear understanding of their design and the reasoning for their design. They answer questions clearly and with logical reasoning
Use of Technology/ Attractiveness	The students fail to incorporate technology into their presentation.	The students incorporate technology into their presentation, but the presentation looks sloppy and ill prepared.	The students incorporate technology into their presentation. Presentation is neat and presents most of the main ideas for the product.	The students incorporate technology to clearly and effectively present their product to the class. The presentation is attractive, neat, creative, and clearly presents the main ideas for the product.
Fluency/Time	The flow of the presentation is non-existent. The presentation is disorganized and unprepared. The time is under the limit or over the limit.	The flow of the presentation is disjointed, but all of the main ideas are presented and understood. The time is under the limit or over the limit.	The students adequately present their ideas and reasoning in a structured and logical flow. The time is within limits.	The time is 8 to 12 minutes long.

Design Rubric

Category	1	2	3	4
Scientific Accuracy	The design fails to meet current scientific constrictions. It is not scientifically accurate and is not supported with valid evidence.	Most of the design components come from existing or emerging technology but may not come from the valid sources.	All design components come from existing or emerging technology with a valid source to adequately meet the challenges introduced.	All design components come from an existent or emerging technology with multiple valid sources to address the challenges provided in a hostile environment. All components are plausible and are quasi-self sufficient.
Comprehensive	The problems and challenges identified were addressed poorly and have no clear solution with appropriate validation.	Most of the identified problems have clear solutions, but some of them have not been explored in depth or explained clearly.	All problems and challenges identified have been adequately solved with a clear solution.	All problems and challenges identified are met with a logical, effective, and clear solution and extra, fun elements have been included.
Creativity	The students are not creative with their design and do not make the their design appealing.	The students demonstrate some creativity with their overall design.	The students are creative with the different technologies and components of their design.	The students are extraordinarily creative with the components, reasoning, and overall layout of their design.
Content Knowledge	The students do not demonstrate a basic understanding of the living conditions on Mars nor the design elements they are going to use.	The students demonstrate of basic understanding of the challenges to living on Mars and a very basic understanding of their technology	The students adequately demonstrate an understanding of their challenges and the technologies they are using to solve them	The students demonstrate a clear understanding of the challenges that comes with living on Mars and the innovative technologies they are using to combat those problems
Design Evaluation	There is little to no evidence that students neither evaluated their design nor addressed complications the evaluation revealed.	The students evaluated their design but poorly addressed the problems they identified.	The students adequately evaluated their design and attempted to refine their design based on the identified problems.	There is clear evidence of evaluation of the design and refinements based on discovered problems.
Design Knowledge	The students do not demonstrate a basic understanding of their design or the reasoning for its components. Little design process shown.	The students show a basic understanding of the design but not a solid understanding of the reasoning.	The students adequately exhibit an understanding of their design and the reasoning for its components. They adequately exhibit the design process.	The students exhibit a clear and thorough understanding of their design and the reasoning for its components. They understand the problem and the process they used to reach their final product.

Teamwork Rubric

Category	1	2	3	4
Contribution	A few of the students did the entirety of the work.	The project was evenly divided for the most part, but a few of the students contributed far more than the others.	The students had a well-balanced division of the workload for the project.	Each of the students contributed equally to the research and design of their project. Each student completed their divided task and within their decided role.
Collaboration	The students failed to effectively collaborate within their team.	The students communicated within their team with minor misunderstandings.	The students effectively collaborated within their team.	The students collaborated within their team and with other teams effectively and successfully.
Reliability	The students did not meet the deadline decided by the team.	The students completed most of their assigned topic on the decided deadline.	The students completed their team decided topic on the decided deadline.	The students completed their assigned topic in the project before the team decided deadline.
Quality of Work	The students' work was of poor quality and work was very incomplete.	The students did most of the work on their required topic, but there were times when topics were not adequately completed. Quality of work was fair.	The students adequately completed their part of the project. Students provided quality work.	The students completed their part of the project beyond expectations. Students provided work of the highest quality.
Attitude	The students did not effectively participate within the team nor have a positive attitude.	The students effectively participate with the team but failed to have a positive attitude on occasion.	The students demonstrated a positive attitude and a friendly attitude throughout the project.	The students demonstrated a positive attitude throughout the project and a willingness to adapt to help meet the needs of other members.

Team Evaluation: Evaluator

The teacher will complete this Rubric. Also present a copy of this rubric to the students and have them grade their team members:

Member	Category	1	2	3	4	Comments
Member 1	Contribution					
	Collaboration					
	Reliability					
	Quality					
	Attitude					
Member 2	Contribution					
	Collaboration					
	Reliability					
	Quality					
	Attitude					
Member 3	Contribution					
	Collaboration					
	Reliability					
	Quality					
	Attitude					
Member 4	Contribution					
	Collaboration					
	Reliability					
	Quality					
	Attitude					

APPENDIX

Example format for brainstorming page in research notebook

Names of Group Members:

Date:

Problem	Ideas for Solutions
Example 1) Need electricity for System (such as a heater).	*Example:* 1) Nuclear generator 2) Solar Panels 3) Geothermal Power 4) Wind Power
Problem 2	*Solutions for problem 2*
Problem 3	*Solutions for problem 3*
Problem 4	*Solutions for problem 4*

Example of Consultation Form

Consultation Form

Consultants: *List names of students with which you consulted.*

- Potential Problem 1:
  - Possible solution 1
  - Possible solution 2
  - …
- Potential Problem 2:
  - …

Was this consultation useful? ___Yes ___No

Notes: Any additional thoughts on the matter.

Example of Daily Meeting and Decision Log

Daily Meeting and Decision Log

Date: *Give date of meeting*
To: *Recipient of log (teacher or project manager Name)*
From: *Names and signatures of team members*

Name of person filling out log: ***Give name of person who is recording meeting information on this form,***

Subject: *Summarize general topics discussed.*
Use this area to record the day's events. Have the students log the decisions made, from the design of the base to the division of the workload. Have them record reasoning for these decisions and what each team member is doing. As the days continue, have them record progressing schematics, research, the consultations, etc. For example: Today, we agreed on using [blank] as a power source for reasons X, Y, and Z. Any visual designs should be attached at the end of the memo. The students will need to use proper grammar and punctuation.

Attachments:
- *(Possible Sketch of first design)*
- *(Consultation notes)*

WATER

KATIE NESLONEY AND MATTHEW J. ETCHELLS

10. AQUAPONICS

SCHEDULE AT A GLANCE

Days 1 and 2	Days 3–5	Days 6–9	Days 9–10+ (two weeks to two months)
Engagement and research	Research and design	Making, presenting, and feedback	Set up and sustain the aquaponics system

WELL-DEFINED OUTCOME

Students will work together to design and create from recyclable materials a functioning aquaponics system in the classroom.

TEACHER INTRODUCTION

This project is designed for students on or above grade level in biology or environmental science. Students will use their understanding of the life cycle of plants and fish to develop a functioning aquaponics system. The plants, fish, water, nitrogen, oxygen are all variables that need to be in proper ratio in order to function properly. The students will find and bring in recyclable materials from their homes and design their containers for the system. The students will then decide what type of plants they want to grow and what type of fish will work the best. The students must understand the relationships necessary to create a balanced system. The students must measure the oxygen and nitrogen levels in their system and decide the levels necessary for their chosen fish and plants. The students can also decide if other things are necessary for their system (snails, bugs).

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- Use understanding of the life cycles of plants and fish to balance an aquaponics system.
- Measure output of the nitrogen and oxygen cycles to keep systems functioning.
- Research aquaponics systems and the possible effects more sustainable farming could have on the environment.
- Develop an understanding of the delicate balance necessary to sustain life.

Mathematics – The student is expected to:

- Calculate necessary nitrogen and oxygen levels needed for plants and fish.

Engineering – The student is expected to:

- Design a container for an aquaponics system from recyclable materials.
- Decide an appropriate location for the aquaponics system (at home, large scale, rural village).

Language Arts – The student is expected to:

- Work as a team to develop the project.
- Communicate reasoning and design concepts to the class during the project.
- Produce a final presentation of the project, including the reasoning for its design.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 75–79.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

– Students will use prior knowledge of the life cycle of plants and fish, and nitrogen and oxygen cycles

Engineering

– Students will design and construct an aquaponics system

Math

– Students will use formulas to calculate necessary nitrogen and oxygen levels

STUDENT INTRODUCTION

Two of the greatest problems in the world today are hunger and pollution; aquaponics can work in reducing both. Aquaponics is an agricultural tool that combines aquaculture and hydroponics (growing plants in water). The development of an aquaponics system combines knowledge of science, math and engineering. The system can be used to teach the life cycle and structure of plants, sustainable farming, effective use of recyclable materials, and the nitrogen cycle. Students will work together to think of creative ways to design their systems; there are so many materials aquaponics systems can be made of. After designing and building their systems the students will decide what types of plants and fish will be best to meet their objectives. After developing the system, students will track their plant growth and maintain their aquaponics systems. After completing the design and construction, students will conceptualize other sustainable farming techniques that could be made from recyclable materials.

MATERIALS USED

Research:

– Computer with internet

Building the container:

– Recyclable materials from around the house (suggestions)
– Bottles
– Cans
– Plastics straws/tubing
– Tape
– Glue
– Water
– Plants
– Fish
– Water pump (optional)

Measurements:

– Ammonia testing kit or papers
– Oxygen sensor, titration set up, colorimetric set up

DAYS 1 & 2 (100 MINUTES)

Depending on what aspect of the project the teacher wishes to focus on there are many introductory videos the teacher can present to the class. These videos provide an introduction to the topic and methods of aquaponics, as well as the importance of aquaponics systems. The most important thing to discuss is the large impact aquaponics and sustainable farming as a whole can have on the world. *Feed*

the World – Aquaponics is a great example of the ways aquaponics can affect an entire community. *Urban Farming in the City* is an example of how a small sustainable farming set up can be useful in different environments. Students should participate in a discussion on sustainable farming and the problems of hunger and pollution in the world today.

Why Organic, Sustainable Farming Matters: https://www.youtube.com/watch?v=mD5jnxhne7o (06:25)

Feed the World-Aquaponics: https://www.youtube.com/watch?v=ofS9MFXFIBE (02:21)

Small Scale Aquaponics: https://www.youtube.com/watch?v=4DMylpQqVKI (05:43)

Urban Farming in the City: https://www.youtube.com/watch?v=QJcACw_--Nk (03:26)

After showing these videos to the class on the first day the students will then have the remainder of the class and the following class period to conduct research for their project.

DAYS 3–5 (150 MINUTES)

This project can take from two weeks to an entire semester. If the teacher wants to focus more on the design and construction phase than the sustaining the system phase, the project will be shorter.

In the design phase, students will have time to do more research on aquaponics and sustainable farming. The students will need to research design and construction methods and waterproofing. They will also need to understand nitrogen levels and which plants and fish can live together in a system. The students will also look into the environmental impacts of sustainable farming and the importance of aquaponics. The students will decide what type of environment they are designing for their systems. For example, they will decide if it is a small single-family system, or a large-scale system to feed many people (these types will have to be scaled down depending on classroom space available.)

DAYS 6–9 (200 MINUTES)

In the making phase, students will bring in recyclable items from home in order to construct their own systems. The students will present their ideas to the class and give each other constructive feedback on their ideas. The teacher should also offer feedback on the designs. After feedback is given the students will construct their containers and decide on their fish and plants for their systems. The teacher should pay close attention to the students' choices and make sure they are feasible and within the budget for the district. The project can be modified as far as plants and fish based on available budgets.

The projects can be simple and small like a soda bottle, or much larger and more advanced like commercial aquaponics systems. Students should carefully consider all aspects of their project to ensure their systems are as healthy as possible.

DAYS 9–10+ (100+ MINUTES) 2 WEEKS TO 2 MONTHS

This phase of the project is sustaining the system. During this stage the students will add their fish and plants to the set up and begin the process of growing plants in their aquaponics systems. The students will need to take daily measurements of the oxygen and nitrogen levels in their systems; they will maintain the levels in the system. The students can also measure the growth of their plants and fish in the systems. Depending on the plants chosen and how the plants started, as seeds or as sprouted plants, this stage will vary in length. This part of the project is not entirely class consuming. The students will need about 10 minutes a day to check on their systems and could do it before or after school if needed.

EXTENSION

Extensions to the assignment can be in the design of more sustainable farming techniques. Most students will complete an assignment on where their design for aquaponics would be most beneficial. They could focus on providing food for a small single family home, a restaurant, or an entire rural village. The students will create a report on why they designed their systems as they did and how they're suited to the environments they choose. As an extension to the assignment, students could create their own sustainable farming techniques or systems. They could develop ideas for other biotic systems that could be used in

farming, or any engineered system to make farming self-sustaining. All ideas should reflect the benefits for the environment and the people intended as recipients for the food.

EVALUATION

Aquaponics evaluation rubric				
	Criteria	**3-Exeeds expectations**	**2-Meets expectations**	**1-Fails to meet expectations**
Final Product	Presentation	Students present the reasoning for their system effectively. They put time into their presentation and it looks clean and is presented clearly. The logic behind their design is evident.	Students present their reasoning but it is not as well explained. The presentation is complete but not as clearly presented.	The presentation is not well reasoned. The logic for their system is lacking. The students' presentation skills are lacking, and the presentation is hard to understand.
	Final System	Students took care to build their system properly, and it functions as it should.	Students' system is constructed with some care, but there are some problems with the product.	Students' system are poorly constructed
Functionality final product	Nitrogen and oxygen levels	The measured levels of nitrogen and oxygen are correct for the system and sustain both the fish and the plants with no added nutrients. The calculations for the levels were correct.	The measured levels sustain most of the plants and fish. The calculations were mostly correct with some corrections needed.	The measured levels do not sustain the fish and plants. The calculations done were incorrect.
	Materials used	All materials are recyclable.	Most of the materials used are recyclable.	None or only a few of the materials are recyclable.
Design of the system	Original design	The design is well thought out and has all of the components necessary for an aquaponics system.	The design is somewhat original and has most of the necessary components for an aquaponics system.	Design is not complete. Does not use recyclable materials. Does not meet all of the needs of an aquaponics system.
	Plant life and fish	The chosen plants and fish can live together and the students have a good explanation for their decisions.	Chosen plants and fish can live together but are not as compatible.	The chosen fish and plants cannot function together. The students have not done enough research to understand what their system needs.
	Critique/criticism/ problem solving	During the critique session the students give constructive criticism to other projects and problem solve the feedback they receive	Students give some feedback to classmates. Use some of the feedback they receive but not to the best ability	Students provide to constructive criticism for other groups and do not alter their projects at all following their feedback.
Coordination of resources	Teamwork (Students evaluate their peers)	The students work together on the project; each student contributes to the project equally and communicates effectively with the team	The students mostly worked well together; the work was not as evenly distributed between the students. Communication with team members was lacking.	The students do not work together well. Some students did more work than others.
	Research	Worked hard and efficiently to prepare for the design, construction and presentation of the system	Worked well most of the research time provided.	Did not contribute to the research of the project.

Peer Evaluation Rubric		
Evaluate participation from 1 to 10, with 10 being high participation and 1 being no participation		Comments:
Communication: Student discusses and talks about all aspects of the project	1 2 3 4 5 6 7 8 9 10	
Research: Student uses research time efficiently, uses valid sources	1 2 3 4 5 6 7 8 9 10	
Design: Student contributes to the design, uses class criticism for improvement	1 2 3 4 5 6 7 8 9 10	
Construction: Student contributes to the construction	1 2 3 4 5 6 7 8 9 10	
Presentation: Student helps prepare for the presentation, student presents clearly and effectively	1 2 3 4 5 6 7 8 9 10	

The students will rate their peers on a scale of 1 to 3 in each of the categories. The scores will be averaged for the students' teamwork scores on the final rubric; students can also give comments on their peers' work during the project.

REFERENCES

Aquaponics. *National Agriculture Library*. N.p., n.d. Web. 16 May 2015.
Feed the World-Aquaponics: https://www.youtube.com/watch?v=ofS9MFXFIBE
Small Scale Aquaponics: https://www.youtube.com/watch?v=4DMylpQqVKI
The Aquaponic Source | Systems, Supplies and Education. *The Aquaponic Source*. N.p., n.d. Web. 16 May 2015.
Urban Farming in the city: https://www.youtube.com/watch?v=QJcACw_--Nk
Why Organic, Sustainable Farming Matters: https://www.youtube.com/watch?v=mD5jnxhne7o

VICTORIA LANCE AND MATTHEW J. ETCHELLS

11. DAM

Will It Hold?

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Engagement and research	Exploration and research	Work on presentations and begin dam construction	Finish presentations and dam construction	Presentations and dam testing	Presentations and dam testing

WELL-DEFINED OUTCOME

Students will be designing and building their own dams that will stand up to the pressure of three gallons of water. Students will also demonstrate their knowledge of the effects of dams and dam construction.

TEACHER INTRODUCTION

This PBL is designed for students in the environmental science section of their biology course. Dams impact the environment, so in addition to finding materials that will hold water back, they will also research positive and negative impacts of dams on the environment. This assignment allows students to tap into their engineering creativity and ingenuity to design their own dams. Prior knowledge required for this project includes the ability to complete algebraic equations, familiarity with materials that can hold water, familiarity with research techniques, and the ability to use computer presentation programs.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Mathematics – The student is expected to:

- Apply mathematics to problems arising in building and designing a dam.
- Display and explain the logic behind an argument.
- Communicate mathematical equations and ideas.

Science – The student is expected to:

- Identify materials that will hold water.
- Learn the dynamics of water.
- Demonstrate principles of fluid dynamics, including hydrostatic pressure and density.

English – The student is expected to:

- Use appropriate strategies for rehearsing and presenting speeches and interpersonal communication in professional contexts.
- Use new vocabulary.
- Differentiate between good and bad resources and information.

Technology – The student is expected to:

- Use the Internet to gather reliable information
- Demonstrate the ability of computers in presenting ideas

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 81–87.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Apply the scientific method
- Understand hydrostatic pressure
- Water conservation
- Fluid mechanics

Technology

- Proper use of the Internet
- Use of presentation technology
- Understand ancient and modern dam technology
- Technology used to minimize environmental impact

Engineering

- Dam construction

Mathematics

- Find unknown scientific values
- Building a budget

STUDENT INTRODUCTION

There are many famous dams throughout the world: the Hoover Dam in Nevada, the Three Gorges Dam in China, and the Aswan Dam in Egypt. Dams have also been constructed since ancient times, some dating back to circa 3000 B.C.! During this project you will design and build a dam that can stand up to the pressure of three gallons of water. You may choose what materials you think would best contain the water, whether you use mud and rocks, as were used in ancient times, or bricks and cement, as are used in modern dams. You will also research and learn the purpose of building a dam, including, but not limited to, positive and negative effects to nature and society, practical uses, and cost. With your research information and the details on how you built your dam and what materials you used, you will put together a short slideshow to present with your finished dam, and we will test the projects together as a class. After testing all of the dams, the class will look at the effectiveness of the materials used in each dam.

MATERIALS USED

- Large 10-gallon storage bin
- Sealant (to fit dam to storage bin)

Materials to build each dam will vary, but some examples include:

- Rocks
- Brick
- Mud
- Clay
- Cement

For research and experimental design

- Ruler
- Calculator

– Computer with Internet access and presentation software (such as PowerPoint® or Prezi)
– Copies of the presentation worksheet, multiple choice question sheet, and grading rubrics for the presentation

DAY 1 (50 MINUTES)

To support student engagement in this project, show them pictures of places before and after dams have been erected and discuss some positive and negative impacts of specific dams. For example, the Three Gorges Dam is less than ten years old and is already losing its functionality due to the massive amount of natural sediment in the area. The cost of moving millions of people from the areas that would be flooded by the dam and the impact on the environment of leaving an entire city abandoned and submerged in water is huge. Another dam to discuss would be the Hoover Dam and how this dam has changed the landscapes of Nevada and Arizona. Students should also consider the effects of non-manmade dams like those made by beavers. To focus the discussion, consider the following questions;

– Why are dams built?
– What species were affected by the erection of the Hoover Dam?
– What positive economic aspects have arisen as a result of the dam?
– What positive and negative impacts can these structures have on the environment?
– We know we are looking for alternative energy sources, such as hydroelectric power, but what are the costs of these types of energy sources?
– Can you think of any positive effects of dams and hydroelectric power?
– There are tens of thousands of dams worldwide that create hydroelectric power, but these dams also change the course of the on which rivers they sit. What impact does this have on the surrounding area?

At this point group the students into groups of four or five and distribute their storage bin, which includes their dam introduction letter.

Dam Builder Project Letter

Dear Dam Builder,

Our company, Lance's Dam Builders (LDB. Inc.), is experiencing a huge increase in business; however we are also experiencing an increase in production and material costs. LDB. Inc. is seeking talented groups working on STEM projects to work as subcontractors to complete some of our existing projects. We request you send a model of your proposed dam, considering lower dam costs and the impact dams in general have on the environment. Elements to consider while building your dam are materials of your choosing (they may be from home or store bought), but must also be teacher approved. At the end of this project you will present your research, and we will test all of the dams together as a class. Your presentation must include:

– Reasons for dam design
– Reasons for dam materials
– Positive and negative effects on society and the environment
– Practical reasons behind building dams
– The cost of building your dam

Once all of the dams have been tested, we will look as a class at the effectiveness of different materials and methods used and their specific impacts.

LDB. Inc. looks forward to reviewing your final presentation and dam model.

Regards,

Herbert. C. Hoover. Jr

Display pictures of dams (see references – Pictures of Three Gorges Dam, Hoover Dam, and beaver dam) to the class and ask why they think each dam was built, what it is made out of, and what effect it has had on the surrounding area. Compile the group answers to these questions and post the questions and answers in a designated area of the classroom. This activity could be done on large sheets of paper with marker pens. Direct the students to the school library website where they can complete their own research in groups. Direct the students to turn to the grading rubric for the presentation and go over the minimum requirements for their presentation. Allow students to break into their groups and begin research for their presentations. Each presentation should include a minimum of:

Three positive effects of dams on society and the environment

– Three negative effects of dams on society and the environment
– Two practical reasons behind building dams
– The average cost of building a dam
– Why the group built their dam the way they did
– What materials the group used
– Why the group chose those materials

DAY 2 (50 MINUTES)

Begin with discussing the different materials used to build dams, starting with older dams and moving closer to modern materials. Ask students which materials they think would be best suited to contain water and why. This is also a good time to show the *Hoover Dam Clip* from the movie Vegas Vacation so students can see the sheer mass of certain dams https://www.youtube.com/watch?v=SnmX4f6VBRw (02:16). Be sure to remind students this project is not meant to be more than a five-minute presentation, so their information should be clear but concise. Following this, show *What impact will Isimba dam have on the environment?* https://www.youtube.com/watch?v=DtQZwoJ3K1o (06:39) to allow students to grasp the real-world impact of dams. Have students break into their groups once again and complete their research and create their short presentations. Towards the end of the period inform students that during Day 3 they should be finishing their presentations and starting to construct their dams. Students should begin to discuss what materials they want to bring to class to construct their dams. Students should also understand they need to seal their dam to the bottom of the container; otherwise the dam will shift under the pressure of the water. The type of material used to build the dam will affect the type of sealant used.

DAY 3 (50 MINUTES)

Start the day by reminding students that their dams should hold three gallons (11.3 litres) of water. Students should have brought their dam supplies to class, but be sure to have some materials they can use as well in case they do not have all the materials they need. In this period students can finish their presentations by adding what materials they chose and why and begin the actual construction of their dams.

DAY 4 (50 MINUTES)

Today is the final work day for students to build their dams and divide up who is going to be in charge of each part of the presentation. Students also should use this time to test their dams to resolve any major issues and leaks.

DAY 5 (50 MINUTES)

Each group should present their respective projects as the other students take notes on the presentations on their presentation rubrics. Each dam will be tested following all presentations. The teacher will be in charge of pouring the water into each bin one gallon (3.7 litres) at a time. Students will measure the effects of the water on hydrostatic pressure; students will record measurements and predict what will happen on their presentation rubric. After all the dams have been tested, the class will discuss why some materials were more effective than others and the dam could be improved in the future.

DAY 6 (50 MINUTES)

Continue presentations and testing dams. Have students engaging in the extension activity complete the water pressure calculation section. As a class, go over how to fill in each value for the water pressure equation and use the first group as an example the class can work on together. Once the class has a grasp on how to work through the equation, have students break into their groups and work out the equation for each group's dam.

EXTENSION

Ideas for advanced students

Most students should only be holding back three gallons of water; for advanced students, have the students hold back four to five gallons.

Water pressure calculation

Advanced students can calculate the water pressure acting upon their dams using the equation below;

$$P = \frac{1}{2}\gamma_w h^2$$

where γ_w is the specific weight of water and h is the height of water. Water pressure acts perpendicularly to the dam's surface and is calculated per unit width.

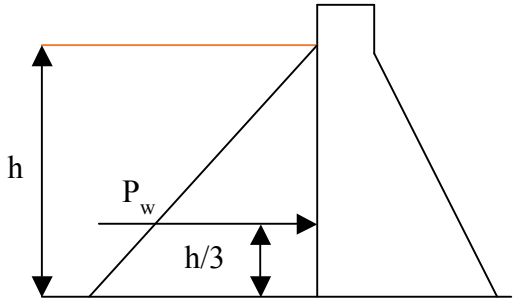


Figure 1. Water pressure to dam surface calculation

Ideas for students who finish early

Students can research what process dam builders must follow in order to build their dams.

- Do they have to bring in environmental experts?
- What type of engineer builds a dam?
- How do you choose what materials and design to use?

Students can also research how manmade dams compare to naturally formed dams.

- What structural similarities are there?
- What functional similarities are there?
- Where do animals commonly build dams, and where do humans commonly build dams?

EVALUATION

Rubric for Creativity Award

Please circle the appropriate indicator for Creativity Award. Awarded to the team whose dam reflects the most original idea for spanning two distances.				
Design Structures	Indicator (1 points)	Indicator (2 points)	Indicator (3 points)	Indicator (4 points)
Originality in Design	Dam with no real design.	Dam has a good design but unoriginal. Looks like typical existing dams.	Dam has unique design elements modifying standard elements and has good aesthetic properties.	Dam has a unique design/approach for spanning the gap and is highly aesthetically pleasing.

Rubric for Engineer Award

Circle the appropriate indicator for Engineers Award – Awarded to the most professional-looking dam				
Design Structures	Indicator (1 points)	Indicator (2 points)	Indicator (3 points)	Indicator (4 points)
Design	Dam with no real design.	Dam with limited design. Shows flawed understanding of dam design principles.	Overall a cohesive dam design based on standard dam types. Shows a reasonable understanding of dam design principles.	A cohesive design based on standard dam types and is appealing. Shows a good understanding of dam design principle
Construction Quality	Work is sloppy throughout. Shows overall very shoddy construction.	Shows somewhat reasonable care in building.	Tidy work most of the time. Shows reasonable care in building.	All construction is clean and attractive. Dam is artfully constructed.
Material Optimization	Did not maximize use of materials.	Limited use of materials.	Good use of materials.	Excellent use of materials.

Presentation Rubric

Place a check mark in the appropriate indicator box.				
Meet Presentation Criteria	Not meet (1)	Somewhat meets (2)	Mostly meets (3)	Perfectly meets (4)
Includes dam research.				
Presentation information is clear and concise.				
Three positive effects of dams on society and the environment.				
Three negative effects of dams on society and the environment.				
Two practical reasons behind building dams				
Logic behind dam construction.				
Materials the group used.				
Prediction of what will happen when the water is poured in.				
Total Score	_____ out of 32 points			

REFERENCES

Lives, interrupted – China and the Three Gorges Dam: http://newamericamedia.org/2011/05/lives-interrupted---china-and-the-three-gorges-dam.php
Hoover Dam: http://www.history.com/topics/hoover-dam
7 Architectural Wonders of the Natural World: http://webecoist.momtastic.com/2009/01/04/7-architectural-wonders-of-the-natural-world/
Hoover dam Clip: https://www.youtube.com/watch?v=SnmX4f6VBRw
What impact will Isimba dam have on the environment: https://www.youtube.com/watch?v=DtQZwoJ3K1o
Creating a Dam: https://www.youtube.com/watch?v=7rXd2kZNFnE
My dam project: https://www.youtube.com/watch?v=hFP0IJH4qwM
First Science Earthen Dam Project: https://www.youtube.com/watch?v=8zLry4b3ZhU

BETHANY K. BELL AND MEGAN E. KRAIL

12. HARMFUL ALGAL BLOOMS

Seeking a Solution for Our Safety

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Days 5–10
Engagement and research	Exploration and research	Begin the lab exercise	Finish lab exercise, work on data collection	Spend 10 minutes a day recording lab data

Day 11	Day 12	Day 13	Days 14 and 15
Begin working on presentations	Field trip to local water source (optional)	Final work day in class for presentations	(one week after day 13) Student Presentations

WELL-DEFINED OUTCOME

Students will devise and present a plan to halt and prevent the growth of algal blooms by creating a product or model of a possible solution by using available school and at-home resources in three weeks time.

TEACHER INTRODUCTION

This project-based learning assignment is designed for high school students and takes a prevalent problem found in nature and educates students on the causes and effects of harmful algal blooms. It encourages students to exercise ingenuity in order to develop a possible solution to this problem. Students will use their knowledge of freshwater and marine environments, the impact of humans on various Earth systems, the connectedness of life on Earth, and the importance of water as a natural resource to conduct an experiment of measuring algal bloom growth. Students will work to record their findings in a laboratory journal, analyze the data, develop a solution, and present their findings and solutions in a class presentation. The prior knowledge required to complete this project includes a general knowledge of clean water uses and demands, the impact of phytoplankton and zooplankton on the marine life food web, use of a microscope, general lab safety procedures, and how to effectively use school and internet research resources. This project allows students to demonstrate their ability to effectively work in teams while displaying their critical thinking and problem solving aptitude.

This project provides many opportunities for students to understand various types of algal blooms and their effect on water sources by researching different causes, effects, and solutions for algal blooms. Students are then able to form their own solution to the problem and perform laboratory tests to have a hands-on approach in dealing with algal blooms. With a variety of guiding and open-ended questions, students are given many opportunities to develop strong metacognitive skills. Additionally, because this is a small group project/presentation, students will foster teamwork and communication skills throughout the project.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 89–101.

Science – The student is expected to:

- Analyze the relationships of various aquatic systems.
- Observe changes within aquatic environments.
- Demonstrate safe practices during laboratory experimentations by properly using laboratory equipment.
- Use the scientific process by implementing an experiment with measurable outcomes.
- Investigate how human activities impact unbalanced systems such as algal blooms in aquatic environments.
- Evaluate scientific information through scholarly research.

English – The student is expected to:

- Collaborate with teammates through communication.
- Organize written data and findings in a manner that can easily be read and interpreted by others.
- Deliver a finalized solution and/or findings of the experiment to the class through an oral presentation.
- Explain the details of the solution created with visual supports.
- Demonstrate proficiency in professional communication skills during an oral presentation.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Understand the dangers of invasive species in nature.
- Consider the importance of clean and safe water.
- Create models and experiments that display the effects of algal blooms.
- Analyze the ways humans impact the environment.

Technology

- Use technological resources to gather information and research-based support.
- Consider how technology is currently being used to help navigate these problems.

Engineering

- Work to design a solution to the problem by using rational thinking and various design processes.
- Create a working product or model to present to the class.
- Consider the importance of financial, time, and conceptual constraints.
- Use innovative techniques to consider various solutions to a problem.

Mathematics

- Calculate class average values for various measurements.
- Work to create a graph which clearly represents the numerical data.
- Measure the rate of growth in the form of a graph.
- Make connections between numerical data for a thoughtful comparison.

STUDENT INTRODUCTION

Water is a resource all life on Earth needs to survive. Without clean water, the quality of life can rapidly decline as health, economic, and social problems emerge. For this project-based learning assignment, you will be faced with the problem of algal blooms taking over the water resources in your community. If you do not take appropriate action, we may find ourselves faced with the dreaded fear so often quoted from *Rime of the Ancient Mariner*, "Water, water, everywhere, but not a drop to drink."

In this project, you will be challenged with devising a way to halt and prevent future growth of algal blooms. You will begin by dividing into teams of four and selecting a specific type of algal bloom to research. You may choose to research either saltwater or freshwater blooms. You will then consider how these blooms grow as a result of human activities. After you research the various causes and effects of these dangerous blooms, you will grow your own algal blooms with water collected from a nearby water

source in our community. You will be expected to record the growth of your algal blooms in a laboratory journal, analyze the data you gather, and ultimately devise a way to halt or reverse the harmful effects of this invasive growth. Your final product or model will be presented to the class through an oral presentation with visual supports. With your help, the use of various water resources can be made safe again in your community. Prepare to begin thinking critically, creatively, and scientifically. It is time to sink or swim!

MATERIALS USED

Instructional Materials

- Clear jars
- Various algal cultures (see References section for more information on obtaining the cultures.)
- Educational photographs and/or video of algal blooms
- Student information packet (see Appendix)
- Student lab journals (see Appendix)

For Initial Research

- Student computers
- School library research resources including scholarly articles, newspapers, encyclopaedias, documentaries, etc.
- Journals
- Pencils

For Experimental Design

- Various algal cultures collected from a local source (if available) or ordered online
- Fresh and/or saltwater collected from a nearby water source
- 250–500 mL clear glass tanks or plastic containers
- Available light source
- Droppers or pipettes
- Liquid plant fertilizer or catalyst equivalent
- Wax pencils
- Tape
- Microscopes
- Charts and graphs to measure progress
- Rulers
- Litmus paper
- pH probes (if available)
- Dissolved oxygen probes
- Nitrate probes

For Project and Model Prototypes

- Various at-home and school resources that may be used in the students' creative design process such as glue, duct tape, polyvinyl chloride pipe (PVC), coffee filters, popsicle sticks, clear jars, markers, test tubes, flasks, measuring scales, thermometers, aquarium pump, etc.

For Student Presentations

- Projector and projector screen or an interactive whiteboard
- Lectern
- Poster boards

Assessment

- Model/prototype rubric
- Oral presentation rubric

DAY 1 (50 MINUTES)

Begin the unit activity by showing students a short picture slideshow or educational video of how algal blooms affect water sources. Here are a few examples of short videos:

- http://oceantoday.noaa.gov/predictinghabs/
- https://www.youtube.com/watch?v=YO3Gg3YfJ84
- http://earthjustice.org/slideshow/toxic-algae-outbreaks-in-florida

Present students with the scenario that the nearby water resources in their community have been invaded with algal blooms. Give students a visualization of this problem by displaying clear jars of water with examples of various algal blooms. Inform students they are now a select group of local scientists and inventors who have been commissioned by the city to solve this water crisis problem. At this time, teachers will distribute the Algal Blooms Student Information Packet (see Appendix) for students to review. This packet describes the specific problem, identifies local water sources for students to consider, and lists the deadlines of the project for the teams. Also within the packet is a brief overview of algal blooms and the various speculated causes of the blooms. This information will help to give students a starting point for their own additional research. Once students are acquainted with the Student Information Packet, allow students to divide into groups of four and begin devising their solution to the problem. Be sure each group identifies their main reasons for wanting to help clean the local water resources. Do the students feel passionate about fishing, water recreation, commercial uses of the water, etc.? Allow students to share their motivation behind finding a solution through a class discussion.

DAY 2 (50 MINUTES)

Allow the students time to research their topic in class with their groups by providing online access through school or student owned computers. Ask the librarian to pull any school resources beforehand so students can have easy access to these materials. Encourage students to research using a variety of sources including but not limited to: online databases, books, encyclopaedias, scholarly journals, and any relevant primary sources. As students work with the various resources, have students take notes of the research process in their lab journals. A lab journal template can be found in the Student Information Packet (see Appendix). This journal will be collected, evaluated, and graded. In addition, students who need help with their specific algal bloom research topic can turn to the "Guiding Research Ideas" page of their information packet. This sheet should list contact information for a local environmentalist or specialist who is willing to talk with the students about the importance of clean water, the impact humans have on water, and how algal blooms are formed. Day two concludes with students engaging in a short classroom discussion over the types of information they found and the direction they want to pursue within the project. Students will turn in the "Experimental Direction Slip" found in the student information packet after determining the type of algal bloom and two initial solution ideas they plan to work with. This slip can be turned in either at the end of class or at the beginning of class the next day for students who need to continue independently researching at home. The teacher should review these slips and offer one-on-one assistance to students who do not appear to be on the right track.

DAY 3 (50 MINUTES)

Begin the lab exercise by having each lab group label a plastic tank with their names or group number. Label another plastic tank at the front of the classroom "control tank." Next, have each group retrieve a predetermined amount of water for their tank (200mL for a 250mL tank and 450mL for a 500mL tank). This water should be provided by the teacher and should be gathered from a nearby water source such as a lake or pond. If you are in an area with saltwater resources, this lab can easily be adapted to use saltwater from a nearby beach to consider how algal blooms affect marine life and local fisheries. Be sure students label their tanks with their water source and the type of algal bloom culture they are working with. After students add the selected amount of water to each tank, each group should retrieve 5 mL of their selected type of algal culture to be added to their tank. Finally, students will add to their tank 1 pipette of fertilizer or other student selected catalyst equivalent. The "control tank" at the front of the room will not receive any additional chemicals (e.g., no fertilizer). Once students have completed their lab set up, have each group measure the characteristics below and record the data in their journals.

- Temperature
- pH
- DO
- Nitrate

– Color
– Smell
– Opacity

Place each tank on a shelf near a window or an aquarium lamp to receive light. Allow the students to spend any remaining time setting up charts and tables in their lab journals to make data collection quick and easy.

DAY 4 (25 MINUTES)

Spend the beginning of day 4 finishing the lab journal charts and tables. Each day should begin with students adding another pipette of fertilizer to their tank. Allow students time to collect their data after adding the fertilizer. Plan on today's measurements taking more time as students are still becoming accustomed with the data recording process of this experiment. Assign a student to collect data for the control tank each day. Have this student write the data collected from the control tank on the board for the class to copy into their lab journals.

DAYS 5–10 (15 MINUTES EACH DAY)

Allow students time at the beginning or end of class to collect and record data samples from their laboratory experiments after adding another pipette of fertilizer to their tanks. Make note of any weekend breaks or holidays. Student data collection should be done quickly and independently during the time allotted by the teacher.

DAY 11 (50 MINUTES)

Explain to the students they will be expected to take their data findings and devise a solution to the algal bloom problem in their community. Students should feel free to work with their sample of algal blooms during this process to possibly find a way to eliminate or decrease the size of the bloom. Students can present their ideas in any way they feel best promotes and explains their created solution (PowerPoint®, model, prototype, video, etc.). Allow students time to talk with their peers and other groups about the various findings across the class. Students can turn to their information packet to locate guiding discussion questions to answer in their lab journals. Finally, have students finalize their solution to the algal bloom problem and inform the teacher of any necessary classroom materials may need for their presentation.

DAY 12 (OPTIONAL)

Take a field trip to a local water source (pond, lake, creek, beach, etc.) that is currently impacted by algae. Have students take data from the water supply to determine the severity of the algae growth. Calculate a class average of the nitrate, oxygen, and pH levels, and have students record this information in their lab journals for another source of data comparison. Compare the results from the field trip to the results from the lab experiment.

DAY 13 (50 MINUTES)

Provide the students time to work on their final projects, data analysis, and reflection questions. Additional student research and time is expected during this process. Make technology available for students who may need to look up specific information regarding their solution.

DAYS 14–15 (ONE WEEK AFTER DAY 13)

One week after day 13, hold a classroom presentation day where students will present their ideas for possible preventative and/or restorative solutions. Students will also turn in their laboratory journals on this day. Invite a local environmentalist or water specialist to speak to the class about why this issue is important in their own community and why society depends on clean water. Students will give their presentations after the speaker leaves if the speaker is unable to stay. After grading the projects, invite students to place their finalized projects in their student portfolios. Once the unit of study is complete, dispose of the algal cultures properly by heating the cultures until they boil (see References section for

more help on properly disposing of the cultures). Once the water and algal cultures have boiled, the cultures can be safely poured down the drain.

EXTENSION

Have students who are more advanced or who may finish early keep track of cell counts of different algal experiments by using microscopes, slides, and slide covers. Students should record the data in their lab journals and make a graph summarizing the data. Have the students make conclusions about the impact of different fertilizers and chemicals concerning the speed of growth.

Have students who are more advanced or who may finish early keep half of their experiment in the sunlight and half covered and away from the sun. Have students perform the same tests on each sample and make conclusions as to how sunlight impacts algal blooms.

EVALUATION

Oral Presentation Rubric

	Exceeds expectations 3	**Meets expectations 2**	**Nearly meets expectations 1**	**Fails to meet expectations 0**
Work Ethic	The student presentation was broad in scope, well integrated with peers, and flowed seamlessly among peers.	The student portion of the presentation reflected required knowledge and showed a smooth transition of knowledge his or her peers.	The student portion of the presentation was limited in scope, depth or flow.	The student completed only a portion of the project, which resulted in an incomplete presentation.
Data and Visuals	The data, findings, visuals, and solutions are correctly represented, organized, and easily interpreted.	The essential data, findings, visuals, and solutions are included in the presentation.	Only a portion of the necessary data, findings, visuals, or solutions was included in the presentation.	The necessary data, findings, visuals, or solutions were absent from the presentation.
Organization	The presentation was logically organized and sequenced so there were no interruptions in the flow of the presentation and was easily understood and interpreted.	The presentation was sequenced and logically organized so that it was likely to be easily understood by the majority of the audience.	The presentation was sequenced but lacked clarity and at least some audience members of the audience had difficulty understanding.	The presentation was disorganized or not presented in a logical sequence. At least some audience members had difficulty understanding.
Presentation Skills	The student demonstrated exceptional professional and interpersonal communication skills when presenting and in all interactions with teammates.	The student was generally organized and professional; however, some comments or interpersonal communications could have been improved.	The student was organized but made some inappropriate comments, statements, or jokes. At least some of the audience or team might have felt uncomfortable.	The student was unprofessional, disorganized, impolite, or disrespectful while working with peers or presenting

Laboratory Journal Rubric

	Exceeds Expectations 3	**Meets Expectations 2**	**Nearly meets expectations 1**	**Fails to meet expectations 0**
Research	The student shows synthesis and evaluation of scientific information through scholarly research from sources.	The student shows evaluation of scientific information through scholarly research from sources.	The student lacks evaluation of scientific information through scholarly research from sources.	The student does not provide any scholarly research from sources.
Analysis of Importance	The student analyzed the relationship of various aquatic systems and the importance of these systems concerning human and animal life while making further connections.	The student analyzed the relationship of various aquatic systems and the importance of these systems concerning human and animal life.	The student attempted to analyze the relationship of various aquatic systems and the importance of these systems concerning human and animal life but failed to make clear connections.	The student did not analyze the relationship of various aquatic systems and the importance of these systems concerning human and animal life.
Human Impact and Solution	The student investigates how human activities impact unbalanced systems and makes further connections to create an appropriate solution.	The student investigates how human activities impact unbalanced systems and creates an appropriate solution.	The student investigates how human activities impact unbalanced but fails to create an appropriate solution.	The student fails to investigate how human activities impact unbalanced systems.
Scientific Process	The student displays an understanding of the scientific process by implementing a successful experiment where measurements are taken with precision and accuracy, data is appropriately recorded, and results are analyzed and implemented through a possible solution while thoughtfully monitoring the progression of the scientific process and making appropriate adjustments along the way.	The student displays an understanding of the scientific process by implementing a successful experiment where measurements are taken with precision and accuracy, data is appropriately recorded, and results are analyzed and implemented through a possible solution.	The student displays an understanding of the scientific process by attempting an experiment; however, the student lacks measurements taken with precision and accuracy, data that is appropriately recorded, and/or results that are analyzed and implemented through a possible solution.	The student does not display an understanding of the scientific process.
Laboratory Safety	The student demonstrates safe practices during laboratory experimentations, uses laboratory equipment properly, and is a model for others to follow.	The student safely uses laboratory equipment.	The student unknowingly misuses laboratory equipment.	The student does not demonstrate safe practices during laboratory experimentations and deliberately misuses laboratory equipment.

Multiple Choice Questions

1. Which of the following places would most likely not have a problem with algal blooms?

   A) A neighborhood drainage system of ponds that collect runoff from landscaping, household recreational use, and rainwater.
   B) A small river consisting of melted snow flowing from the top of a mountain to the base of the mountain
   C) A saltwater marina near that houses several yachts and boats year-round
   D) A body of water located on a farm used for watering large nearby crops

2. How might sunlight impact the growth of algal blooms?

   A) Sunlight has no effect on the growth of algae
   B) Sunlight enhances the growth of algae
   C) Sunlight decreases the growth of algae
   D) None of the above

3. What changes would you expect to see in the growth of algae if fertilizer is only added to the water tanks on the first day?

   A) The algae growth would slow considerably
   B) The algae growth would increase considerably
   C) The algae growth would not grow
   D) The algae growth would decrease considerably

4. Which of the following is not an area algal blooms impact?

   A) Human consumption of seafood
   B) Marine reproductive capabilities
   C) Economy of fisheries
   D) All of the above

5. What is the main cause of blue-green algae?

   A) Increased levels of phosphorous and nitrogen
   B) Increased levels of oxygen and nitrogen
   C) Increased levels of phosphorous and calcium
   D) Decreased levels of oxygen and nitrogen

Correct Answers: 1-B 2-B 3-A 4-D 5-A

REFERENCES

For help with developing the laboratory portion of the plan:
– http://serc.carleton.edu/eslabs/fisheries/7_a.html
– http://teachingboxes.org/upwelling/lessons/lesson1_supplement/MakingAlgaeGrow.pdf

For help with disposing algal blooms properly:
– http://shawhighstudents.org/apes/lab/making-algae-bloom/

APPENDIX

Algal Blooms Student Information Packet

What are algal blooms?

Algal blooms result when the algae population in a body of water rapidly increases. Algal blooms can occur in bodies of both freshwater and saltwater. These blooms can be green, yellow, brown, or red in color. Algal blooms can be dangerous because their invasive nature takes over an area of water, bacteria levels increase, dissolved oxygen levels decrease, and animals are unable to survive. Some algal blooms produce biotoxins that negatively impact wildlife. These blooms are referred to as Harmful Algal Blooms, or HABs.

Causes of Algal Blooms

Scientists believe that an increase in nutrients such as phosphorus and nitrogen greatly contribute to the rapid growth of algae. Speculated sources that contribute these nutrients to bodies of water include runoff from fertilized farmlands, deforestation, and discharged sewage. Other factors that influence the growth of algae include sunlight, temperature, water levels, water flow, pH, and salinity.

Problem

Water is a resource all life on Earth needs to survive. Without clean water, the quality of life can rapidly decline as health, economic, and social problems emerge. For this project-based learning assignment, you will be faced with the problem of algal blooms taking over the water resources in your community. If you do not take appropriate action, we may find ourselves faced with the dreaded fear so often quoted from *Rime of the Ancient Mariner*, "Water, water, everywhere, but not a drop to drink."

Description:

In this project you will be challenged with devising a way to halt and prevent future growth of algal blooms. You will begin by dividing into teams of four and selecting a specific type of algal bloom to research. You may choose to research either saltwater or freshwater blooms. You will then consider how these blooms grow as a result of human activities. After you research the various causes and effects of these dangerous blooms, you will grow your own controlled tank of an algal bloom with water collected from a nearby water source in our community, analyze and chart the growth of the algae, and ultimately devise a way to halt or reverse the harmful effects of this invasive growth. Your final product or model will be presented to the class through an oral presentation with visual supports. With your help, the use of various water resources can be made safe again in your community. Prepare to begin thinking critically, creatively, and scientifically. It is time to sink or swim!

Experimental Direction Slip

Name(s)_____

1. Please circle your preferred local water source below

*Freshwater
- Lake or pond
- Stream or river
- Collection from a wetland

*Saltwater
- Ocean

2. If an algal culture is unable to be collected from your selected local water source, indicate the type/color of algae you would like to work with below.

Algae: _____

3. Please write two initial ideas that may help decrease or stop the growth of algal blooms below.

* These water sources can be made more specific or changed depending on what water sources are available in your specific area.

Guiding Research Ideas for Students

Contact information of a local environmentalist

Name: _____

Phone number: _____

Email address: _____

Contact information of a local water specialist

Name: _____

Phone number: _____

Email address: _____

Which of the following reasons most motivates you to research algal blooms?

Clean water for safe drinking

Clean water for safe recreational use

Clean water for animal safety

Clean water for seafood consumption

Clean water for industrial use

Clean water for agricultural use

Clean water for bathing, washing clothes, house cleaning, etc.

Other: _____

Important Dates/ Deadlines

Lab journal:_____

Presentations:_____

Fieldtrip:_____

Lab Journal Template for Research Process

Experimental Design/Ideas:

Possible Solutions:

Causes of Algal Blooms:

Additional Notes:

Sources:

Lab Journal Template for Experiment Data

Name(s): _____ Water Source: _____

Algal Culture: _____

Day	Date	Algal Measurement			Catalyst and Amount	Physical Description	Additional Notes
1		Nitrate	O_2	PH			
2		Nitrate	O_2	PH			
3		Nitrate	O_2	PH			
4		Nitrate	O_2	PH			
5		Nitrate	O_2	PH			
6		Nitrate	O_2	PH			
7		Nitrate	O_2	PH			
8		Nitrate	O_2	PH			

TONI M. SZUTKOWSKI

13. HEALTHY WATER IS WELL WATER

Homemade Water Filtration

SCHEDULE AT A GLANCE

Day 1	Day 2	Days 3–4
Engagement and initial discussion	Research on what makes water potable	Sketch a prototype of water filter and begin construction
Day 5	Days 6–7	Day 8
Finish constructing water filter	Create presentation	Conduct presentations

WELL-DEFINED OUTCOME

Design a water filter that is made out of easily accessible supplies that can be found around the house. The water filter must contain no more than eight different pieces and be able to filter the water to produce potable water when tested using a water test kit. Students must also design an instruction manual on how to make the water filter they constructed.

TEACHER INTRODUCTION

This PBL is designed for high school students. The project uses a real world issue and allows students to use their creativity to demonstrate their ability to think "outside of the box" in creating a filter than can make pond or river water potable. In completing this project, students will have hands on experience in creating a three-dimensional model to test their theories of finding the most efficient way to filter water. Prior to this project the students will need to have a basic understanding of the importance of clean water for survival and what criteria are involved in categorizing water as potable. The students must also be familiar with creating presentations that show raw data and detailed procedures that can be replicated by others. This project can be used as a major project for the students to demonstrate and test their abilities to create a water filter that passes a water kit test and then present their design to a room of observers.

Before the start of the project, the students need to be familiar with the roles that clean water has in the lives of eukaryotes. While working in groups of three, the students will each find no more than eight total materials from home to use to filter water from a nearby stream. Materials can include cloth, cotton balls, gauze, tulle, gravel, and so on. Once the students have completed the water filter and tested the water using a water test kit provided by the instructor, they will need to pitch a proposal to the class. The students will be able to vote for each other's projects, and the team with the winning project will be able to earn bonus points on their project. In exploring the different ways to construct water filters, this six-day project will demonstrate to the students how important water is to the environment and how crucial it is to be able to filter water in a cost efficient way.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- State the dynamic properties of water.
- Demonstrate the knowledge pertaining to the properties and characteristics of potable water.
- Apply the understanding of how a eukaryote uses water to everyday life.
- Design an experiment that follows the steps of the scientific method.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 103–109.

– Display an understanding of the scientific method by keeping a notebook to log all work done.
– Communicate scientific ideas using multiple representations, including graphs, data, photos, and terminology that is understood by the scientific community.

English – The student is expected to:

– Determine the meanings of English words that are used in multiple content areas.
– Demonstrate appropriate strategies for rehearsing and presenting speeches.
– Use appropriate communication strategies in professional and social contexts.

Mathematics – The student is expected to:

– Demonstrate a knowledge of surface area.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

– Understand the chemistry behind water and be able to explain why those properties make it the universal solvent and the molecule of life.
– The importance of water in biological functions.
– Understand the effects that potable water versus non-potable water has on eukaryotes.
– Understand the effects bacteria can have on eukaryotes.
– Identify the term potable.
– Identify and quantify causes and effects of uncertainties of measure data.
– Effectively communicate data to an audience.
– Use the steps of the scientific method to create a three-dimensional product.

Engineering

– Use engineering design methodology to understand the different limits of a system.
– Use decision making in construction of a water filter.
– Develop skills to manage and assist in the project.

Mathematics

– Students will use geometry skills to construct their filters by matching up angles and ensuring that all samples of water are required to pass through the filter.
– Understand relationship between surface area and filter efficiency.

STUDENT INTRODUCTION

You and your friends are on a senior trip to Big Bend National Park. After a huge storm hits, you and your friends are left with very few supplies. Knowing that you can only survive three days without water, you begin to dig through your backpack and find random supplies that you brought from home. You realize that you must make a water filter with these supplies in order to make the 45 mile hike to the nearest ranger station.

We see it all over the news. Drinking water has become an ever-pressing issue throughout the world. It's important that people are aware of the different techniques that can be used to filter water. Without water, the human body will cease to function. Without clean water, the human body is susceptible to various viruses, bacteria, and diseases.

MATERIALS USED

– Sterilized bin for the water to be filtered into
– A water test kit
– Scissors

- Tape
- Rulers
- Pencils
- Glue
- Rubric
- Computers
- Poster Board
- Markers
- Construction Paper/Colored paper
- Non-potable water that will be used in the water filter and tested with the water test kit.

DAY 1 (50 MINUTES)

Start the project off by giving the following scenario to the students.

> You and your buddies just graduated high school and are looking for something to do before you all go different ways to college. You all ponder different activities to do and you remember that really cool place your super awesome biology teacher talked about, Big Bend State Park. The group decides that this is the place to go. You all spend the evening packing your bags and that very next morning you leave for Big Bend State Park. The first few days go wonderfully, but a storm hits one night and wipes out all of your supplies except for your tent and the supplies you have kept in a backpack that is in the tent. You wake up in a panic and realize you have nothing to eat for breakfast. Your buddies remind you that it's more important to find clean water than to worry about food because you can only survive three days without fresh water. You know there is a ranger station about 45 miles away. In order to make it to the station you need water. You remember your biology teacher relating everything about the human body back to the importance of water. Without water, you'll wither away and to dust you'll turn! You and your buddies sit down to start working on a design for a water filter that will provide clean water for your long journey to the ranger station.

At this point, split the students into random groups of three. One technique you can use to group students is to use a deck of cards that has been configured to only contain three of each number or face; the students will draw a card and find their groups by matching the cards to each other. Once the students have found their group members, the teacher will then hand out identical plastic bins (size is teacher's discretion) to each of the groups. The plastic bins will be used to collect the water as it passes through the filter.

Students will be given the theory behind the project and any other information will be made clear to the students. The students will need to understand the aspects of water as it relates to the human body. In order to create a water filter that is potable, the students will need to have a basic understanding of the criteria that makes water potable. The students will generate charts and tables using Excel® based on the results of their water test kit. The students will also generate a presentation in the form of a slide show, poster board, instructional video, brochure, etc.

DAY 2 (50 MINUTES)

Once the students have found their groups, the students will research the criteria that make water potable. Once the students have found the criteria that make water potable, they need to begin research on the different parts of a filter. The students must turn in their findings in order to exit the classroom on day one.

DAY 3 (50 MINUTES)

The students sketch a prototype of their water filters. The prototype should be drawn to scale with a legend provided so the reader can depict the actual size of the prototype. The drawings of the prototype should be crisp and clean with measurements labelled properly, and students should insert as much detail into their prototype as possible. A rubric for the prototype is in the Evaluation section of this PBL.

DAY 4 (50 MINUTES)

Students will finish their prototype and begin constructing their water filters. Students must have the eight items they brought from home and will construct their water filters using all items brought from

home. Somewhere in the classroom there must be a basin filled with the water that the students will filter. This water can be from a nearby stream, pond, or other nearby water source. The filters must produce potable water when tested with a water test kit.

Students must also take careful notes on how they constructed the water filter so they can create the instruction manual for their water filters. This manual will be shown in their final presentation and assessed with the Water Filter Manual Rubric found in the Evaluation section of this PBL.

DAY 5 (50 MINUTES)

Students will use this day to finish building their water filters, test their products, and then work to improve their filters.

DAYS 6–7 (50 MINUTES PER DAY)

Students will use these two days to create a presentation that presents the audience with a detailed guide to constructing the filters and the results (i.e. photos of the filters or tables) that are obtained once the water is filtered. The presentation must start with a brief explanation as to why water is so important to the human body. The presentation must include scientific terminology as well as photos of the finished product, a step-by-step list of how the filter is made, and a chart that contains any data obtained. The rubric for the student presentations is given in the Evaluation section of this PBL.

DAY 8 (50 MINUTES)

The students will present their projects to the class.

EXTENSION

Instruct students to create a presentation of their choice that reflects all steps in creating a water filter that generates potable water and that integrates factual information and data. Ask the students to address questions such as:

- In what ways is water viable to the human body?
- What properties of water allow water to play such a vital role in the human body?
- What happens if humans consume water that is contaminated?
- Explain the importance of water in all three of its phases (solid, liquid, and gas) as it pertains to life on earth?

EVALUATION

Presentation Rubric

Points	**5**	**10**	**15**	**20**
Subject Knowledge	Students don't have a solid grasp on the information. Statements are incorrect.	Students have some inaccurate information or leave out important information. Students seem uncomfortable presenting the information.	Students have correct information. Students seem comfortable presenting the topic information.	Students have detailed and correct information. Students are comfortable presenting the topic information and expand upon material that isn't listed in the presentation.
Tables, Graphs, Graphics (Must contain two of the three)	The students have no conclusions or the conclusions are irrelevant to the information presented in the tables, graphs, or graphics. The table, graph, or graphic takes away from the message.	The students' conclusion is unrelated or irrelevant to the information presented in the tables, graphs, or graphics.	The students' tables, graphs, or graphics are supported by the conclusion, but the conclusion is unclear and needs more detail.	The students' tables, graphs, or graphics are well supported by the conclusion and the student accurately explains the graphic during the presentation.

Steps to Recreating Water Filter	Steps are not presented. All materials are listed.	The steps are inconsistent and not clear. All materials are listed.	The steps are clear but missing detailed instruction. All materials are present in the steps.	The steps present clear and detailed instructions that include all materials used.
Questions	Students cannot answer questions regarding the importance of water or various aspects of the water filter.	Students are able to answer rudimentary questions but cannot elaborate on the answers given.	Students are at ease with answers to most questions and can elaborate on half of the questions asked.	Students are comfortable with the material and can elaborate on all questions presented by the class and / or instructor.
Format and Grammar	The presentation contains more than five grammatical or spelling errors. The project reflects minimal effort and creativity.	The presentation contains less than five grammatical or spelling errors. The project reflects creativity and moderate effort.	The presentation contains less than three grammatical or spelling errors. The project reflects creativity and is detail oriented.	The presentation has no more than one grammatical or spelling error. The project reflects creativity and is detail oriented.

Water Filter Manual Rubric

Criteria	**5**	**10**	**15**	**20**
Purpose	No attention to the purpose of the manual is given.	Purpose is not clear at all. Manual just starts with instructions and no purpose.	Purpose is somewhat clear but not outlined well for the audience. Has a weak introduction and incomplete table of contents	Purpose of instructions is very clear and audience knows what they will be able to do after reading the document. Includes an introduction and table of contents
Use of Images	No pictures are included in the instructions. The document includes text only.	Some pictures are included with the instructions, but they are not clear, well labelled, or connected to the text.	Pictures accompany the instructions and most are well labelled. But images do not necessarily enhance the instructions.	Well-labelled pictures accompany the instructions. The images make the instructions clear and easy to follow.
Visual Design	Instructions are poorly organized or have no clear organization at all.	Instructions are organized into sections.	Instructions are well organized into major sections that are labelled.	Instructions are very well organized into major sections with clear labels and a table of contents.
Thorough-ness	Instructions are incomplete and offer no help for the user.	Instructions may be missing some steps, or the steps are not clear.	Instructions include information needed to complete the task.	Instructions include all necessary information and pictures, including any contact information for help and troubleshooting.

Prototype Rubric

Criteria	15	10	5
Planning of Prototype	Students did thumbnail sketches and preliminary drawings to get an idea how to develop the product.	Students did some planning ahead of time to develop ideas.	Student just began drawings without any thinking of other possibilities or ideas. Students did no planning.
Attention to Detail and Completeness	Evidence of thorough work relative to the time allowed designing the prototype. Drawings were complete with a lot of detail.	The project is complete and there is evidence that students worked on the project during allotted time. Drawing had some detail, but could have benefited from more detail.	Students left some parts of the drawing unfinished. Drawing was not complete and lacked necessary details.
Aesthetics	Drawings are neat, clean, and professional looking. Measurements are properly labelled. Drawing is visually very attractive.	Drawing contains some smudge marks or other evidence of sloppy work. Drawing has some measurements (but not all) and is somewhat attractive.	Drawings are messy and very visually unattractive. Eraser marks, scratch-out marks, and other mistakes are clearly evident.
Scale	Drawings are accurately drawn to scale. The scale is depicted on the drawing and is precise.	Drawings are somewhat drawn to scale, but there are some instances where the scale is inaccurate.	There was little to no attempt to draw the prototype to scale. Mistakes with the scale are very obvious.

Exit Slip: Potable Water Criteria

Name:

In order to leave class today, you must work with your group to research the criteria that make water potable. You must find eight facts about potable water, including at least three percentages of bacteria and other aspects that are allowed to be in water before it's considered unclean.

1._____

_____

2._____

_____

3._____

_____

4._____

_____

5._____

_____

6._____

_____

7._____

_____

8._____

Multiple Choice Questions

1. Water is a _____ molecule.

2. Why is water important to cell processes?

   A) It readily dissolves all biological molecules.
   B) It's the universal solvent.
   C) It is an important aspect of the cell membrane.
   D) B & C
   E) All of the above

3. What type of bond does a water atom have?

   A) Ionic
   B) Covalent
   C) Hydrophobic
   D) Hydrogen

4. The human body is _____ percent water.

5. True or false (if false please correct the flaw in the statement): Water removes waste from the body as well as regulates the temperature of the human body.

6. How much freshwater is on the surface of the Earth?

   A) 10%
   B) 7%
   C) 3%
   D) 25%

7. True of false (if false please correct the flaw in the statement): Water has a low specific heat.

8. Water can readily _____ across the _____.

9. Which of the following macromolecules is NOT soluble in water?

   A) Lipids
   B) Carbohydrates
   C) Polar molecules
   D) Proteins
   E) Nucleic Acids

10. In the cell water will diffuse from areas of _____ concentration to _____ concentration.

BONUS: List one fact that you know about water that was not tested in this quiz.

Correct Answers: 1 - polar 2 - D 3 - B 4 - 70 5 - True 6 - C 7 - False: Water has a high specific heat 8 - diffuse, plasma membrane 9 - A 10 - high, low

REFERENCES

Simpler version of the project: http://thewaterproject.org/resources/water_pollution_filtration_experiments
Helpful videos:
– Properties of water: https://www.youtube.com/watch?v=Wnx9thXySGw
– What if you stopped drinking water: https://www.youtube.com/watch?v=zCheAcpFkL8
– Reading water test kits: https://www.youtube.com/watch?v=Lq_qqvqA0h0

LAUREN DREY

14. SINK OR FLOAT? YOU BE THE JUDGE

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Discuss buoyancy and density	Brainstorm and research. Begin design	Begin construction of model boat	Test and redesign	Judgement Day	Presentations

WELL-DEFINED OUTCOME

Design and build a model boat that will hold as much weight as possible without sinking using no more than three items from a material box.

TEACHER INTRODUCTION

The purpose of this project is to allow students to explore and investigate the concepts of density and buoyancy by relating them to an object's ability to sink or float. With this knowledge, students will be able to apply these concepts to build a boat of their own using higher level thinking skills and creativity. Students can use this knowledge to relate to the real world by determining why they themselves might float or sink when they go swimming or why they can lay on a floating device in the pool without sinking. At the end, students will try to persuade their fellow classmates to use their boat to travel home.

Students in a classroom (around 5th grade) will work in groups of 3 or 4 assigned by the teacher before the lesson begins. Groups will assign each of their members to a specific role such as the project leader, planner/recorder, or the builder. The project leader is responsible for making sure the group stays on task and for gathering materials. The planner/recorder is responsible for drawing the design of the boat and recording observations or notes made during the building process. The builder is the one who builds the actual boat according to the design agreed upon by members in the group. Even though students are assigned roles, they should be reminded to assist each other when needed. They are responsible for working together.

After students have completed some research on how to build a boat, each group will receive one yard of tape and three pieces of printer paper to use during their planning phase. The planning phase should last about thirty minutes. The building phase should last about thirty to forty-five minutes and the revising phase between fifteen and thirty minutes. Students' persuasive presentations at the end should last no longer than ten minutes per group.

Several factors affect whether an object will sink or float when placed in a body of water. In order to complete the project, students must be familiar with the properties of water and the different states of matter. Students should also have some knowledge on density and should have an understanding of what it means for an object to be more or less dense than another object. The teacher should briefly review students on prior knowledge relating to density and buoyancy.

When accessing prior knowledge, the teacher should include the following information: 1) Density is the measure of how much mass is in an object, related to its volume 2) Buoyancy is the upward force from the water to stay afloat, measured in Newtons, 3) Buoyant forces are why we feel lighter in water. Another factor that determines if an object will float or sink is its displacement. Displacement is the amount of water it pushes away when placed in the tub. For example, when you get in the bathtub, the water rises because your body pushed some of the water away. The size and weight of the object in the water will determine the amount of water that will be displaced. An object will float if it is lighter than the water it pushes away.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 111–119.

Mathematics – The student is expected to:

- Apply measurement concepts involving length (including perimeter), area, capacity/volume, and weight/mass to solve problems.
- Perform basic conversions within the same measurement system (SI [metric] or customary).
- Incorporate the problem solving process (i.e., understand the problem, make a plan, carry out the plan, and evaluate the solution for reasonableness) when solving problems.

Science – The student is expected to:

- Apply the property that matter has measurable physical properties and that those properties determine how matter is classified, changed, and used.
- Classify matter based on physical properties, including mass, magnetism, physical state (solid, liquid, and gas), relative density (sinking and floating), solubility in water, and the ability to conduct or insulate thermal energy or electric energy.

English – The student is expected to:

- Apply prewriting strategies to generate ideas, develop voice, and plan.
- Write persuasive texts to influence the attitudes or actions of a specific audience on specific issues.
- Determine, locate, and explore the full range of relevant sources addressing a research question and systematically record the information he or she gathers.
- Synthesize collected information then organize and present ideas and information according to the purpose of the research and the student's audience.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Explore the scientific investigation process.
- Students will make a plan, test their design, and draw conclusions based on their learning throughout the project.
- Students will describe different forces by exploring buoyancy.
- Students will be able to apply what they know about forces to design a boat that will float.
- Students will be able to classify matter based on which objects are more or less dense as well as other ways to classify matter according to their physical properties.

Technology

- Students will access the internet to research the concepts of buoyancy and density.
- Students will use technology of their choice as part of their presentations (PowerPoint®, videos, Prezi, etc.).

Engineering

- Students will design, build, test, and reconstruct a model boat to meet specific constraints and criteria.

Mathematics

- Students will measure and compute volume, area, and the perimeter of different materials and objects to build their boat.
- Students will solve a problem (building a boat to get home under certain constraints and criteria) that incorporates their understanding of the problem, making a plan, carrying out the plan, and evaluating the solution for reasonableness.
- Students are learning how to become real life problem solvers by using their math and problem solving skills and applying them to a real world context.

STUDENT INTRODUCTION

A tropical storm has completely flooded the streets in your neighborhood. Unfortunately, you are stuck at school. The only way to get back home is to build a boat to travel the streets covered in water. You and two of your classmates will explain the concepts of buoyancy and density that will lead to designing and creating a model boat that will hold as much weight as possible without sinking using the materials provided. You will be given a box of materials that can be found throughout the school, and you may not use more than three different types of materials from the box to build your boat. Your boat may be any size or shape as long as it meets the given criteria: The ability to safely float while holding at least one classmate (5 small marbles). To complete the project your boat must be transported to the docking station and be able to float without you touching it. Once the boat is placed in the water, it will be judged on how much weight it can hold before it starts to sink. Lastly, using what you learned about buoyancy and density, you will present your boat design to the class by persuading your classmates to use your boat in order to get home safely.

MATERIALS USED

- Scissors
- Tape (duct, Scotch, packing, etc.)
- Elmer's glue
- Tub of water
- Formula Chart
- Ruler
- Computer (PowerPoint®/presentation media, Internet access)
- Variety of materials found in classroom to build boat (cardboard, foil, clay, tin can, popsicle sticks, etc.)
- Pencils
- Notebook paper or student journals
- Marbles or some sort of object to use as weight measurement
- Balance beam

DAY 1 (50 MINUTES)

The teacher begins the project with an open discussion about the terms buoyancy and density. Students will take five minutes to brainstorm in their journals what they already know about these two concepts and prepare to share with another classmate and the class (think, pair, share). Once the discussion is over the teacher will show a video of the Titanic sinking (video link: http://www.youtube.com/watch?v=FSGeskFzE0s). Students should start to wonder why a ship of that size floated in the first place. Following the video, the teacher leads another discussion among students about the Titanic. Important questions to pose to students during the discussion include: Why did the ship sink? How are some ships able to hold more than others do? Why do some objects sink when other objects float? What about objects that are the same size but different masses or different shapes? When you go swimming, do you float or sink? Can you ever have too many people aboard a boat? How do you know? What might happen? What is surface area? Do you think surface area relates to ships and their ability to float or sink? Lastly, the teacher will have several different objects (e.g. an apple, tennis ball, ping pong ball, pencil, eraser, etc.) at the front of the room with a tub of water. The students will have to guess whether each object will float or sink before the teacher places it in the water. This demonstration will give students the opportunity to think or brainstorm about materials they can use to build their boats.

DAY 2 (50 MINUTES)

In their groups, students will brainstorm ideas and methods for building a model of a boat that will not sink and then sketch possible designs. Students will determine the dimensions of their boat, what materials (found in the box provided by the teacher) they will want to use, and how they will test their boat before it is put on the dock to be judged. Students will either be sent to the computer lab or given laptops so they may search the internet for ideas and information about buoyancy and density. The goal is to get students to use the concepts of buoyancy and density when deciding on the materials to use and the design or shape their boats should be. If computers are not available, the teacher should make sure that there are other resources for the students to use such as library books, articles, or textbooks on these topics. Students should also have access to formula charts and measurement tools to analyze and develop their boat designs. This brainstorming and researching part of the activity will take about 30 minutes. The

remaining 20 minutes will be used to allow students to sketch their boat designs according to the information they have gathered. Students should also be encouraged to keep track of their designs and information gathered through their research in their notebooks for easy access. Keep in mind that some students may need more time or instructions on how to conduct research depending on their level of experience with research.

**The teacher may need to go over how to find different resources for students' research using the Internet or library and go over how to determine the reliability of a source. It depends on what level of experience the students have with conducting research.

DAY 3 (50 MINUTES)

Students will use the materials given to them by the teacher to build a model of their boat according to their design from Day 2. However, students are not allowed to use all the materials in the box that was given to them. They may only choose a maximum of three materials (or items) from the box to use to build their boats. Students may use either tape or glue but cannot use both. Also, if they choose to use tape, they can only use one type (Scotch, duct, packing, etc.) while building their boat. Remind students to look back at their research from the day before when building their boat. They will need to keep track of any calculations they use for area, perimeter, volume, density, and/or buoyancy in their notebooks for future reference (they will need these when presenting to their classmates at the very end). The teacher will start checking the students' notebooks/journals (see Learning Journals Assessment in the Evaluation section of this PBL) throughout the exploration phase to make sure students are collecting correct information for their final products.

Explanations should occur as students are building and revising their boat designs. To start, students will have an open discussion about their current findings. They should discuss the following:

– What they have learned about ships and their ability to sink or float?
– What challenges have they encountered and what observations have they made on the different types of materials available?

This discussion will allow classmates from other groups to offer some input and help students who may be stuck without having to rely on the teacher for answers. Once the discussion is over, the teacher will bring the students back together as a class and remind them about certain concepts they should be considering.

It is important that students understand what affects an object's ability to float or sink. At this time it may be necessary to explain the concept of buoyancy.

What is buoyancy?

It is the force exerted on an object that is immersed in a fluid (in this case water). In this situation, buoyancy acts upward on our boats as they are placed in the water. Archimedes' Principle says that the magnitude of the buoyant force on an object is equal to the weight of the fluid it displaces. We know that the density of the fluid, the volume of the fluid displaced, and the local acceleration due to gravity affect buoyancy. Explain to students the formula for buoyancy force (B) = ρ V g, where ρ = density of fluid, V = displaced volume, and g = 9.8 m/second (gravity). The teacher will explain to the students in greater detail the meaning of these factors and how they affect the buoyant force on an object.

What are the key factors that affect an objects ability to float?

– Displacement: This is when an object immersed in a fluid pushes the fluid out of the way and takes its place. (Example: When you get in the bathtub and the water rises, your body is taking the place of the water that it displaced when you got in the tub). The volume of the fluid displaced can be measured, and the volume of the immersed object can be deduced (the volume of the immersed object will be exactly equal to the volume of the displaced fluid).
– Size, Shape, Volume: Students should know that a ship will float even though it may be made of steel (which is much denser than water), because it encloses a volume of air (which is much less dense than water), and the resulting shape has an average density less than that of the water. Review students on what volume is and have students brainstorm the different ways to find the volumes of differently shaped objects (also think about how displacement can be used to calculate volume of an object we do not have a formula for).

– Density: Density measures the level of compactness of a substance. Explain to students that each substance (material) has its own density because of the atoms and molecules from which it is made. For example, metal, plastic, and wood cubes each have their own unique density and can be explained by looking at the size and mass of the atoms and how they are arranged. If the density of the liquid is more than the density of the material of the body, then the body floats due to the buoyant force exerted by it and vice-versa. If the object has exactly the same density as the fluid, then its buoyancy equals its weight. It will remain submerged in the fluid, but it will neither sink nor float. The formula for density is D=M/V where D is density, M is mass, and V is volume.

If time allows at the end, the teacher may show students some buoyancy videos found on the internet (see resources section for suggestions).

In Language Arts, the teacher can review the students on what a persuasive speech, paper, or presentation is and what elements should be included. The teacher will explain different strategies students can use when trying to influence the attitudes or actions of their audience (classmates) to use their boat. Have students make a list of what words might be good to use or what facts might they need to present when trying to convince someone. In a sense, the students need to act as the "sales" or "marketing" person. The teacher will explain to students how they can incorporate their research into their persuasive presentation and what role it will play.

DAY 4 (50 MINUTES)

Students will put their model boats on the docking station for a test run before the final judgment. The team will assign one member to add weights (marbles) on their boat one-by-one until either the boat fills with water and sinks or has reached maximum holding capacity. As each team's boat is tested, other teams' students should make observations and take notes in their Learning Journals. They will use this information to make revisions and improvements to their own boats before the final judgment (Day 5). The time needed for this stage will vary depending on how many groups there are in the class. However, as soon as all the boats are tested, the students will be given between 15 and 30 minutes to make necessary revisions to their boats for improvement before the final judgment (Day 5).

DAY 5 (50 MINUTES)

Students will put their model boats on the docking station for the final judgment stage. The teacher will add weights (marbles) one-by-one to each team's boat until the boat fills with water and sinks or reaches its maximum capacity. Once all of the boats have been judged, the students will go back to their groups and prepare a presentation (written or oral) persuading their classmates that their boat is the best boat to use to arrive home safely from school. Each presentation will need to include the following: a) what materials were used to build the boat and why, b) how successful was the boat and how many people could it hold, c) what makes the boat the best using the concepts of buoyancy and density, d) the dimensions or shape of the boat and how that contributed to the boat's success, and e) any other persuasive information the students wish to include (pictures, advertisement videos/posters, etc.). This stage will take about 30-45 minutes plus the time needed to test all the boats at the docking station. The Language Arts teacher may address the presentation and persuasive skills, and as such, it is important to check with him or her to see how you can work together to maximize the learning potential for students. Expect that students will need time to prepare their presentations and extra time might be needed to review the rubric to better ensure students understand requirements and expectations of the presentation.

DAY 6 (50 MINUTES)

Each team of students will deliver its presentation to the class. As soon as each team has presented, each individual student will order the different boats, from the boat that would be his or her first choice to use and the boat that would be his or her last choice to use when traveling home from school. Students will have to include an explanation as to why they ordered the boats the way they did. The teacher will pick up the sheets, tally them, and then announce the winner to the class. Depending on how many groups are in the class, the time for this part of the activity may vary. Each group should stay within a 10-minute maximum period for their presentation.

EXTENSION

Options for students who finish early

- Students can add things to their boats, such as a flotation device to help keep it afloat, or they can design a motor to make their boats move more quickly through the water. Give students more freedom and more supplies to take their boats to the next level. As another option, have students design a boat using only one or two materials. Students will be evaluated on their creative abilities as well as their level of detail while recording their observations, plans, and measurements in their notebooks. Students will use a video recording device to record a documentary as they go through the process of adding extras to their boats so they can watch themselves when they have completed their new boat.
- Students will design a catchy video advertisement about their boats. Instead of persuading their classmates to use their boats, they now need to persuade the entire school that their designs will get their classmates home from school safely. Students must also include a "how-to" explanation of how to build their boat designs if other students decide to use their boats along with an explanation as to why they choose these designs with these materials.

Options or students that finish early or need a bigger challenge…

- Tell students that the principal loved their designs so much he or she has chosen their boat designs to take the entire 5th grade on a field trip in the Gulf of Mexico for a day. Students will need to make adjustments to their boats in order to accommodate the entire 5th grade. The new boat will need to have enough room for the students to be able to sit and walk around safely. Students will need to think about the size of the new boat, seating, bathrooms, driving/steering/motor (how will the boat move), and any extra features they might use. Allow students to use their creativity. Students will need to conduct research on the computers provided. They will need to provide a blueprint with dimensions of their larger new boats along with some type of model for their boats. Students will use computer programing to make a 3-D model and blueprint of their boats to be presented to the principal. Include the cost of building the boat in the presentation. The principal will be looking for the least expensive and safest boat design to use for the class field trip.

EVALUATION

Learning Journals Assessment (100pts)

The teacher will evaluate the journal entries using the Journal Checklist below. Points will be awarded for each item included in their entries.

Dates are listed for each entry	/10
Boat Design Dimensions Calculations and formulas Materials used	/30
Research Notes Buoyancy Density Displacement	/30
Observations from first trial run	/10
Design improvements/what changes are they going to make and why?	/10
Total	/100

Presentation Rubric (24 pts.)

	Exemplary 4	**Mastery 3**	**Proficient 2**	**Introductory 1**
Use of Visuals	90–100% of the visuals are highly developed, clear, and illustrate main points. Visuals enhance the presentation.	80–89% of the visuals clarify and illustrate the main points. Visuals are neat and well organized.	70–79% of the visuals illustrate the main points. Visuals lack neatness and organization.	Less than 70% of visuals illustrate main points. Visuals do not relate to presentation; do not support main points.
Communication of Main Points	Communication is well thought out and clear. All (5) elements were included in presentation.	Communication is good. A majority (4) of the elements were included in presentation.	Communication is lacking. Only a few (2) of the elements were included in presentation.	Communication is poor. The elements were not included or were unclear in presentation.
Content Knowledge	Buoyancy and density concepts were used correctly throughout the entire project, especially in explanations.	Buoyancy and density were used correctly for the majority (80–99%) of the project.	Buoyancy and density were used correctly for part (60–79%) of the project. Explanations lacked understanding and clarity of terms.	Buoyancy and density were used incorrectly throughout at least 40% of the project. The students failed to explain the terms correctly.
Persuasive techniques	Persuasive techniques (4) were present, effective, and used appropriately throughout the presentation.	Persuasive techniques (3) were present and used appropriately throughout the presentation.	Persuasive techniques (2) were present and used throughout the presentation.	Persuasive techniques were unclear and lacking from presentation.
Delivery	Method of delivery was effective and catchy to the audience. Presentation displayed creativity.	Method of delivery was effective and appropriate to the audience. Presentation displayed some creativity.	Method of delivery was somewhat effective. Presentation lacks creativity.	Method of delivery was not effective and was not appropriate for the audience.
Time	Stays within the exact time.	Is within 1 minute of required time.	Is within 2 minutes of the required time.	Completely misses the time requirement.

Model Boat Rubric (16 pts)

	Exemplary 4	Mastery 3	Proficient 2	Insufficient 1
Model Boat	The boat was designed with the correct materials and exactly reflects the team's design.	The boat was designed with correct materials and mostly reflects the team's design.	The boat was designed with correct materials but fails to reflect the team's original design.	The boat uses incorrect materials and fails to reflect the team's original design.
Mathematical Knowledge	All math was solved with correct formulas. No errors were made. Calculations demonstrated the dimensions of the boat and its ability to sink or float.	All math was solved with correct formulas. Few errors were made. Calculations demonstrated the dimensions of the boat	Some math was solved with correct formulas. Errors were made in calculations which somewhat demonstrated the dimensions of the boat.	All math was solved with incorrect formulas and calculations failed to demonstrate the dimensions of the boat.
Float or Sink?	The boat was able to float before and as weights were added.	The boat was able to float without weights but sunk once the first weight was added.	The boat partially floated before the weights were added and sank as weights were added.	The boat never floated at any point throughout the project.
Participation	The student was actively engaged and contributed to the project.	The student contributed a fair amount to the project.	The student had to be told a few times to get back on task.	Student was off-task most of the project.

Multiple Choice Questions

1. The measurement of how tightly matter is packed together is known as _____.
   A) Volume
   B) Mass
   C) Density
   D) Buoyancy

2. What happens to a solid object with a density that is less than the density of water when it is placed in water?
   A) The object dissolves in the water.
   B) The object displaces a quantity of water greater than its volume.
   C) The object settles to the bottom of the water.
   D) The object floats on top of the water.

3. According to Archimedes' principle, if an object floats, the buoyant force on the immersed object equals the weight of
   A) The entire object.
   B) The displaced water
   C) The portion of the object that is submerged.
   D) The portion of the object that is above the water.

4. A ship will float as long as the buoyant force is
   A) Less than the ship's weight.
   B) Greater than the ship's weight.
   C) Less than the ship's volume.
   D) Greater than the ship's volume.

5. Which of the following is true about the buoyant force?
   A) It is a net force acting upward on the object.
   B) It makes an object feel heavier.
   C) It is a net force acting downward on the object.
   D) It acts with the force of gravity

Correct Answers: 1-C 2-D 3-B 4-D 5-A

RESOURCES

Websites for students to use during the research phase:

Edmonds, Molly. “How Life Jackets Work”, 14 March 2008.
HowStuffWorks.com.
– http://adventure.howstuffworks.com/outdoor-activities/water-sports/life-jacket.htm, 25 November 2014.
“MythBusters: Let’s Talk Buoyancy”, *HowStuffWorks*. N.p., n.d. Web. 24 November 2014. http://science.howstuffworks.com/6540-mythbusters-lets-talk-buoyancy-video.htm
Submarines: “How They Work – Archimedes’ Principle”, *Blow the Ballast!* N.p., n.d. Web. 24 November 2014. http://www.onr.navy.mil/focus/blowballast/sub/work2.htm
Buoyancy: https://www.youtube.com/watch?v=mpJevjIAr7s

JENNIFER G. WHITFIELD

15. THE WATER FLOWS THROUGH IT

Design and Build an Irrigation System

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5
Engagement – Present scenario.	Discuss features and benefits of irrigation systems. Analyze professional sprinkler designs.	Discussion on water conservation and irrigation's role in conservation.	Research key topics.	Investigate the functionality of an actual irrigation system.

Day 6	Days 7–8	Days 9–10	Day 11
Create a blueprint of the house and plastic containers.	Draw the design of the irrigation system on blueprint.	Build irrigation system.	Give presentations.

WELL-DEFINED OUTCOME

Students must design and build a scaled-down version of an irrigation (lawn sprinkler) system that equally distributes water to different containers (meant to represent grass on a yard), so the water depth in each container is 1.25 inches.

TEACHER INTRODUCTION

This PBL is designed for an on-level or above-level high school student. It uses a real world event to give students the opportunity to apply their knowledge of two-dimensional and three-dimensional measurements, operations on decimals, spatial reasoning, estimation, and properties of basic angles (45°, 90°, and 180°). Prior to attempting this project students should know how to operate on decimals, calculate the area of basic two-dimensional geometric shapes (circles, rectangles, triangles, etc.), calculate the volume of basic three-dimensional objects (cylinders, rectangular prisms, etc.), use tape measures to precisely measure lengths, and convert fractions to decimals. This PBL can be used as a major project for students to demonstrate understanding and ability to problem solve and think critically.

In this project, the teacher will give each group of students a shallow plastic tub that contains a small house constructed from Lego® and other plastic containers that are fixed to the box. The Lego® house should be constructed so students can easily measure its dimensions. The plastic containers represent the sections of a grass lawn that need to be watered, and the plastic containers will also hold the water that is dispensed from the irrigation system that students build. The plastic containers must be carefully chosen because students need to measure the dimensions and calculate the volume of the containers. Figure 1 shows a possible configuration of the house and the plastic containers.

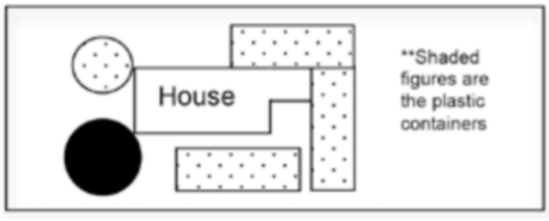


Figure 1. Sample configuration of Lego house and plastic containers

One of the features of an irrigation system is that it spreads water uniformly across a given plot of land. In an attempt to duplicate this feature of irrigation systems, students will build an irrigation system, with actual PVC pipe, that distributes water as uniformly as possible to each of the different containers.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 121–136.

Students may only use hydrostatic pressure and the earth's gravitational pull as the force to move the water through the PVC pipe; students cannot make any adjustments to the plastic containers in the given box. Students must use only materials on the "Materials List" to build the irrigation system, and they will record the cost of building the irrigation system. The cost of the system will help the students generate an invoice used to bill the customer.

Students must design the irrigation system so the water depth in each container is 1.25 inches. Students will have a main water source that will hold all the water used for one cycle of the irrigation system. An example of a main water source is shown in Figure 2.

Figure 2. Example of a main water source

When students run the irrigation system through the cycle, they will fill the water main with a pre-calculated amount of water (i.e., enough water to fill each container with 1.25 inches of water). Then they will turn the valve so the water will run through the system and fill each water container. Students must record how long it takes the irrigation system to run through one cycle and try to minimize the amount of time it takes to uniformly disperse the water.

Once students have finished their irrigation systems (i.e. designed, built, tested, and refined the system), they will present their irrigation designs to an irrigation contractor and justify their designs. With the irrigation contractor present, students will run their irrigation systems through one cycle. Once the cycle is complete, students will measure the water level (height) for each container and report to the contractor how accurately the irrigation systems dispersed the water.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Mathematics – The student is expected to:

- Apply mathematics to problems arising in everyday life, society, and the workplace.
- Use a problem-solving model that incorporates analyzing given information, formulating a plan or strategy, determining a solution, justifying the solution, and evaluating the problem-solving process and the reasonableness of the solution.
- Communicate mathematical ideas, reasoning, and their implications using multiple representations, including symbols, diagrams, graphs, and language as appropriate.
- Display, explain, and justify mathematical ideas and arguments using precise mathematical language in written or oral communication.
- Apply the formulas for the volume of three-dimensional figures.
- Explain flow rates and compare flow rates among their peers.

Science – The student is expected to:

- Identify source, use, quality, management, and conservation of water.
- Recognize and demonstrate that objects and substances in motion have kinetic energy.
- Learn the dynamics of water.
- Demonstrate basic principles of fluid dynamics, including hydrostatic pressure, density, salinity, and buoyancy.

English – The student is expected to:

- Use appropriate strategies for rehearsing and presenting speeches.
- Use appropriate interpersonal communication strategies in professional and social contexts.
- State new vocabulary terms and use them in both written and verbal forms.
- Determine the meaning of grade-level technical academic English words in multiple content areas.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Water flow – Explain how flow rate can be measured in gallons per minute and liters per minute.
- Hydrostatic Pressure
- Water conservation
- Inner workings of valves and other pipe fittings.

Technology

- Learn how technology has advanced irrigation installation and learn about the innovative irrigation products available on the market to help conserve water.

Engineering

- Apply design concepts to problems in physical and mechanical systems.
- Use consistent units for all measurements and computations.
- Engage in design and prototype development.
- Use teamwork to solve problems.
- Complete work according to established criteria.
- Develop a plan for implementation of an individual product.

Mathematics

- Add, subtract, multiply and divide decimals.
- Analyze ratio, proportions, and measurement scales.
- Calculate volume of solids.
- Calculate area of common shapes (e.g., squares, rectangles, circles, and triangles).
- Measure objects with precision.
- Use special reasoning to devise a sprinkler plan.

STUDENT INTRODUCTION

In this PBL you will use graph paper to design a model irrigation system for a scaled down replica of a model home. The design will serve as the blueprint of the house and will need to be as detailed as possible, especially with measurements. Once you have the blueprint of the home, you will use PVC pipe and pipefittings to construct the model irrigation system you designed. You will have a main water source that will hold the water used for the irrigation system. When you are ready to run your irrigation system, you will turn the valve to release the water from the main water source and watch your irrigation system water the “lawn” of the model home. Your goal is to have a water level of 1.25 inches in each of the water containers surrounding your model home.

MATERIALS USED

For the Model Home

- Large, shallow plastic tub
- Structure to represent the house (a house built from Legos works nicely)
- Water Containers of various sizes and shapes
- Hot glue gun to secure the house and water containers in the plastic bin

For the Irrigation Design

- Graph Paper
- Colored Pencils and/or Markers
- Scotch Tape
- Ruler
- Compass

To Build the Irrigation System

- Pipe cutters
- Pipe Glue (May be used by teacher only)
- PVC Pipe Fittings (ells, cross, corner ells, couplers, caps, tees)
- Hand Drill with various drill bits (May be used by teacher only)
- Buckets of Water for testing system
- Safety Goggles
- ½" PVC pipe
- 1", 2", and 3" PVC pipe
- Reducers: 3" to 1½", 2" to 1", 1½" to ½", and others as needed
- Sharpie Markers
- Towels for Clean-up
- 1" and ½" Ball Valves

For Assessments

- Strips of colored paper
- Copies of Formative Assessment #1
- Copies of Final Rubric

DAY 1 (20 MINUTES)

Read the following scenario to the students.

It is May and school is almost out! You start thinking about how great it is going to be to stay up late every night and sleep-in every morning. You just can't wait until the first day of summer when your life does not revolve around a schedule. You can go to bed when you want; you can eat what you want and when you want; you can play when you want; and you can get up when you want. Boy! That is the life! Wait….get up whenever you want…Oh no…that is not going to happen! Suddenly, you remember that last summer every Tuesday, Thursday, and Saturday you had to wake up at 4am to water the yard. Yes, your parents made you spend 2 hours, three days a week, early in the morning, moving hoses and water sprinklers around the lawn. Your parents are sticklers for water conservation and saving money. They have found that the best hours of the day to run a sprinkler system is from 4am-6am. So, they required you to water the lawn during these identified hours. You begin to remember how miserable you were waking up at 4am. You think about how wonderful it would be to have an automatic sprinkler system installed at your house. After all, last summer you saw the neighbor's sprinkler turn on and off automatically while everyone in the house slept peacefully. Wouldn't it be wonderful if a sprinkler system automatically turned on at 4am, went through each watering cycle, and then turned off automatically? You don't know how your parents will react to the proposition of installing a sprinkler system, but you decide to go ahead and try to convince them of the benefits of having an automatic sprinkler system. The next night before bed you discuss this with your parents. You tell them how miserable you were last summer, state the benefits of having an automatic sprinkler, and share with them how many of the neighbors have an automatic sprinkler system. Much

to your surprise your parents say they are open to the idea of getting an automatic sprinkler system installed. You can hardly believe it! They actually listened to you! The discussion continues for a few more minutes and then finally, they agree to have the system installed! How fantastic! Oh, but wait, they tell you this is contingent on a few things and you will find out about specifics of the plan in the morning. Specifics in the morning! Oh no….they have always been sticklers about details! You begin to wonder if getting up at 4am may be a better option. Nonetheless, you doze off to sleep. When you awake the next morning you notice an envelope with your name on the front. You grab the envelope, open it and begin to read.

At this point the teacher gives each student an envelope that contains the letter to the child (see Appendix for sample letter). Let the students either take the letter home to read or read the letter in class.

DAY 2 (50 MINUTES)

Start by showing the class the following images:

- http://www.missouribotanicalgarden.org/Portals/0/Gardening/Gardening%20Help/images/Pests/Pest2460.jpg
- http://www.outsidepride.com/blog/wp-content/uploads/2013/03/lawnUCVerde.jpg

Ask students to identify similarities and differences among the pictures. Students should notice one lawn is covered in green grass and the other has spots of brown and green. Conduct a discussion on how a sprinkler system can affect the appearance of a lawn and how the design of the system is a large factor in maintaining a lawn that looks nice. The discussion should address important concepts like:

- The placement of the sprinkler pipe in the yard
- The placement of the sprinkler heads in the yard
- The number of sprinkler heads used in the system
- How much water is released from each sprinkler head.

You could have the students discuss where they think the pipe and heads would be placed in the pictures previously shown. You could show different pictures of lawns and see where the pipe is laid and where the sprinkler heads are placed. You could also show pictures of a sprinkler system that is watering a lawn and ask students if they can figure out where the pipe is laid. The whole discussion must focus on the importance of the design of the sprinkler system. If more motivation is needed during the discussion, show them this video: https://www.youtube.com/watch?v=uBKCDHnxJZw#t=28 (03:08).

Next put the students in groups and give each group of students a professional sprinkler design. Some sample sprinkler designs are given in the Appendix section, but there are also examples on the internet. Have the students discuss, as a group, why the sprinkler pipe and sprinkler heads are placed as they are on the plan. Once each group has discussed the irrigation plan, distribute Formative Assessment #1 and have the students turn it in before they leave the classroom. A handout for Formative Assessment #1 is given in the Evaluation section of this PBL.

DAY 3 (50 MINUTES)

Conduct a discussion on the conservation of water and the role lawn irrigation systems play in the conservation of water. The discussion should surface concepts like the control of water flow (i.e. you don't want too much pressure or too little pressure), the strategic positioning of the sprinkler heads, and the time of day at which the automatic system can run. Follow this by showing students videos to help motivate the idea of lawn irrigation and the details of designing an irrigation system. Two possible videos are:

- https://www.youtube.com/watch?v=2UVoDRXx66Q (01:56)
- http://www.youtube.com/watch?v=mhZrzI0mNSo#t=257 (start at beginning but stop at 05:10)

After watching the videos, break into groups. In their groups have the students list three roles that sprinkler systems play in the conservation of water. Give each group of students a different coloured strip of paper and have the students neatly write the results of their discussion on the strip. They should write one idea per strip of paper. When the discussion period is over, have the students post their strips on a wall in the back of the classroom. Once all strips are posted, have a class discussion to share the ideas written on the strips of paper and sort the strips of papers so those that have the same theme are grouped together.

DAY 4 (50 MINUTES)

Allow students to research key topics online. There are at least two key concepts students should understand.

- The basic concept of hydrostatic pressure and the role that it plays in this PBL. Students need to know how hydrostatic pressure will help push the water through their irrigation system. Students should do a web search of simple videos that explain fluids and hydrostatic pressure. Here is a website in the event students are having a difficult time finding simple explanations of pressure due to fluids. http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/water-pressure/
- The features and purposes of each of the different pipefittings. Students need to research irrigation design. What parts are they going to use and how will each of these parts affect the flow of water within their irrigation systems? It will be helpful for them to go to a home improvement store (i.e., Lowe's, Home Depot) and look at the fittings. Alternatively, you could have some of the fittings and small pieces of PVC pipe available in the classroom for students to play with and see how they fit together. A list of necessary fittings is given in the materials list that is located in the Appendix section of this PBL.

DAY 5 (50 MINUTES)

During this time students will explore the functionality of a real sprinkler system. To do this you could invite a sprinkler contractor to class as a guest speaker and allow some time for students to ask questions. Ideally, this would be the same sprinkler contractor that will listen to the presentations of the students at the end of the PBL. If possible, the class could take a field trip to a job site where the contractor is installing an irrigation system. This would allow the students to see how the system is installed and ask the contractor questions. If a field trip is not possible, try to get some video footage of an actual sprinkler system being installed.

DAY 6 (50 MINUTES)

Once students have had the opportunity to research irrigation design and are familiar with the physical parts that make up the system, it is time for students to begin designing their irrigation systems. In this process students need to create a blueprint of the model houses they selected. The blueprints should be precise scale drawings of their model homes. Have students draw their blueprint on grid paper. Tip: Grid paper that has one-inch squares subdivided into a 10 × 10 grid work nicely. The blueprint should include the following:

- A drawing of the house and of each water container. Students need to measure the dimensions of the house and of each water container, paying close attention to the location of the water containers relative to the house.
- Labels of the dimensions of the house and of the water container.
- The location of the main water source.
- A legend that identifies icons used on the blueprint as well as scale factors (i.e. 1 square = 1 inch).

A final blueprint is shown in Figure 3 below. The blueprint the students construct during this day should not be as elaborate as the one shown in Figure 3. Rather, it should only have the items listed directly above.

DAYS 7–8 (50 MINUTES EACH DAY)

After the students have the model houses drawn on the blueprints, it is time for the students to draw the designs of the irrigation systems. During this stage, students need to consider the following items:

- Students should consider the irrigation fittings that are available. The supplies students will use can be found on the supplies page (see Appendix). Notice that most of the fittings allow only for 90 degree or 180 degree turns in the system. Students must consider these angles during the design stage.
- Students must be sure they plan for the pipe to stay on the exterior of the house. It is unreasonable, for example, to have pipe go over the house. In a real situation, sprinkler contractors do not bore pipe under the house. Sprinkler contractors bore under driveways and other small concrete objects, but not under an entire home. The pipe needs to remain outside the perimeter of the house and on the ground.

- Students need to think about how much water needs to flow to each water container. Some of the bigger water containers will hold more water (at a 1.25 inch depth) than others and will consequently need more water flow. Water flow can be managed by the size of PVC pipe used and the number of turns in the system. If the students design a linear system (i.e. no tees) then the water flow will be different at the start of the linear design (closest to the water source) than at the end.
- During the design stage, students need to plan where each water orifice will be placed and how many orifices will supply each water container. Discussion should also take place about the size (in diameter) of each orifice and the distance between each orifice, especially if there will be more than one orifice feeding one water container.
- Students need to think about where they are going to put the pipe relative to the water container. Are they going to design the pipe to go through the center of the water container or are they going to place it more toward the edge?

Once students have an idea of their irrigation designs and all the intricacies of the designs, they need to draw the irrigation designs on the blueprints. Students should use some icon to show where all the orifices will be located on the irrigation system and also label the linear measurements of the system. Figure 3 contains a sample blueprint. In the sample blueprint different colors are used to represent a different aspect of the design. For example, black lines could represent the borders of the house, green lines the borders of the water containers, and blue lines the location of the pipes that will be carrying the water. The blueprint also contains a unique name for each water container and displays the volume of water each container will hold if the water level is 1.25 inches.

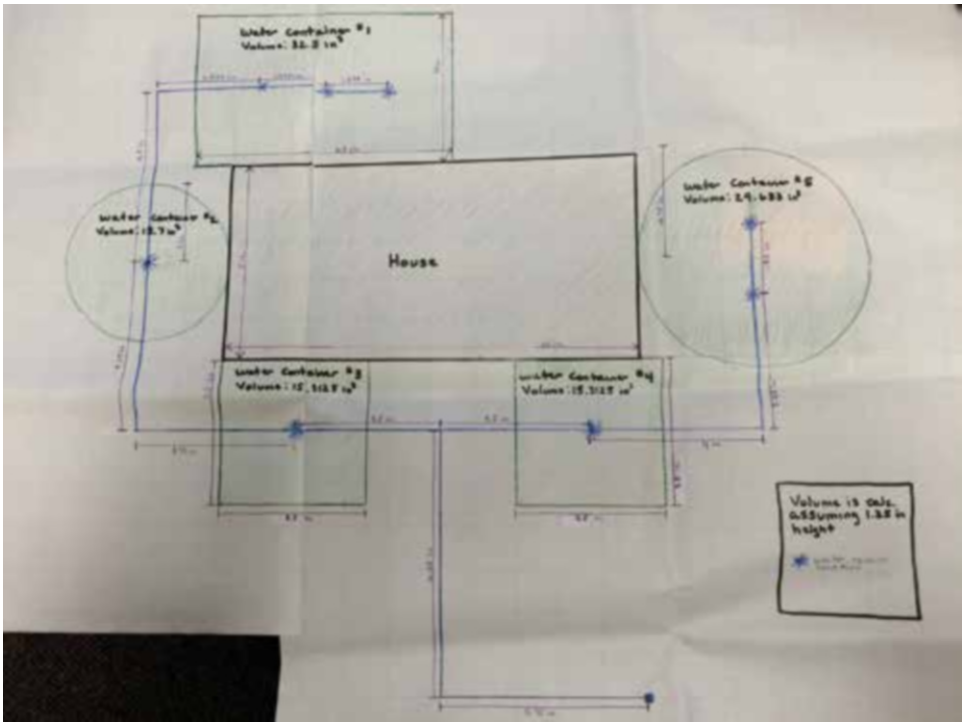


Figure 3. Sample Blueprint of Sprinkler Design

Once students have the designs of the system completed, they need to calculate the items listed below:

- The total amount of pipe they will need (in linear feet).
- The total number of fittings they will need to construct the system.
- The total cost of the system (based upon the prices in the supply list that is provided to them). Students will use the Irrigation PBL Customer Invoice sheet to help them calculate the total cost of their system. See Evaluation section of this PBL for Invoice handout.
- The total amount of water (in cups) they will need to start with to ensure each container has 1.25 vertical inches of water in each container. This will involve a conversion from cubic inches to cups (students can figure this conversion factor on their own).

When students are finished with all aspects of the blueprint they should take their blueprint and the Checklist For Blueprint (see Appendix section) to at least 2 other groups for evaluation. Each group should have the blueprint peer reviewed – via the checklist – by at least 2 other groups.

DAYS 9–10 (50 MINUTES EACH DAY)

Students will build the systems they designed in the blueprints. Students will measure and cut the PVC pipe as indicated on the blueprints. Students should go through several iterations of measuring pipe, cutting pipe, and then making sure that they can lay the pipe over the containers and the Lego® house to ensure their construction is practical. Some adjustments may need to be made during this phase so their configuration of pipes matches the configuration of the Lego® house and containers. The students should wait to glue the final products together in the event changes are necessary to make the products operational. Once the final products are glued together, students can put the holes in the PVC pipes as planned on the blueprint. Figure 4 shows an example of a pipe configuration that fits the layout shown in Figure 1.

Figure 4. Example pipe configuration that cooresponds to sample blue print shown above

DAY 11

After the students have designed their irrigation systems it is time to put them to the test. Each group – one at a time – will take the plastic bin that contains their Lego home and lay their irrigation system over the containers that will hold the water. Then the group will measure the amount of water that was previously calculated to run one cycle of the system and put the water in the main water source. Once all water is in the main water source, the group will turn the value and let the system run through its cycle. When the system has finished running the cycle, the teacher will measure the water depth in each water container and record it for each group. Ideally, the irrigation contractor should be at this presentation to rate the design and operation of the system.

EXTENSION

There are a number of different extensions you can provide for students.

- For most students, they should use ½" pipe for their whole project. For students who are more advanced, you can allow them to mix the sizes of pipe for their project. This will require students to think about how water will flow in the different sized pipes and what happens to the flow of water when the pipe size changes (i.e. what happens if they change from 1" pipe to ½" pipe, how the change affects the water flow).
- For most students, the teacher should have the water main constructed for them so they can focus on the sprinkler design. But, for students who are more advanced, you could have the students construct their own main water source.
- Advanced students could figure the scale factor of their models and then figure the amount of materials needed for the large-scale designs. Additionally, they could construct the full "bid" for the sprinkler system and use the computer software a contractor uses to design their systems. IRRICAD is an example (http://www.irricad.com/).
- Students could research the effects of friction on water flow through the pipes. After the research they could discuss how the concept of friction was involved in their designs.
- Students can research how pressure affects the rate of flow within the system.

EVALUATION

Final Product Rubric

Category	4	3	2	1
Resembles the Design	90%–100% of the final product follows the design of the blueprint.	80%–89% of the final product follows the design of the blueprint.	70%–79% of the final product follows the design of the blueprint.	69% or less of the final product follows the design of the blueprint.
Materials	For the entire project, appropriate materials were selected.	For most of the project, appropriate materials were selected.	For some of the project, appropriate materials were selected.	For most of the project, inappropriate materials were used.
Care During Construction	Great care was taken in the construction process so that the structure is neat and follows plans accurately.	Construction was careful and accurate for the most part, but 1-2 details could have been refined to improve the product.	Construction accurately followed the plans, but 3-4 details could have been refined to improve product.	Construction appears careless or haphazard. Many details need refinement.
Accuracy of Measurements	The total amount of pipe used is the same amount calculated on the blueprint.	The total amount of pipe used is not the same as the amount calculated on the blueprint; it is off by 10%.	The total amount of pipe used is not the same as the amount calculated on the blueprint; it is off by 20%.	The total amount of pipe used is not the same as the amount calculated on the blueprint; it is off by more than 20%.

Functionality of the Final Product Rubric

Category	4	3	2	1
System Accesses all Water Containers	The system distributes water to all of the water containers.	The system distributes water to all BUT one of the water containers.	The system distributes water to all BUT two of the water containers.	The system did not distribute water to three or more of the water containers.
Water Level of Each Water Container	The system distributed 1.25" of water to all of the water containers.	The system distributed 1.25" of water to all BUT one of the water containers.	The system distributed 1.25" of water to all BUT two of the water containers.	The system did not distribute 1.25" of water to three or more of the water containers.
Amount of Water at the Water Main	The system had the exact amount of water in the water main to run the system.		The system had too little or too much water in the water main to run the system.	
Amount of Time to Run One Cycle of System	The amount of time it took for the system to run through one cycle was very reasonable.	The amount of time it took for the system to run through one cycle was reasonable. One adjustment could have made the system run more efficiently.	The amount of time it took for the system to run through one cycle was somewhat reasonable. Two adjustments could have made the system run more efficiently.	The amount of time it took the system to run through one cycle was not reasonable. Major improvements are required for the system to run efficiently.

Design of the System Rubric

Category	4	3	2	1
The Blueprint	Lines are clear and not smudged. There are almost no erasures or stray marks on the paper. Color is used carefully to enhance the drawing. Overall, the quality of the drawing is excellent.	There are a few erasures, smudged lines or stray marks on the paper, but they do not greatly detract from the drawing. Color is used carefully to enhance the drawing. Overall, the drawing is good.	There are a few erasures, smudged lines or stray marks on the paper, which detract from the drawing OR color is not used carefully. Overall, the quality of the drawing is fair.	There are several erasures, smudged lines or stray marks on the paper, which detract from the drawing. Overall, the quality of the drawing is poor.
Checklist for Blueprint	3 other groups completed the Checklist for Blueprint.	2 other groups completed the Checklist for Blueprint.	1 other group completed the Checklist for Blueprint.	No other groups completed the Checklist for Blueprint.
Modification/Testing	Clear evidence of troubleshooting, testing, and refinements based on data or scientific principles.	Clear evidence of troubleshooting, testing and refinements.	Some evidence of troubleshooting, testing and refinements.	Little evidence of troubleshooting, testing or refinement.

Formative Assessment #1

After you have listened to another group's presentation list three reasons why the sprinkler pipes and heads were placed as they were on the irrigation plan.

1.

2.

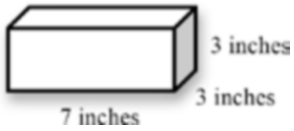
3.

Multiple Choice Problems

1) Sally had a sprinkler pipe that was 3.5 feet long. She wants to cut this piece of pipe into four equal pieces. Where should she make the first cut on the pipe?

   A) The first cut should be made at 7/8 of a foot.
   B) The first cut should be made at 7/16 of a foot.
   C) The first cut should be made at exactly 1 foot.
   D) The first cut should be made at 1/4 of a foot.

2) Find the volume of the three-dimensional container below.



   A) 21 cubic inches
   B) 63 cubic inches
   C) 13 inches
   D) 9 cubic inches

3) Which of the following are ways in which automatic sprinkler systems help with water conservation?

   A) Water in 2-3 short cycles rather than a single long period of time.
   B) There are numerous accessories (rain sensor, smart controller, etc.) that can be added onto sprinkler systems to help prevent the system from running when unnecessary.
   C) Program the system to run in the early hours of the morning.
   D) All of the above.

4) A rectangular block of length 8 cm and width 4 cm has a volume of 96 cm^3. What is the height of the block?

   A) 32 cm
   B) 3 cm
   C) 8 cm
   D) 54 cm

5) For every 33 feet (10.06 meters) you go under water, the pressure _____ by 14.5 pounds per square inch (1 bar).

   A) Decreases
   B) Increases

Correct Answers: 1-A 2-B 3-D 4-B 5-A

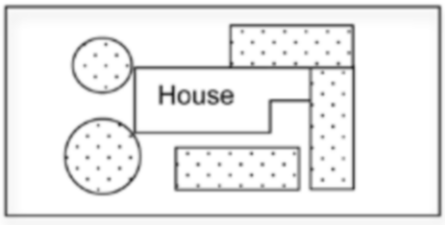
APPENDIX

Letter to Child

To our dear and sweet child;

We are thrilled that you have approached us with the idea of installing an automatic sprinkler system. This could be a great thing for all of us involved. For us to finalize this deal, however, we want you to use this as a learning opportunity. We want you to design and build a model of an irrigation system for a scale-model of a house. Here is how it will work:

We will give you a box that contains a Lego®-constructed house and other containers that are fixed to the box. These containers represent the sections of the lawn that need to be watered and will hold the water that is dispensed from the irrigation system. Here is a possible configuration of the house and containers you may see.



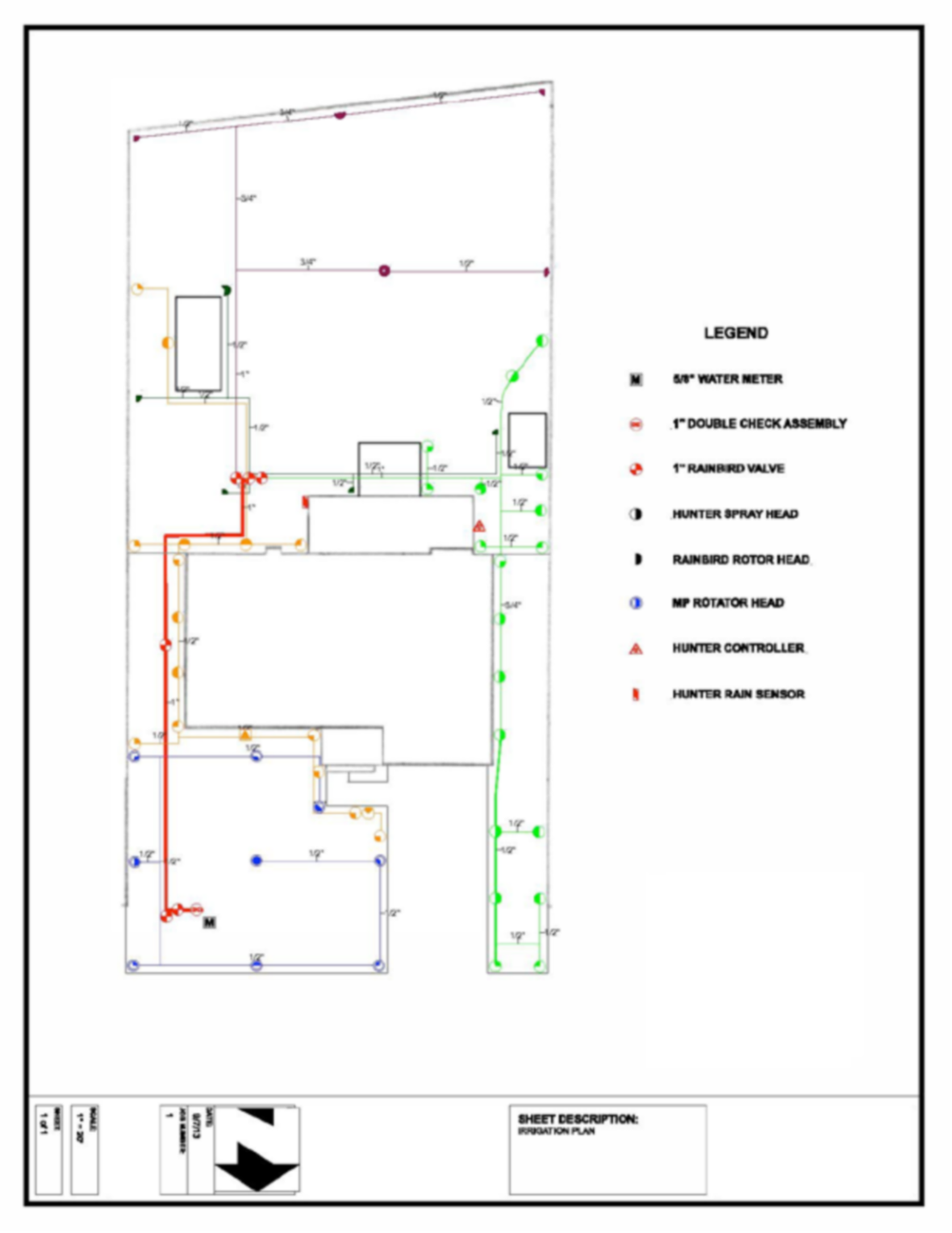
You told us that one benefit of an irrigation system is that it can spread water uniformly across a given plot of land. Thus, you must design an irrigation system that disperses water as uniformly as possible to each of the different containers. You may only use hydrostatic pressure and the earth's gravitational pull as the force to move the water and cannot make any adjustments to the containers in the given rectangular box. We will give you a list of materials you can use for the project and their corresponding prices. You may only use materials listed on this supply list. You must minimize the cost and adhere to the prices given on the supply list. You must design the system so the water depth in each container is 1.25 inches. You will have a main water source that will hold all the water you will use for one cycle of the irrigation system. When you run the irrigation system through the cycle, you will fill your water main with a pre-calculated amount of water. Then you will turn the valve so that the water runs through your system and consequently fills each water container. You must record how long it takes your irrigation system to run through one cycle and try to minimize the amount of time it takes to uniformly disperse the water.

Once you have finished your irrigation system (i.e. designed, built, tested, and refined your system), you will present your irrigation design to an irrigation contractor and justify your design (i.e., why did you design it the way you did). With the irrigation contractor present, you will run your irrigation system through one cycle. Once the cycle is complete, you will measure the water level (height) for each container and report to the contractor how accurately your irrigation system dispersed the water.

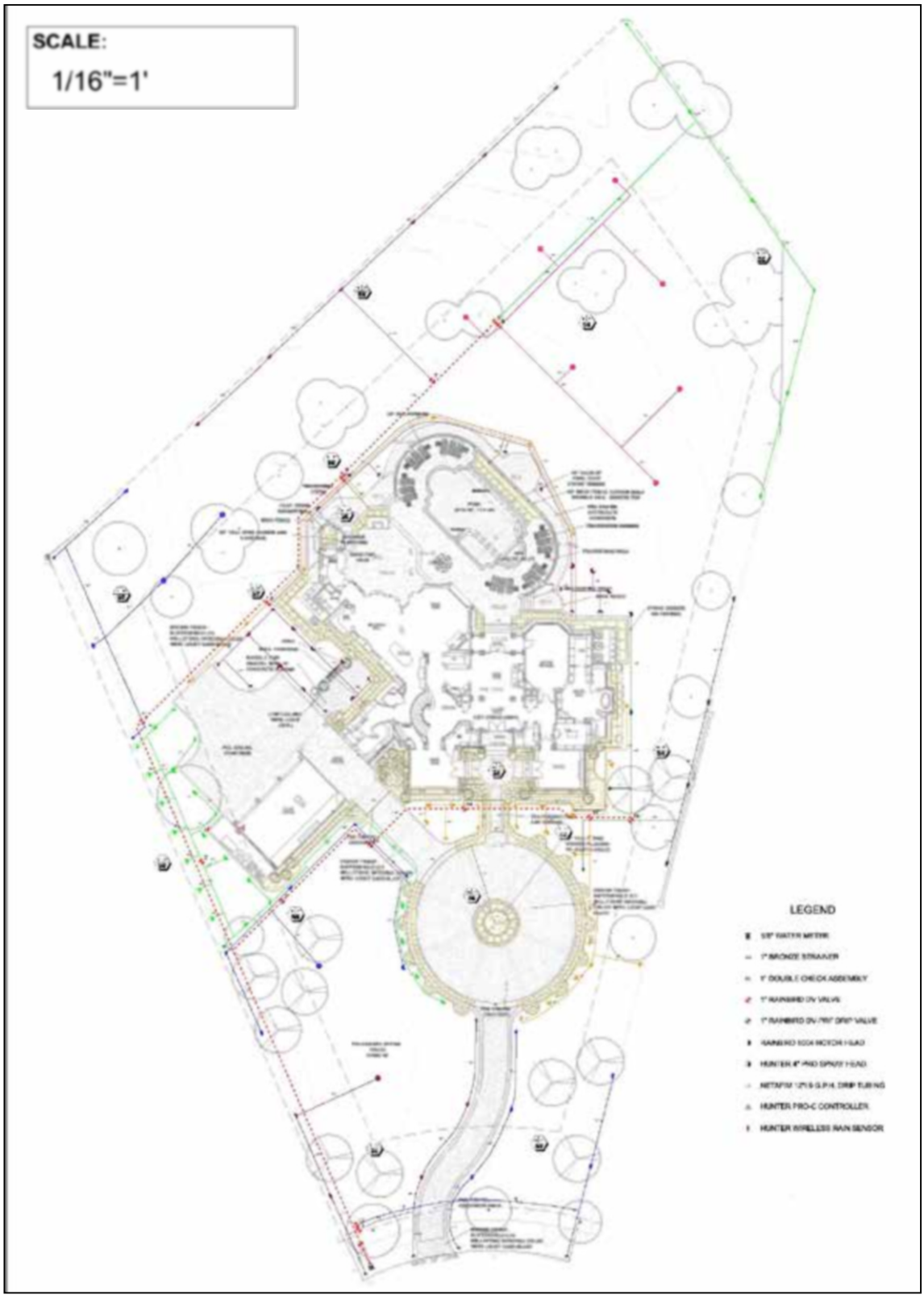
If the irrigation contractor is convinced that your irrigation system is well designed, then we will pay the irrigation contractor to install the sprinkler system. If the irrigation contractor is not convinced your irrigation system is well designed, then you will have to help the contractor install the system so you can better master the details regarding irrigation design and construction.

With Love,
Mom and Dad

Professional Sprinkler Design #1



Professional Sprinkler Design #2



Materials List

Item	Unit cost
½” 90 degree Slip Elbow	$0.19
½” 45 degree Slip Elbow	$0.58
½” 90 degree Side Outlet Elbow	$1.18
½” Coupling	$0.29
½” 90-degree Tee	$0.35
½” Cap	$0.35
½” 90-degree Cross Tee	$0.98
½” PVC Pipe (1 linear foot)	$0.20
½” PVC In-line Ball Valve	$2.52
¾” 90 degree Slip Elbow	$0.35
¾” 90-degree Cross Tee	$1.79
¾” 45 degree Slip Elbow	$0.74
¾” Coupling	$0.35
¾” 90-degree Tee	$0.42
¾” Cap	$0.42
¾” PVC Pipe (1 linear foot)	$0.26
¾” PVC In-line Ball Valve	$3.05
¾” x ½” Bushing	$0.39
½” x ½” x ¾” 90-degree Tee	$0.71
1 ½” x ½” Bushing	$0.88
3” x 1 ½” Adapter Coupling	$3.72
2” x ¾” Bushing	$0.98
1 ½” x 3” Adapter Coupling	$3.72
3” x 2 ft. PVC-DWV Pipe	$6.28
Primer and Glue charge	$1.50

Sample Customer Invoice

Date	Order No.	Sales Rep.	FOB	Ship Via	Terms	Tax ID

Quantity	Item Description	Unit Price	Total

Subtotal:	
Tax:	
Miscellaneous:	
Balance Due:	

Checklist for Blueprint

Once you believe your blueprint is complete, take your drawing and this checklist to at least 2 other groups and have them check for the following items:

BP=blueprint	Yes	No
1. The BP contains the drawing of the house and is labeled as such on BP.		
2. The drawing of the house on the BP is accurate (measured correctly).		
3. The drawing of the house on the BP is precise.		
4. The BP contains drawings of all the water containers.		
5. The drawing of the water containers on the BP is accurate.		
6. The drawing of the water containers on the BP is precise.		
7. The dimensions of all house measurements are labeled on the BP.		
8. The dimensions of all water container measurements are labeled on the BP.		
9. The volume of water that each water container will hold (depth = 1.25”) is labeled.		
10. The location of the pipe is drawn on the BP.		
11. The length of each section of pipe is labeled on the BP.		
12. The location of the orifices are drawn and labeled on the BP.		
13. The total amount of pipe (in linear feet) is displayed on the BP.		
14. The total number of fittings they will need to construct the system is displayed on BP.		
15. The total amount of water (in cups) necessary to run the system is displayed on the BP.		

REFERENCES

For help creating rubrics try http://rubistar.4teachers.org/index.php
A simpler version of this PBL is found at http://tryengineering.org/lesson-plans/irrigation-ideas
Special thanks to the owner of Raintec Irrigation Systems for helping with this PBL. http://www.raintecirrigationsystems.com/
Videos and other resources to help with concepts within this PBL:
- https://www.youtube.com/watch?v=2UVoDRXx66Q
- http://www.youtube.com/watch?v=mhZrzI0mNSo#t=257
- http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/water-pressure/

ENVIRONMENT

LINDSEY OSEGUERA, MATTHEW J. ETCHELLS AND
JENNIFER G. WHITFIELD

16. CARBON FOOTPRINT REDUCTION

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5
Engagement and research	Engagement and research	Begin working on presentations	Student presentations	Student presentation

WELL-DEFINED OUTCOME

Identify at least three items that are thrown away on a daily basis and create a plan that will eliminate these items from city landfills.

TEACHER INTRODUCTION

This is a project-based learning assignment designed for 7th and 8th grade students of all abilities. This project is versatile and can be adjusted to meet the needs of any student. This project will both inform students of the issues that carbon footprints leave as well as engage them in finding solutions to the problem. Students will think about how much they contribute to their own carbon footprint and find solutions to reduce or eliminate some of these factors. Students will work in groups and use brainstorming, critical thinking, and team-building skills in order to complete this assignment. Students will also use computers, cameras and printers. Knowledge of how to properly utilize these materials is also required. This project enlightens the students about their effects on the environment in which they live. The assignment allows students to work together to create their own solutions to the problem with minimal necessary guidance. This encourages the students to solve the issue by using critical thinking and problem solving skills. The students also are given the task of creating an oral presentation to share their findings with the rest of the class, which greatly enhances communication skills.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- Describe the carbon footprint problem and identify at least 3 ways they are contributing to the carbon footprint problem.
- Display solutions and explain/justify how they formulated their solutions.
- Formulate solutions to eliminate or reduce toxins that contribute to the carbon footprint problem.
- Determine reasonableness of solutions posed by other students.

Math – The student is expected to:

- Calculate the average effects these solutions will have on the city, state, country, and worldwide.
- Calculate the averages of how many times each group member throws away the chosen items in the span of one week.
- Calculate the cost increase or reduction that these changes will create.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 139–143.

English Language Arts – The students is expected to:

- Create a list of items the student and teammates use and throw away on a daily basis.
- Create an oral presentation of solutions and results.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Technology

- Utilize resources in order to gain further knowledge.
- Use cameras, computers, and printers in order to convey the visual aids necessary to strengthen the argument.

Problem solving

- Use brainstorming and critical thinking skills in order to find problems and accessible solutions through group discussion.
- Trial and error within group discussion using theoretical approaches.

Communication

- Use professional and clear language in order to present ideas to teammates.
- Project orally in order to present the project to classmates.

STUDENT INTRODUCTION

How can you reduce your "carbon footprint"? There are many ways in which we can make a difference in the world. One is preserving our environment and reducing waste production. Think of how many times you throw items away in the trash on a single day. Did you know that you can help reduce these problems with a few minor adjustments to your daily life?

MATERIALS USED

For student research

- Journals
- Pencils
- Computers
- Cameras
- Printers
- Markers
- Scissors
- Glue/Tape

For student presentations

- Poster board

Assessment

- Project rubric
- Oral presentation rubric

DAY 1 (50 MINUTES)

Introduce the topic of "carbon footprints" by showing an informative video of the effects that this issue has created on the environment and living organisms. A brief 15–20 minute video should suffice; however, this can be extended depending on how long it takes the instructor to explain the procedures of the project. The following link is a great video suggestion that explains the origins of our contribution to carbon emissions; https://www.youtube.com/watch?v=VTfgNFz1DBM (09:59). After viewing the video, a class discussion should be held to talk about what is being done to help reduce different areas of carbon production; examples include electric cars, recycling efforts, etc. A discussion of the severity of this issue should also be included. This will help the students think of ways they can also contribute to the efforts. Once this introduction has been completed, the instructor is then able to introduce the project. Students should then be assigned to groups of 3 or 4 students to work. The explanation of the project and assembling groups should take the remainder of the class period.

DAY 2 (50 MINUTES)

Students should begin the class period brainstorming with their groups about what they use and throw away on a day-to-day basis that is contributing to their carbon footprints. Their individual and group contributions should be logged in their journals along with how many times a week they throw away the specific items. The students will then be able to choose the items that they would like to modify or eliminate (minimum of 5 items). Students will then calculate the averages of how many times each group member throws away the chosen items in one week. This information should be used to figure the average of the number of items used in one month, one year, and 10 years. Another calculation that needs to be addressed is the cost differences that these accommodations will make. Will the accommodations cost the individual more than they would by simply staying with their original habits, or will this in fact cause the individual to save money? If students wish to bring in objects for their poster boards, this should be done today and brought to school the next class period.

DAY 3 (50 MINUTES)

Today students should be working on their poster board presentations. Students who did not bring their objects may use computers to print pictures that correspond with their accommodations. Students will complete their posters and oral presentation scripts by the end of the class period.

DAY 4 (50 MINUTES)

Students should be given a short period of time to finish their posters as well as prepare for their oral presentations. After the groups have completed this, the presentations may begin! Each presentation should be no less than 5 minutes, but no more than 6 in order to get through the presentations within two class periods.

DAY 5 (50 MINUTES)

Today should be the last day of presentations. If time permits, showing another video or documentary of the efforts being made to reduce carbon and waste production would be useful to show students reduction efforts on a larger scale.

EXTENSION

Students can take the assignment further by inventing a product that will help reduce carbon wastes. The invention may be explained in an essay along with a picture of the product, or the student may create a model of the product at home and do a 3-minute oral presentation of the invention in front of the class in addition to the original group project. Students may also choose to investigate the carbon footprint of a large corporation and if they are taking any actions to reduce this issue.

EVALUATION

Oral Presentation Rubric			
	Exemplary 15	**Developing 12**	**Introductory 9**
Delivery	The student uses direct eye contact and seldom glances at notes. Speaks clearly with inflection and emphasizes key points. Shows mastery knowledge and understanding of the subject.	The student speaks with satisfactory variation of volume and inflection. Uses direct contact for most of the presentation. Glances at notes occasionally.	The student seldom glances up at the audience to make eye contact. Heavy reliance on notes. Voice inflection is minimal. The student does not show complete understanding of the subject.
Content/ Organization	The student provides clear purpose and uses pertinent examples to further explain his or her argument. The student is fluid in the presentation of topics and information.	The student is mostly at ease with the presented topics. The chosen content is mainly essential to the argument. The student has a general understanding of the topics being provided.	The student is uncomfortable with the information being presented. The evidence and content being provided is insufficient and does not support ideas or conclusions.
Conclusion	The information the student provides significantly enhances and enforces the audience's understanding of the topic. The student answers any questions the audience may have with effective and informative responses. The student displays enthusiasm throughout the entire presentation.	The student provides some interesting points during his or her presentation. The student is able to answer questions the audience may have with brief explanation. The student shows enthusiasm about a few of the points given.	The student has difficulty explaining key points of the presentation. The student shows minimal enthusiasm about the topic. The student's understanding of the topic is less than satisfactory. Improvement is needed with explanatory skills.
Grade Calculation: Project Rubric Points: _____ + Oral Presentation Points: _____			TOTAL =
Project Rubric			
	Exemplary 15	**Developing 12**	**Introductory 9**
Visual	The student contributed high effort and skill towards the final product. The project is well organized and meets expectations. Illustrates main points.	The student showed effort in creating the project. Most visuals support the content of the presentation.	The student showed minimal support in creating the project. Visuals do not meet expectations. Needs improvement on organization.
Content	The student showed great detail in journal entries and provided the group with many great ideas. All research materials the student provided were essential to completing the project.	The student has collected and contributed several ideas to the group that were utilized. Journal writings may be incomplete or slightly under expectations.	The student has not contributed much, if any, useable research ideas for the group. The student's journal is incomplete and vague. Needs improvement in research and recording skills.

Calculations/ Results	The student has participated in all of the mathematical calculations that were required. All calculations are correct and fulfil the requirements. The student worked to ensure the accuracy of the results.	The student participated in most of the calculations. The student somewhat collaborated with the group to assist in result findings. One or two of the results may be inaccurate.	The student gave minimal assistance to the group in calculating the results of the project accommodations. Some of the results may be incorrect. Needs improvement in accuracy and collaboration.
Use of class time/ Teamwork	The student remained on task throughout the project. The student showed leadership and was an asset to the group.	The student coordinated with the group often. Moderate contributions were made. The student stayed on task for the majority of the project.	The student occasionally had trouble staying on task. The student provided limited contributions to the group. Communication skills need improvement.

REFERENCE

What you can do about climate change: https://www.youtube.com/watch?v=VTfgNFz1DBM

ANTONIA KETSETZI AND MARY MARGARET CAPRARO

17. RENEWABLE ENERGY SOURCES

SCHEDULE AT A GLANCE

Days 1–2	Days 3–4	Days 5–6	Days 7–8	Days 9–10
Discuss impact of energy; videos; info table	Teams evaluate sites and its renewable energy potentials	Determination of the proper RES system and its components	System design initiation and installation in a poster design	Presentations

WELL-DEFINED OUTCOME

Students will explore the Renewable Energy Source (RES) options for their state and design a poster depicting realistic facilities that produce energy for their home with maximum energy efficiency by combining at least two renewable energy sources (RES).

TEACHER INTRODUCTION

Through its energy and climate policies, the U.S. has set recently a number of ambitious goals (e.g. by 2020 the share of renewable energy sources should increase to 20% of total energy consumption). At the same time the use of RES in the U.S is still significantly low compared to the European Union (EU). Therefore, it is particularly important to support information flow, raising awareness, and involvement of organizations in RES research and technology demonstration projects. The U.S. currently relies heavily on coal, oil, and natural gas for its energy. Fossil fuels are non-renewable, that is, they draw on finite resources that will eventually dwindle, becoming too expensive or too environmentally damaging to retrieve. In contrast, many types of renewable energy resources – such as wind and solar energy – are constantly replenished and will never run out. At the beginning of the project, the middle school teacher will talk with students about their experience with this topic and briefly present the energy problem (warming, high costs, sustainability) and the global map of RES vs fossil fuels.

The purpose of this project is for students to identify and understand all these factors and the impact of RES on their everyday lives. Furthermore, students need to understand the origins, uses and limitations of these resources, while examining the advantages and disadvantages of their long-term use. Topics that students can further explore include RES options for their home state, RES contributions to total U.S. energy consumption during this period of time, social/economic benefits from RES, and how RES systems work for generating energy ("Know how"). With this in mind, the students will be able to understand that the first step in solving the energy problem is saving energy and the second step is knowing the possible renewable energy for each region. Students will be able to make their final decision about the plan they need to follow for designing an efficient RES system for their home.

In this PBL, students will work in teams to identify alternative-renewable energy sources (wind, solar, water [hydroelectric wave power], geothermal, and biofuels) and research and debate the advantages and disadvantages, while also exploring correlations with sustainability and environmental protection. Students will create a poster depicting their RES designs as a proof of RES effectiveness in society. As an extension to this project, students should consider the ethical/social/economic impact of the use of RES by creating an electronic brochure raising public awareness of RES and presenting their findings to city officials. The project will take approximately ten days to complete, and the team groups will need to select a house and investigate all the appropriate parameters needed for designing their RES (measure the area of the property, locate the best places to install the RES system, make appropriate calculations).

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 145–153.

Mathematics – The student is expected to:

- Select and use appropriate units, tools, or formulas to measure and to solve problems involving length, surface area, time, temperature, volume, and weight.
- Measure angles, length, area, time, temperature, volume, and weight.
- Use a problem-solving model that incorporates understanding the problem, making a plan, carrying out the plan, and evaluating the solution for reasonableness by collecting, organizing, displaying, and interpreting data.
- Use ratios to describe proportional situations.
- Estimate and round to approximate reasonable results and to solve problems where exact answers are not required.
- Select or develop an appropriate problem-solving strategy from a variety of different types, including drawing a picture, looking for a pattern, systematic guessing and checking, acting it out, making a table, working a simpler problem, or working backwards to solve a problem.

Science – The student is expected to:

- Identify the major sources of renewable energy and research and debate the advantages and disadvantages of their long-term uses.
- List the origins and uses of these resources enabling informed decision making.
- Discuss how energy can be changed in order to create energy we use every day and apply those principles to his or her home RES design.
- Discuss the ethical/social issues surrounding Earth's natural energy resources.
- Design a logical plan to manage energy resources in their home.

Social Studies – The student is expected to:

- Explain how excessive use of non-renewable energy sources has led to energy crisis, environmental pollution, and resource depletion.
- Investigate the energy map of RES and identify the potentials of their state.
- Raise public awareness about the beneficial use of RES while also exploring with sustainability and environmental protection.
- Identify a situation that requires a decision, gather information, identify options, predict consequences, and take action to implement a decision.

English – The student is expected to:

- Use pre-writing strategies to generate ideas, develop voice, plan and design.
- Organize ideas in writing to ensure coherence, logical progression, and support those ideas.
- Design a brochure, poster, or another formats in order to draw a design.

Geography, Economics and Environment – The student is expected to:

- Explain factors that influence economic development and sustainability.
- Identify the potential uses of RES depending on the geographic area.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Engineering

- Use a problem-solving engineering design process to identify a problem, gather information, list and consider options, consider advantages and disadvantages, choose and implement a solution, and evaluate the effectiveness of the solution.

– Identify the high cost of energy, and based on the energy consumption of his or her house, minimize this cost through his or her RES home design system.

Technology

– Design a brochure with Power Point® or other software.
– Process data and communicate results in digital format and take pictures and insert them in a document.
– Use the Internet and send emails.
– Demonstrate effective file management strategies such as naming, folder structure, and emerging digital organizational strategies.

STUDENT INTRODUCTION

The cost of energy has become larger and larger. The city commission is trying to find solutions to minimize the costs of electrical bills. The mayor wants to establish an energy plan to utilize the variety of options of the RESs in the area and learn the "know how" from other states in the U.S. that already use RESs. For that reason he is looking for a collaborative scientific team that will travel along the coast of the U.S. He has chartered a boat (one that uses the power gained from an RES), and he is waiting for the team to come aboard. The mayor and his team are planning to visit some cities along the U.S. coast and share ideas, new technologies, and business ventures. Their continuous professional interactions with other mayors and stakeholders will also be emphasized to stimulate the direct and indirect communication between organizations from other states and raise awareness about the importance of sustainable energy based on a wide field of renewable energy. Students will form teams and identify two RESs available for a home. Teams will follow a design methodology with five steps in order to accomplish their designs. There will be no cost limitations, but there will be energy efficiency preferences. Teams will present their final tables and explanations to justify the particular design that was chosen, as well as descriptions of the RES parts of their poster boards. Through research and exploration, teams will design a poster depicting a realistic facility that produces energy to demonstrate their increased awareness of RESs. The student research teams are also expected to discuss and debate with other teams in order to demonstrate the effectiveness of their RES house facility designs. As an extension, students can design an electronic slide show to present their findings to the city commission and create an electronic brochure that will be published in a local newspaper to increase awareness of RESs environmental and economic impact.

Students should also be aware of the design methodology in order to adhere to the following steps:

– Initial discussion and understanding the system's requirements (Days 1–2)
– Evaluation of the site and its renewable energy potentials (Days 3–4)
– Determination of the proper RES system and its components (Days 5–6)
– System design initiation and installation in a poster design (Days 7–8)
– Presentation of posters explaining the design and the benefits of their system designs (Days 9–10).

The teacher will introduce and give more detail concerning these five steps during the day identified next to each step above.

MATERIALS USED

– Computers with internet access
– Microsoft Power Point®, Excel® and Word®
– Manual of REN21
  – (http://www.ren21.net/) and
– Manual of International Renewable Energy agency
  – (http://irena.org/remap/REmap_Report_June_2014.pdf)
– Poster boards, paper, markers, map pencils, rulers, protractor
– Past electrical bills
– Camera (pictures of their poster)

– Tables to be filled with students' data
– Tape measure

DAYS 1–2 (45 MINUTES EACH DAY)

In order to generate interest in the project the teacher will start an open discussion about the impact of energy consumption in our everyday lives. Teachers should ask students if there is any way to save money on their home's monthly electrical bills. Before starting the dialogue about the topic, teachers should motivate students about the important role they need to play in this project. By designing their posters they will raise public awareness of the topic. As part of the extension, they can create an electronic brochure for the city commission. Teachers should create a dialogue to develop student interest in discovering the types of RESs by engaging them in the energy problem and environmental protection policies. Teachers can show two short videos about environmental pollution, the types of renewable energy and also introduce students to a webpage that gives the meaning, history, and introduction of renewable power:

– https://www.youtube.com/watch?v=sW7fxGG9cEM (10:48)
– https://www.youtube.com/watch?v=mIj8EuEJ8FY (5:55)
– http://energyquest.ca.gov/movieroom/index.html

During this exploration students will seek answers to questions such as: Why is renewable energy important? What kinds of problems can RES solve? How many kinds of RES exist? How do RESs generate energy? The teacher will allow brainstorming, and students should use the time to write down all of their ideas. It is important to develop a common understanding of the sources of energy needed in every type of RES and think of what is needed. For that reason the teacher can draw a chart on the board for students to copy in their notebooks. Students will engage in a teacher led discussion while filling in the chart. Figure 1 shows a sample table for this exploration.

	Source of energy	How
Solar resources		
Wind energy		
Water: Hydro power+waves		
Geothermal		
Biofuels		

Figure 1. Sample RES Information Table

The teacher should ask students to share experiences they have had with RESs. Teachers should also engage students with global aspects concerning RESs by briefly presenting the energy problem (warming, high costs, sustainability) and the global map of RESs vs. fossil fuels. Students should fill in the above *RES Information Table* either individually or in groups.

DAYS 3–4 (45 MINUTES EACH DAY)

At the beginning of class, present the story in the Student Introduction. After the story, the teacher should divide students into research teams what will help the city mayor. Each team will have an open discussion about available RESs at their site, discuss the system requirements, identify the benefits of this design, and then determine how the design can be implemented. The process of system design begins with understanding the requirements for the renewable system and the basic components. This is key to determining the best system for both performance and cost savings. This requires that students understand the RES usage requirements and electricity demands which can be obtained by reviewing their prior electric bills. The second step is for students to find the available renewable resources at their site.

The student teams should understand that their task as a research team is to help the mayor establish an energy plan for their area of interest. The purpose of each team is to prove to the mayor (and extend to society) through their poster designs of the RES facilities of their homes that every house in the area has the potential for RES home installations. Students should be ready to come aboard the RES boat and explore together with the mayor all the potential ideas and possible limitations. The research teams should

begin to adopt a plan by following the system design methodology. During this step students will choose the appropriate materials and RES components (photovoltaic panel, wind generator etc.) for the final determination of the proper system. Students should fill in the RES Materials and Design Components Table shown in Figure 2.

RES needed for the design	Materials and components	Installation measurements

Figure 2. Sample RES Materials and Design Components Table

DAYS 5–6 (45 MINUTES EACH DAY)

At this point each team should be ready to start their RES design. During this stage, teachers need to explain that the design must be realistic and efficient. For that reason, students will have to take measurements of their properties to ensure their homes can accommodate the RESs and that the home is in an appropriate location. Students should remember that the measurements and RES locations must be clearly depicted on their posters. Students need to identify the places needed for assembly of the RESs on their home properties, keeping in mind building limitations and energy efficiency.

At this time, the research teams are expected to identify, depending on the geographic area, the RES options of their site. They will conduct research via the internet. After each research team determines the available RESs, they will (again) fill in the data required in the table shown in Figure 1. Teams need to recognize the limitations or opportunities at their site to effectively combine the RES systems in the design for their home. For that reason, the students will also use the internet (a renewable interactive map, http://map.ren21.net/) to explore the terrain limitations and RES potentials. The results will help with the analysis of their sites to find the proper RES solution. Students will discuss and explore the origins and uses and limitations of these resources while examining the advantages and disadvantages of their long-term uses. They will summarize their findings in the RES Advantages and Limitations Table shown in Figure 3 and determine the combination of two RESs to achieve a more energy efficient design. They will also need to choose one of the available houses. Every research team should start working on this particular house. Order is irrelevant; students may start with the house and then search the RES options of their particular house.

	Area	Advantages	Disadvantages-Limitations
Solar resources			
Wind energy			
Water: Hydro power+waves			
Geothermal			
Biofuels			

Figure 3. Sample RES Advantages and Limitations Table

DAYS 7–8 (45 MINUTES EACH DAY)

Students will brainstorm ideas and methods for designing the proper RES house system and sketch sample designs. They will also search the internet to find the "know-how" of similar problems. They will determine the energy consumption of the house by analyzing the electrical bill and researching the appropriate materials and RES components (photovoltaic panel, wind generator, etc.). The previous day the students will have taken installation measurements and pictures from the house property in order to construct realistic designs.

After the students are satisfied with their system designs, they will create presentations. They will need to demonstrate how their systems work and answer any questions about their operation. Also students need to design a poster explaining their designs and focus on system benefits for environmental and energy saving to raise public awareness. Students should be free to make their plans and discuss ideas within their teams.

Each team should be ready to create their posters for their RES system installation design. They will need to place all the appropriate RES components on their poster design in order for the RES facility to be realistic. For example, if one of the appropriate RESs for the house is solar energy, then the photovoltaic panel will need to have the appropriate installation specifications (e.g., angle, position with the sun) in order to output the maximum efficiency. If necessary, the students will have to add extra information to the poster with all the extra characteristics of the design (e.g., position of components, angles, amount of energy saving, symbols of north/south orientation, building limitations).

DAYS 9–10 (60 MINUTES EACH DAY)

Research teams will make poster presentations of their final product that last no longer than 20 minutes. This will take at least two class periods. They will present their final tables, explanations for the reasons a particular design was chosen, and descriptions of the RES parts on their poster boards. Students should make important connections with environmental issues, economic development and sustainability. The research teams are also expected to discuss and debate with other teams in order to demonstrate the effectiveness of their RES house facility designs.

EXTENSION

As an extension of this project, student teams can create an electronic slide show and a brochure with their findings to present to the city commission in an attempt to increase public awareness of RESs.

Additionally, those students who have more interest in the topic can search and provide future strategies and an action plan for achieving sustainable development in communities for the needs of future generations. These future plans, as well as future energy sources, can additionally be included in the brochure (mentioned above). Students can generate ideas for future energy sources after watching the video https://www.youtube.com/watch?v=uStFvcz9Or4 (13:11).

EVALUATION

Project Design Formative Rubric

	Below Expectations	**Meets Expectations**	**Exceeds Expectations**
Design specifications	Design does not meet the specifications.	Design meets most of the specifications.	Design meets all specifications.
Appropriate measurements and RES components	Inappropriate field measurements and RES components used.	Satisfactory field measurements with few errors and basic RES components used.	Appropriate field measurements and RES components used.
Justification	Inadequate justification.	Adequate justification.	Outstanding justification; all design decisions justified.
Oral presentation	Severely lacks detail.	Adequate details presented.	Extreme attention to detail during presentation.

Project Design Summative Rubric

	Below basic (0–1 pt.)	**Meets basic (2–3 pts.)**	**Exceeds basic (4–5 pts.)**
Scientific accuracy	Minimal scientific concepts with little explanation provided.	Some scientific concepts related to energy are discussed and explained.	All scientific concepts related to energy are clear and explicitly explained.
Findings & Engineering plan	Data and results are incomplete and inconclusive, and the plan lacks sufficient details and steps.	Data and results are complete and conclusive, and the plan contains sufficient detail and steps.	Data and results are complete, accurate, and neatly organized, and the plan is logical with easy-to-follow steps.
Content & recommendations	Content is irrelevant, recommendations are illogical, and limitations are not included.	Content is relevant, recommendations match the stated problem, and 1–2 limitations are listed.	Content contains all components, recommendations are comprehensive, and 3–4 limitations are listed.
Graphics & relevance	The design does not meet the energy efficiency criteria, is incomplete, and no constrains are followed.	The design applies to average energy efficiency and follows only a few of the requirements.	The design applies to maximum energy efficiency and fits into the required parameters of the project.
Group Work-participation	Difficulty with others; students do not share decisions/ responsibilities and were off task frequently and required redirection	Works with others but has difficulty sharing decisions/responsibility and was poorly engaged in most of the project.	Works very well; assumes a role in decisions and follows through, and students were actively engaged throughout the project.
Visual quality and quality of explanations	Poster is messy and incomplete, and explanations are unclear, inaccurate, and incorrect.	Poster is well organized and clean but not visually stimulating, and explanations are mostly accurate but difficult to follow.	Poster is well organized, clean, and visually appealing, and explanations are clear, accurate, and easy to understand.
Creativity	Ordinary design with poor combination of the two RESs and without any big ideas.	Ordinary design but with a great combination of the two RESs; contains many big ideas.	Innovative design with great combination of the two RES smart ideas.
Time	The oral presentation was poor and exceeded the time limits by more than 5 minutes (too long or too short).	The oral presentation as well as the whole design was too long or too short by 5 minutes.	The oral presentation as well as the whole design was finished on time.

Extension Rubric for the Electronic Brochure

Category	Exemplary–4	Mastery–3	Proficient–2	Introductory–1
Language use	Highly developed essay with well-organized assumptions, findings, conclusions, and 0–2 writing mistakes.	Well- developed essay with well-organized assumptions, findings, conclusions and 3-6 writing mistakes.	Well- developed essay but not well-organized assumptions, findings, conclusions, and more than 10 writing mistakes.	Essay is poorly developed without any organization.
Communication	Main points and conclusions are clear.	Most of the main points are covered with few conclusions	Conclusions are somewhat lacking, but the main points are still evident.	Main points do not appear to be fully covered and no conclusions are provided.
Focus	Students fully explain and show many aspects of the impact of RESs on society as well as possible future RES ideas.	Students stay on task while explaining some of the RES impacts on society without suggestions for the future.	Students are off task and show few aspects of RES impacts on society without accurate explanations.	Students are not focused and not sure of the impact of RESs on society and give no explanations.
Format	Essay contains 5 paragraphs with detailed explanations, pictures, and tables.	Essay contains 4 paragraphs with satisfactory explanations, pictures, and tables.	Essay contains 2 paragraphs with few explanations, pictures and tables.	Essay contains only one paragraph without pictures and tables.

Rubric for Electronic Slide Show

Category	Exemplary–4	Mastery–3	Proficient–2	Introductory–1
Visuals	Highly developed transparencies, slides, text, pictures or video.	Visuals help to clarify and illustrate main points. Presentation is interesting.	Lack or a poor choice of visuals but linked to main points.	Visuals are poor and do not support the main points.
Organization	Appropriate amount of material is prepared, clear objectives, logical structure.	Material included is relevant, with few clear objectives, logical structure.	Material included is relevant, but with no clear objectives, logical structure.	Material included is mostly irrelevant, and lack logical structure.
Content Knowledge	All information in the extension project is accurate.	Most of the information in the extension project is accurate.	Some of the information in the extension project is accurate.	The extension project contains irrelevant information.
Body posture	Student stands with confidence, with eye contact with the public, and is familiar with the presentation and its organization.	Student stands with confidence, with eye contact with the public but sometimes talks to the computer or floor.	Student is nervous and talks too quietly but conveys the important ideas of the presentation.	Student is clearly nervous and unsure of the presentation, talks to the floor, and is hard to hear.
Presentation fluency	Technical terms are well defined, student makes minimal pauses, and handles disruptions or questions.	Technical terms are defined; student makes several pauses and is side tracked by questions.	Technical terms are not well defined; student has difficulty with words and is easily side tracked.	Student is not familiar with the presentation and consistently stumbles over words.

Multiple Choice Questions

Answer the questions by choosing only one answer:

1) What energy sources are considered to be renewable?

A) Solar energy, nuclear energy, wind energy, biomass, and natural gas
B) Wind energy, solar energy, water, biomass, and geothermal energy
C) Biogas, wind and solar energy, water and gasoline.

2) When you begin to design a renewable facility, what things you need to take into account?

A) Simplicity/maintenance
B) Energy requirements /energy consumption
C) Power Efficiency/area limitations
D) All of the above

3) What are the criteria for sustainable development?

A) Environmental protection-ecosystem integrity
B) Social equity
C) Economic vitality
D) All of the above

Correct Answers: 1-B 2-D 3-D

REFERENCES

https://www.youtube.com/watch?v=qigImQK8B3s (Solar School projects)
http://vimeo.com/7541320 (example of PBL for Teachers)
http://www.renewableenergysys.com/system-design
http://www.dallasisd.org/Page/863
http://www.uwsp.edu/cnrap/KEEP/Documents/RE_in_Building_Science_Conceptual_Framework_Final.pdf
http://www.apsva.us/Page/7851
http://www.projectsharetexas.org/search-standards?&external_1=2663&external_2=3469&external_3=All&page=1
Middle school (6–8 grade): (http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112b.html)
Math: http://ritter.tea.state.tx.us/rules/tac/chapter111/ch111b.html
Science: http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112b.html
Social science: http://ritter.tea.state.tx.us/rules/tac/chapter113/ch113b.html
USA department of Energy: http://energy.gov/eere/office-energy-efficiency-renewable-energy
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The energy problem: http://web.mit.edu/fnl/volume/196/schreiber.html
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Green house ideas
http://www.navarino.org/Renewable%20Energy%20Brochure%20on%20the%20Building%20addition%20--%20letter%20size.pdf
Types of photovoltaic panels
– http://www.solar-facts.com/panels/panel-types.php
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– http://centurionenergy.net/types-of-wind-turbines
Types of Geothermal Systems
– http://www.greenearthenergy.com.au/geothermal/
– https://www.youtube.com/watch?v=sbiq_yd-znM&feature=pyv&ad=11568750823&kw=environment
Components of a small hydro-electric system
– http://www.homepower.com/articles/microhydro-power/basics/what-microhydro-power
– https://www.youtube.com/watch?v=fYfs-qYGzvs

LESLIE THOMAS

18. THE MODERN WORLD

Plastic Pollution Shown through Fibonacci Numbers

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5	Days 6–10
Exploration and research Fibonacci numbers	Exploration and research	Share and continue research	Student inquiry on plastics	Field trip to plastics factory	Design, make, and present project

WELL-DEFINED OUTCOME

Students will create a visual project demonstrating the use of the Fibonacci numbers and the Golden Ratio in nature by reusing the plastic materials found within the community.

TEACHER INTRODUCTION

This project-based learning assignment is proposed for students who are currently in or have previously taken a Geometry class. The project's goal is to connect science, math, engineering, and technology to the real world by introducing the students to the Golden Ratio and Fibonacci numbers along with the hazards of plastic pollution. The students will use their knowledge of fractions, decimals, angles, area, and basic arithmetic to grasp the concepts of the Golden Ratio. They will then use their observation skills to see how they are seen in nature. In turn, the students will research about the effects of plastic pollution's impact on the environment; brainstorm ways to reduce the harm. Finally, the students will create and present to the class an art project displaying their knowledge on Fibonacci numbers and plastic pollution to bring awareness, by communicating their ideas to the class.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Mathematics – The student is expected to:

- Describe the pattern associated with the Fibonacci numbers and state the first 15 Fibonacci numbers.
- Explain how the Golden Ratio is found.
- Communicate mathematical patterns and explain why these are true through written or oral proofs of words, numbers, and drawings/diagrams.
- Illustrate patterns within the Fibonacci sequence.
- Apply the Golden Ratio and the Fibonacci sequence to nature.

Science – The student is expected to:

- Identify and provide examples of the Fibonacci numbers and Golden Ratio in nature.
- Research the effects of plastic in nature and the plastic pollution problem.
- Use problem-solving techniques to formulate a solution to the plastic pollution problem.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 155–161.

English – The student is expected to:

- Present the final project according to the rubric
- Determine the new vocabulary and concepts about Fibonacci numbers, Golden Ratio, and pollution with which they are not familiar.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Learn about the properties of plastics
- Evaluate the effects of plastic on the environment
- Identify patterns of the Fibonacci sequence and the Golden Ratio in nature
- Learn Reduce, Reuse, Recycle Methods

Technology

- Use the computer and other resources to research about Fibonacci, nature, and pollution

Engineering

- Collaborate well with peers
- Develop strong and informative project through allocation of time and resources

Mathematics

- Use basic algebra skills when working with Phi (Φ)
- Use a protractor and find the angle when a circle is divided by Phi
- Use addition, subtraction, multiplication, and division in order to work with fractions and decimals
- Explain and prove the mathematical ideas within the project
- Show ideas through visual elements
- Understand the concepts of Phi
- Observe the patterns within the Fibonacci sequence

STUDENT INTRODUCTION

Americans alone create about 200 million tons of trash each year (www.epa.gov), 10% of which is plastic (www.ecowatch.com). Plastics take 10 to 1,000 years to decompose depending on the type of object (www.recycling.about.com), but as plastics break down, animals, such as birds and fish, consume them or get trapped in them. These animals starve to death because their stomachs are full of plastic. How can we clean up the earth and prevent the albatross being starved because its stomach is full of plastic? How do we keep the bits of plastic in the ocean out of the stomachs of the fish we consume ourselves? In this PBL you will research the plastic pollution in the world and discuss how to combat the problem. You will also learn about the Fibonacci sequence and the Golden Ratio, which can be found everywhere in nature, from the number of petals on a flower, to the body structure of humans, to the spiral on a shell. You will then incorporate your research of the Fibonacci sequence and plastic pollution to create a visual project, which you will present, reusing plastic materials from the community to illustrate the plastic pollution dilemma in the world. You will transform the plastic from a destructive force into a beautiful and informative piece of art.

MATERIALS USED

Research

- Computers
- School Library
- Nature

– Journals
– Pens/Pencils

Project Design

– Paper (Graph, Printer, and Lined)
– Writing Utensils (pencils, pens, markers)
– Rulers and Protractors

To Build the Art Project

– Plastics from the community
– Hot glue gun and glue sticks
– Acrylic Paint
– Scissors/ X-Acto knives
– Pieces of cardboard for students to mount their project (optional)

For Assessments

– Research Assessment Form
– Copies for Final Rubric

DAY 1 (50 MINUTES)

The teacher can begin the class with a sunflower, holding it up and getting the students to describe its features. If an actual sunflower is not available, then display a picture of a sunflower from the internet. The students should discuss the number of petals on a sunflower. After the students have guessed, give them 4 answer choices, one being the correct answer (34, 55, or 89 depending on the size of the sunflower) and the other 3 answer choices not being a Fibonacci number.

So how does this relate to mathematics? Play Arthur Benjamin's TED talk "The magic of Fibonacci numbers": https://www.youtube.com/watch?v=SjSHVDfXHQ4 (06:24). After watching the video, the students and teacher can explore the Fibonacci numbers and its patterns, making it a game. Here is an example:

– Start with 0 and 1 and make the next number the sum of the previous two.
– Is there a pattern with the even and odd numbers within the sequence?
– Choose any three consecutive Fibonacci numbers. Multiply the first by the third. Square the second. Repeat this for other groups of three.
– Choose any four consecutive Fibonacci numbers. Multiply the first by the fourth. Multiply the second by the third. Repeat for other groups of four.
– If F_1 = the first term, F_2 = the second term, F_3 = the third term and so on:
– Find the sum of the first four terms. Compare the total with F_6.
– Add the first five terms. Compare the total with F_7.
– Add the first six terms. Compare the total with F_8.
– Without adding, find the sum of the first 12 terms.

For the rest of the class period, the students should research more on the places in nature where Fibonacci numbers are found. The students should be prepared to discuss the findings of their research at the beginning of Day 2. If the students have pictures to support their research for the next class, tell them to have the pictures prepared to show the class as they explain. Here is a resource that the students can use throughout their research on the Fibonacci sequence: http://yozh.org/2010/11/11/nature-by-numbers/

DAY 2 (50 MINUTES)

The teacher can begin class by holding up a nautilus shell, or an image of that shell, and ask the students to describe its features. The students should be encouraged to inquire how this shell relates to the Fibonacci sequence.

The students will share with the class on what they found in their research about where Fibonacci numbers can be found in nature.

Play Vi Hart's video on Fibonacci Numbers:
Vi Hart Fibonacci Part 1: https://www.youtube.com/watch?v=ahXIMUkSXX0 (05:54)

The teacher can have the students draw spirals using Vi Hart Fibonacci Part 1. The students should continue to explore Fibonacci numbers on their own and know how to approximate the Golden Ratio/Phi. This is a resource that the students can use to help them understand the approximation of Phi through Microsoft Excel®: http://www.mathsisgoodforyou.com/worksheets/fibonacciexcel.pdf

DAY 3 (50 MINUTES)

The teacher can begin the class with a plant branch, holding it up and asking the students to describe its features. The students should inquire how this branch relates to the Fibonacci sequence. Review with the class regarding the angles between each leaf (137.5/222.5).

The students will share their research about Fibonacci numbers, the Golden Ratio and Phi with the class.

Play Vi Hart's videos on Fibonacci Numbers:
Vi Hart Fibonacci Part 2: https://www.youtube.com/watch?v=lOIP_Z_-0Hs (06:13)
Vi Hart Fibonacci Part 3: https://www.youtube.com/watch?v=14-NdQwKz9w (06:06)

The teacher can have the students draw an exact flower with a protractor after watching Vi Hart Fibonacci Part 3. As a conclusion on the research on the Fibonacci sequence show the students this video on how it all ties together: https://www.youtube.com/watch?v=P0tLbl5LrJ8 (03:43).

The students should continue to research the Fibonacci sequence. They can even explore the musical aspects of the numbers, through Solfeggio Frequencies:
http://www.somaenergetics.com/forgotten_in_time.php#How%20Did%20The%20Solfeggio%20Frequencies%20Get%20Lost.
http://themindunleashed.org/2014/03/miracle-528-hz-solfeggio-fibonacci-numbers.html

DAY 4 (50 MINUTES)

The teacher can begin the class with a box of plastics that the class has collected from around the school property and their homes for a week. The class can discuss the variety of objects that have plastics, from the typical plastic bag to a toothbrush. The discussion can shift toward how this amount of plastic is affecting our world today. Play "It's A Plastic World" video: https://www.youtube.com/watch?v=n5KMGZHyUk8 (04:51)

The students will research and discuss:

- How much plastic are we putting into our environment?
- What are the effects of this plastic in our environment?
- How does plastic help and hurt our lives as humans?
- How does the plastic life cycle affect our economy?
- What are some actions we can take to reduce the amount of waste we produce?

DAY 5 (50 MINUTES)

The teacher can began class with showing "The Story of the Bottled Water": https://www.youtube.com/watch?v=-Zn0qi80IIY (08:04). The class can discuss the economic effects of the plastic life cycle. Then the conversation can transition into the direct implications of plastic on nature. The teacher can show the students images and allow the students to do the same through their explanation.

Figure 1. Example of plastic consumed by a bird
Source: http://www.chrisjordan.com/gallery/midway/#CF000313%2018x24

The students can discuss what they have found from Day 4 Exploration.

A possible extension task is a field trip to a recycling plant to expose the students to the process of recycling plastics.

The class can discuss how to fix the plastic pollution problem. What are some ways we can reduce plastics in our lives? Are plastic water bottles necessary? Is the water you are consuming better for you? Could all of the plastic in our lives be causing cancer?
http://www.onegreenplanet.org/animalsandnature/10-ways-to-adopt-a-zero-waste-lifestyle/

DAY 6–10 (50 MINUTES)

The teacher assigns the students the overall project. The students can create any type of artistic presentation with the plastics collected from the community as long as that artistic presentation uses the Fibonacci sequence or Fibonacci numbers. The students must use the materials given some way throughout their project in order to inform the community on the hazards of plastic pollution. The students must also include the Fibonacci sequence, the Golden Ratio, or the angles of the golden ratio within their project. Allow the students one week to create their project and presentation.

Figure 2. Example of the type of project students' could design and make
Source: http://www.treehugger.com/natural-sciences/bioneers-2010-washed-ashore-art-exhibit-explores-plastic-pollution-with-giant-beach-trash-bird.html

EVALUATION

Formative Assessment Checklist

Objective	**Completed**	**Not Completed**	**Teacher's Comments**
Came well prepared to class, presenting the information acquired professionally.			
Researched the Fibonacci Sequence and presented the information in class.			
Researched the Golden Ratio and presented the information in class.			
Researched Phi and presented the information in class.			
Researched the effects of plastic in nature in depth and with excellent use of time given.			
Used problem-solving techniques to figure out what can be done about the plastic pollution problem.			
Determined the new vocabulary and concepts that the student is unfamiliar with.			
Participated in the engagement by coming prepared and giving input.			

Summative Assessment Checklist

Objectives	**Completed**	**Not Completed**	**Teacher's Comments**
Demonstrated knowledge on the Fibonacci numbers and the Golden Ratio through communication of the mathematical ideas, explaining with written or oral proofs.			
Illustrated patterns within the Fibonacci sequence.			
Identified the Fibonacci sequence and Golden Ratio in nature.			
Applied the information learned about Fibonacci Sequence and the Golden Ratio to how they are seen in nature.			
Presented the final project appropriately.			
Created an artistic presentation with the plastics collected from the community.			
Used in some way the materials given throughout their project in order to inform the community on the hazards of plastic pollution.			
Included the Fibonacci sequence, the Golden Ratio, or the angles of the golden ratio within the project.			
Completed the project within the given time constraints.			

REFERENCES

Shown in Class

Economic “The Story of the Bottled Water”: https://www.youtube.com/watch?v=-Zn0qi80IIY
General Fibonacci: https://www.youtube.com/watch?v=P0tLbl5LrJ8
Plastic Waste: https://www.youtube.com/watch?v=n5KMGZHyUk8
TED talk Fibonacci: https://www.youtube.com/watch?v=SjSHVDfXHQ4
Vi Hart Fibonacci Part 1: https://www.youtube.com/watch?v=ahXIMUkSXX0
Vi Hart Fibonacci Part 2: https://www.youtube.com/watch?v=lOIP_Z_-0Hs
Vi Hart Fibonacci Part 3: https://www.youtube.com/watch?v=14-NdQwKz9w

Other References

10 Fast Facts on Recycling http://www.epa.gov/reg3wcmd/solidwasterecyclingfacts.htm
22 Facts About Plastic Pollution (And 10 Things We Can Do About It) http://ecowatch.com/2014/04/07/22-facts-plastic-pollution-10-things-can-do-about-it/
An Abiding Ocean of Love: A Conversation with Chris Jordan. http://www.dailygood.org/story/493/an-abiding-ocean-of-love-a-conversation-with-chris-jordan-lisa-bennett/
Bioneers 2010: “Washed Ashore” Art Exhibit Explores Plastic Pollution with Giant Beach-trash Bird. http://www.treehugger.com/natural-sciences/bioneers-2010-washed-ashore-art-exhibit-explores-plastic-pollution-with-giant-beach-trash-bird.html
How Long Does It Take Garbage to Decompose? http://recycling.about.com/od/Resources/fl/How-Long-Does-It-Take-Garbage-to-Decompose.htm
Khan Academy Golden Ratio: https://www.youtube.com/watch?v=5zosU6XTgSY&list=PL26812DF9846578C3&index=55
Midway: Message from the Gyre. http://www.chrisjordan.com/gallery/midway/#CF000313%2018x24
Turtles and Pollution: https://www.youtube.com/watch?v=uTfdkEtX2Po
Plastic pollution: https://www.youtube.com/watch?v=fddYApFEWfY

MIXTURES

LAURA REEVES

19. EXPERIMENTING WITH MODELING CLAY RECIPES

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5
Decide on a purpose for modelling clay, research modelling clay recipes and select one to use for the control batch and mix the control batch	Create the first test batch of modelling clay	Create the second test batch of modelling clay	Create the third test batch of modelling clay	Presentations

WELL-DEFINED OUTCOME

Decide on a purposeful use for modelling clay and make three test batches of modelling clay (all different) by adjusting only one ingredient from a given (control) recipe and explain how and why each test batch differs from the given (control) batch.

TEACHER INTRODUCTION

The purpose of this project is to analyze how changing the amount of one ingredient in a modelling clay recipe of flour, salt, water, and oil will affect the clay. The students should already know how to differentiate between elements, compounds, and mixtures, as well as justify that modelling clay is a mixture rather than an element or a compound. With this knowledge, students will work in groups of four to decide on a purpose for their modelling clay, research a modelling clay recipe for the control batch, mix test batches by changing the amount of one of the ingredients each time, see whether their test batches turned out as they predicted, and determine which batch worked best for their modelling clay's purpose. Each student group will address these issues throughout the project by participating in discussions, experiments, research, and a presentation of the group's findings. Students will keep a running record of the information they've collected on the PBL notebook questions sheets and daily formative assessments, on which the teacher will provide feedback at the end of each class period. (Students will also tape these sheets into their notebooks so they can refer to them throughout the project).

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- Design and implement experimental investigations by making observations, asking well-defined questions, formulating testable hypotheses, and using appropriate equipment and technology.
- Construct tables and graphs, using repeated trials and means, to organize data and identify patterns.
- Analyze data to formulate reasonable explanations, communicate valid conclusions supported by the data, and predict trends.
- Use appropriate tools to collect, record, and analyze information, including journals/notebooks, beakers, Petri dishes, meter sticks, graduated cylinders, hot plates, test tubes, triple beam balances, microscopes, thermometers, calculators, computers, timing devices, and other equipment as needed.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 165–171.

Mathematics – The student is expected to:

- Use ratios to make predictions in proportional situations.
- Select and use appropriate units, tools, or formulas to measure and to solve problems involving length (including perimeter), area, time, temperature, volume, and weight.
- Convert measures within the same measurement system (customary and metric) based on relationships between units.

English – The student is expected to:

- Follow multi-tasked instructions to complete a task, solve a problem, or perform procedures.
- Paraphrase the major ideas and supporting evidence in formal and informal presentations.
- Work productively with in a team.
- Participate in student-led discussions by eliciting and considering suggestions from other group members and by identifying points of agreement and disagreement.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Differentiate between elements, compounds, and mixtures.
- Design and carry out an experiment.
- Use equipment and resources appropriately.
- Use critical thinking and problem solving.
- Connect grade-level information to science careers.

Technology

- Sort between relevant and irrelevant information on the Internet.
- Research a topic through reliable Internet sites.

Engineering

- Design a product for a specific purpose.
- Collaborate with others to form a product.

Mathematics

- Take and interpret various kinds of measurements.
- Express a value as a number and a unit.
- Perform operations with fractions.
- Use appropriate tools and techniques to solve problems.
- Apply mathematics to everyday life.

STUDENT INTRODUCTION

You want to have some modelling clay to do a last-minute school project. Your parents don't feel like driving you to the craft store to buy some, so you decide to make your own clay instead. You search the kitchen for four required ingredients: flour, salt, water, and vegetable oil. If combined in just the right amounts, these four ingredients will make the perfect modelling clay. The perfect modelling clay allows you to create sculptures because the consistency of the modelling clay will hold the shape of the sculpture. However, you are neither sure of what the correct amount of each ingredient is, nor what makes modelling clay "perfect" for sculpting.

To explore these philosophical questions, you work together with three other people to: (1) decide on a purpose for your modelling clay (e.g. to roll into a ball, to make sculptures, to make holiday ornaments) (2) make a control batch of clay based on a given recipe, (3) make test batches of clay by arbitrarily changing the amount of one of the four ingredients in your original recipe, and (4) compare each test batch with the control batch. For each test batch of clay you will record your findings in your notebook. You and your group could approach this task however you want, whether you choose to experiment with a different ingredient each day or experiment with different amounts of the same ingredient. One thing you must do is keep the amounts of the other three ingredients as listed in your control batch recipe (i.e., for each test batch you can only change the amount of one ingredient). After recording all of your observations, your group will create and give a three-to-five minute presentation explaining the control (original) recipe you used, the changes you made to each test batch, what properties changed in each test batch when compared to the control batch. You must also present a case for which test batch made the best modelling clay for your group's specific purpose (e.g., make a sculpture, make a holiday ornament, etc.).

MATERIALS USED

Ingredients for modelling clay

- All-purpose flour
- Salt
- Water
- Vegetable oil

Tools to assist students with project:

- Measuring cups and spoons
- Bowls
- Plastic bags and permanent markers (for storing each group's control batch of clay from Day 1)
- Digital devices with Internet access
- Students' notebooks and pencils
- Scotch tape, PBL Notebook Questions, and presentation rubrics
- Projector connected to class computer
- Computers with Microsoft PowerPoint®
- Flash drives (onto which students save their PowerPoints)

DAY 1 (50 MINUTES)

To engage the students, the teacher will distribute small balls of modelling clay for students to play with as well as play a clip from Art Clokey's short film *Gumbasia* to show modelling clay's many properties: http://www.youtube.com/watch?v=gQL84yXnd4k (01:38). The teacher will then prompt a discussion about modelling clay. Discussion questions may include:

- What properties of clay make it effective and enjoyable for you to play with?
- How can you replicate those properties in your own batch of clay?
- What do you think would happen to the clay if you increased/decreased the amount of one of the ingredients – or if you left out the ingredient altogether?
- What are some real life purposes of modelling clay other than craft projects?

The teacher will then divide students into groups of four. First, student groups will decide on the purpose for which their modelling clay will be used and write that purpose in their notebooks. Then, using their devices, student groups will look up a modelling clay recipe using only flour, water, salt, and vegetable oil. Each student group will make a batch of clay according to the recipe the group has chosen; this batch is the group's control batch. Students will observe the properties (color, feel, level of shearing, etc.) of their control batch and record these observations in their notebooks (see Appendix for sample notebook layout). The group will then compare the properties of this control batch of those of all other batches they make throughout this PBL.

DAY 2 (45–50 MINUTES)

Each student group will choose one of the four ingredients in their control batch recipe and change the amount of that one ingredient from the control batch. It is very important that the students leave the amounts of the other three remaining ingredients the same. This recipe will be the student's first test batch of modeling clay. The students will make the first test batch, handle it to observe its properties, and record those properties on their PBL Questions Sheets for Day 2, which they will tape into their notebooks by the end of the class period. Through recording the properties of the control batch and the test batch, the students can compare the properties of the two batches and determine the effect that the changed amount of their chosen ingredient had on the clay. If students saved their control batch of clay, they may handle the control batch for comparison in addition to recording observations. Should any class time remain after a student group completes its first test batch, that group may either start on its next test batch or begin working on the PowerPoint® presentation. The grading criteria for the presentation are given in the Presentation Rubric that is found in the Evaluation section of this PBL.

DAY 3 (45–50 MINUTES)

Each group will now make at least one additional test batch of clay. Students will decide how this is done. They can either test an amount of another one of the four ingredients or test a different amount of the same ingredient chosen on the previous day. The students will make the second test batch, handle it to observe its properties, and record those properties on their PBL Questions Sheet for Day 3, which they will tape into their notebooks by the end of the class period. Through recording the properties of the control batch and the test batch, the students can compare the properties of the two batches and determine the effect that the altered amount of their chosen ingredient had on the clay. (If students saved their control batch of clay, they may handle the control batch for comparison in addition to recording observations.) Should any class time remain after a student group completes its test batch, that group may either start on its next test batch or continue working on its PowerPoint® presentation. Be sure students are aligning the presentations with the grading rubric for the group presentations (see Evaluation section of this PBL).

DAY 4 (45–50 MINUTES)

Each group will make the third and final test batch of modelling clay. The students will make the test batch, handle it to observe its properties, and record those properties on their PBL Questions Sheet for Day 4, which they will tape into their notebooks by the end of the class period. Students will continue to work on their PowerPoint® presentations for the rest of the period. If a student group does not finish creating the PowerPoint® presentation by the end of the class period, then the group members will need to meet to complete it. Be sure students are aligning the presentations with the grading rubric for the group presentations (see Evaluation section of this PBL).

DAY 5 (50 MINUTES)

Each group will present its 3–5 minutes PowerPoint® presentation. A rubric will be used by each student group, two student peer reviewers in the audience, and the teacher to determine how well each student group presented its findings on the effects of the changes it made in its recipes. This rubric not only evaluates the presentation, but also serves as a summative assessment for the project.

EXTENSION

Students who want to learn more about modelling clay's purpose and properties may research different types of modelling clays and their uses in various industries. Modelling clay is an oil-based clay that maintains the flexibility needed for sculpting. Paper clay (or fiber clay), on the other hand, contains bits of cellulose that increase the clay's strength; this kind of clay is used to create models of cars in the automobile industry. Students can use the websites that are listed in the Resources section in this PBL to aid in their research.

EVALUATION

Experimenting with Modelling Clay Rubric

Group Presenting: _____			Reviewer: _____		
	5	***4***	***3***	***2***	***1***
Time Limit of Presentation	Presentation is between 3-5 minutes long.	Presentation is 1 minute over or under time limit.	Presentation is 2 minutes over or under time limit.	Presentation is 3 minutes over or under time limit.	Presentation is more than 3 minutes over time limit.
Purpose of Modelling Clay	Purpose of modelling clay is clearly stated. Predicted and actual "best" batches for purpose are well justified.	Purpose of modelling clay is clearly stated. Predicted and actual "best" batches for purpose are justified.	Purpose of modelling clay is stated. Predicted and actual "best" batches for purpose are stated but not justified.	Purpose of modelling clay is stated but unclear. Predicted and actual "best" batches for purpose stated but not justified.	Neither the purpose of the modelling clay nor the predicted and actual "best" batches is stated.
Inclusion of Recipes and Changes Made	Presentation includes original (control) recipe and at least 3 other test batch recipes.	Presentation includes original (control) recipe and 2 other test batch recipes.	Presentation includes original (control) recipe and 1 test batch recipe.	Presentation includes original (control) recipe.	Presentation includes no recipes at all.
Differing Properties of Original v. Test Batches	Many different properties compared; possible reasons for changes in properties are well justified.	Many different properties compared; possible reasons for changes in properties explained but not justified.	Two properties compared; little explanation or justification.	Only one property is compared; no explanation or justification.	No properties are compared; no explanation or justification.
Effects of Alteration on Subsequent Test Batches	Predicted effects explained and well justified; clear comparison between hypothesis and observed result.	Predicted effects explained and justified somewhat; looser comparison between hypothesis and observed result.	Predicted effects explained but not justified; weak comparison between hypothesis and observed result.	Possible effects explained, but no comparison between hypothesis and observed result.	No justification or explanation; no comparison between hypothesis and actual result.
Ills	Eye contact throughout classroom; projected voice well; very few verbal pauses	Eye contact in some spots of classroom; voice audible; a few verbal pauses	Eye contact focused in one spot of classroom; voice quiet; verbal pauses somewhat interrupt flow	Eye contact focused in one spot of classroom; voice inaudible; verbal pauses greatly interrupt flow	No eye contact; voice inaudible; speech incoherent

APPENDIX

PBL Questions Sheets for Day #_____

Students,
As you work on your projects, answer these questions in your notebooks. Do this task for every test batch of clay your group makes in addition to recording other notes/findings. Note: I will check each day's entry before you leave class, so I can give your group feedback for improving your data collection.

Record your original (control) recipe and the day's test batch recipe below:

Original (Control) Clay Recipe	*Test Batch #__ Recipe*

For this test batch, which ingredient did your group change? _____

What is the amount of this ingredient in (a) your control batch and (b) your test batch? (Do not forget units!)

_____
_____

What were some properties you observed in each test batch of clay that differed from your control batch of clay? (e.g. was the test batch softer, drier, less stretchy, etc.?)

Original (Control) Clay Recipe	*Test Batch # ___ Recipe*

Why do you think the change in the amount of this ingredient altered the clay's properties?

_____
_____

Hypothesis for your group's next test batch:

If we change the _____ (name of ingredient) from _____ (original amount) to _____ (new amount), then our test batch of clay will become _____ than our original batch.

Purpose of modelling clay:

Predict which batch will work best for your clay's purpose. Justify your answer.

Now that your group has made the control batch and the three test batches, which batch worked best for your clay's purpose? Justify your answer.

REFERENCES

BMW Body Design Process: http://www.bmw.com/com/en/insights/bmw_design_2012/process/opener.html#row03
Brief History of Ceramic Clay: http://www.historyforkids.org/learn/arts/clay.htm
Creation of Gumby: http://www.gumbyworld.com/
Mold Making: http://stonebrashcreative.com/MoldTutorial.html
Overviews of Modeling Clays:
– http://www.wisegeek.org/what-are-the-different-types-of-modeling-clay.htm
– http://www.ehow.com/about_5038468_types-modeling-clay.html
Qin Dynasty Terra Cotta Soldiers: http://science.nationalgeographic.com/science/archaeology/emperor-qin/
BMW Body Design Process (with Paper Clay):
– http://www.bmw.com/com/en/insights/bmw_design_2012/process/opener.html#row03
Brief History of Ceramic Clay: http://www.historyforkids.org/learn/arts/clay.htm

ADRIANA LUNSFORD AND MARY MARGARET CAPRARO

20. QUALITATIVE AND QUANTITATIVE ANALYSIS OF WHITE POWDERS AND CLEAR LIQUIDS

SCHEDULE AT A GLANCE

Day 1	Days 2–3	Days 4–5
Read scenario to introduce PBL and discuss investigative techniques.	Students conduct the chemical quantitative and qualitative tests on powers and liquids.	Students test the unknown mixture taken from the crime scene.

WELL-DEFINED OUTCOME

Students will determine the composition of a toxicology sample composed of unknown white powders and clear liquids. Based on their findings, students will decide if the toxicology sample could be potentially lethal or harmful to humans or animals. Students will create a professional lab report, journal article, or toxicology report.

TEACHER INTRODUCTION

Students will conduct a variety of chemical qualitative and quantitative analysis tests to gather data about a variety of known white powders and clear liquids. The analysis techniques that will be discussed may include, but are not limited to: state of matter, physical properties, density determination, boiling point, melting point, chemical indicators, solubility, paper chromatography, pH, spectroscopy results, and reactivity. Results of the qualitative and quantitative tests7 on known compounds will give students a chance to practice the analysis techniques and identify the results for the variety of potential unknowns. Using that information, students will develop a flowchart, concept map, table, and/or dichotomous key to help them identify one or more unknown compounds. To successfully participate in this PBL, students should have had some high school level science courses and possibly even a year of high school chemistry, but no high-level chemistry content knowledge is required.

Students will use what they know about qualitative and quantitative analysis techniques in chemistry to determine the composition of a toxicology sample composed of unknown white powders and/or clear liquids. The unknown mixture will contain two or three white powders or clear liquids that the students analyze throughout the discovery and research process. Students will be able to use the observations, safety data sheets (SDS), and logic flow charts they create to help identify the components in the unknown mixture. The students will be assessed on whether or not they are able to identify the components of the unknown mixture and on their analytical process for achieving their results. In addition, students will use toxicology literature research processes to determine if the any of the white powders or clear liquids could be potentially lethal to humans or animals at varying concentrations.

Following the completion of their investigation, students will create a professional lab report, journal article, or toxicology report to discuss their experiences and demonstrate their knowledge in writing, along with a hypothesis about the likelihood that the substance was used for a criminal act that may have led to the deaths of individuals consuming the contaminated illicit drugs. Students will participate in laboratory experiences and discussion sessions.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- Use creativity and insight to recognize and describe patterns in natural phenomena.
- Design and conduct scientific investigations in which hypotheses are formulated and tested.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 173–180.

- Collaborate on joint projects.
- Demonstrate skill in the safe and appropriate use of a wide variety of apparatuses, equipment, techniques, and procedures for collecting quantitative and qualitative data.
- Use several modes of expression to describe or characterize natural patterns and phenomena, including narrative, numerical, graphical, pictorial, symbolic, and kinaesthetic.

Foundation Skills – The student is expected to:

- Use correct applications of writing practices in scientific communication.
- Set up apparatuses, carry out procedures, and collect specified data from a given set of appropriate instructions.
- Recognize scientific and technical vocabulary in the field of study and use this vocabulary to enhance clarity of communication.
- Prepare and present scientific/technical information in appropriate formats for various audiences.
- Use search engines, databases, and other digital electronic tools effectively to locate information.

Chemistry – The student is expected to:

- Use physical and chemical properties to describe and classify matter.
- Recognize and classify pure substances (elements, compounds) and mixtures.
- Classify chemical reactions by type and describe the evidence that a chemical reaction has occurred.
- Discuss the behavior of matter and the properties of its various states: solid, liquid, and gas.
- Apply properties of solutions.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Apply the properties of a variety of common chemicals that can often be found in the home.
- Consider the safety and toxicity of these various common chemicals.
- Analyze known compounds to create qualitative and quantitative data that can be used to help identify an unknown compound.

Technology

- Use technological resources to gather information about chemical compounds.
- Use technological resources to prepare an academic paper and/or presentation.
- Demonstrate knowledge about a variety of technological instruments and their use in academia, industry, and everyday life.

Engineering

- Solve a problem through the use of analytical skills and critical thinking.
- Provide evidence for conclusions made through an iterative and investigative process.

Mathematics

- Interpret various data, charts, and graphs that depict numerical information and/or trends.

STUDENT INTRODUCTION

The State Police Crime Lab was alerted to an abandoned warehouse that was believed to conceal a clandestine drug laboratory. The location of the warehouse was unusual and suspicious. Those involved in the act were believed to have been manufacturing and selling large quantities of illicit drugs as well as participating in violent criminal activities. During the raid of the warehouse, officers confiscated several large bags of suspicious white powders and bottles of clear liquids. Officers believe

the laboratory may have also been mixing the suspected drugs with other materials to improve profits. Recent drug overdoses and deaths in the area have been associated with the addition of potentially lethal contaminates to already potentially life threatening drugs. In order to prosecute the individuals responsible for operating the laboratory, the identity of the confiscated material must be accurately determined. The illicit drugs must be identified and characterized and it must be determined if there were any materials used to cut or dilute the drugs. In addition to identifying if any materials were being added to the illicit drugs, it must be determined if any of these additional materials could be harmful or lethal to anyone consuming the drugs.

MATERIALS USED

- White powder samples: ex. baking soda ($NaHCO_3$), borax/soap ($Na_2B_4O_7 \cdot 10\ H_2O$), salt (NaCl), sugar ($C_{12}H_{22}O_{11}$), etc.
- Clear liquid samples: ex. water (H_2O), 1.0M NaOH, 1.0M HCl, vinegar (dilute CH_3COOH), ammonia cleaner (dilute NH_3), etc.
- Safety and Data Sheets (SDS) for each chemical used
- Mass Spectrometry results for each chemical used
- Paper Chromatography: paper, development jars, pencils, rulers, solvents
- Physical Properties and Reactivity: well plates, disposable dropper pipets
- Density Determination: various glassware (graduated cylinders), balances, rulers
- Solubility: various glassware (graduated cylinders), balances, stir bars
- Melting/Boiling Point: Vernier temperature probes, various glassware, melting point apparatus, melting point tubes
- pH: Vernier pH probes, litmus paper, pH paper
- General Supplies: lab notebooks, pens, pencils, computers with appropriate software, printers, Internet

DAY 1 (120 MINUTES)

Provide the students with the scenario as described in the Student Introduction section above. While it could be simply provided as a document, instructors could further engage the students by reading it in a dramatic fashion or having a police officer or detective come into the classroom and present the scenario to the students. In addition to the scenario description, YouTube videos, newspaper articles, or movie/television scenes could be used to boost students' interest and engagement. Here are a few examples of short videos:

- "Behind the Scenes-Forensic Chemistry Lab" found at https://www.youtube.com/watch?v=bztlYwckmVE (03:30)
- "Follow your interest in forensics: Chemistry" found at https://www.youtube.com/watch?v=xVdfpY6ovVc (03:25)

The instructor will then lead a class discussion to help brainstorm ideas that students may have for the variety of methods that they might be able to use to identify an unknown white powder, clear liquid, or mixture of each. Questions such as "What would the results from that method tell you about the chemical composition of the unknown?" or "Is that a qualitative or quantitative test?" will allow the teacher to dig deeper into the students' prior knowledge and begin to plant the seeds of scientific thinking. The instructor should incorporate open-ended, probing, and guiding questions into the class discussion. Some possible open-ended, probing, and guided questions are:

Open-ended Questions

- What techniques might we be able to use to identify an unknown white powder?
- What techniques might we be able to use to identify an unknown clear liquid?
- What techniques might we be able to use to identify a mixture or powders?
- Would these techniques be the same as identifying a pure compound?

Probing Questions

- What would the results from that method tell you about the chemical composition of the unknown?
- What instruments or tools might we need to measure these properties?

Guiding Questions

– Is that a qualitative or quantitative test?
– Does it measure numerical or descriptive data?

After the class discussion, the instructor will identify various techniques that are more complex and may or may not have come up in the class discussion. They will be identified as techniques that the students will be instructed on and learn about so they can then use them as applications in the investigation. These techniques will include mass spectrometry and paper chromatography. Lecture PowerPoint® presentations can be created to provide students with the necessary content background information. In addition, the teacher should lead a short discussion on laboratory safety and personal protective equipment to reinforce safe practice throughout the course of this PBL activity.

DAYS 2–3 (120 MINUTES EACH DAY)

Students will be placed into groups of 2–4, depending on the size of the entire class as well as the number of materials and instruments available for use. Students should be given the guidelines and requirements for the completion of the PBL activity, as well as a list of chemical tests or concepts that can be used to help characterize their known compounds and identify their unknown mixture and substances. This list will include mass spectrometry, paper chromatography, physical properties, chemical reactivity, density determination, solubility, melting point and boiling point, and pH.

Provide the students with a "Chemistry Glossary," "Chemical Reactivity Guide," "Density Guide," "Solubility Rules Guide", and user manuals for the Vernier pH and temperature probes. See the References section of this PBL for samples of the glossaries, and manuals. These documents can be used for supplemental guidance and general information when investigating physical properties, reactivity, density, solubility, melting point, boiling point, and pH.

The teacher will provide samples of clear white liquids (e.g., water, vinegar, ammonia cleaner, etc.), and white powers (e.g., baking soda, Borax, salt, sugar, etc.) for the students to conduct the chemical quantitative and qualitative tests. The students must gather data from digital resources and interpret the results from the instrumental tests. The data, both qualitative and quantitative, must be documented in a laboratory notebook throughout the course of the investigation. By day four, the students must take the data that they have gathered and organize it into a flowchart, concept map, table, and/or dichotomous key to help them identify one or more unknown compounds.

Throughout the course of the activity, students should also be working on their professional lab report, journal article, or toxicology report to discuss their experiences and demonstrate their knowledge in writing, along with a hypothesis about the likelihood that the substance was used criminally and may have led to the deaths of individuals consuming the contaminated illicit drugs.

DAYS 4–5 (120 MINUTES EACH DAY)

Provide the students with an unknown mixture from the crime scene to test using the data they have collected during the qualitative and quantitative tests performed throughout the week. After determining the composition of their unknown mixture, students will continue working on their professional lab report, journal article, or toxicology report to discuss their experiences and demonstrate their knowledge of the unknown sample. Students should formulate a hypothesis about the likelihood the substance was used for a criminal act and whether the substance could have led to the deaths of individuals consuming the contaminated illicit drugs. If time permits, students can present their findings to the entire class in an oral presentation of their summative document.

EXTENSION

Extensions or expansions for this project can be varied in the level of complexity or area of emphasis. The Qualitative and Quantitative Analysis of White Powders and Clear Liquids PBL already has a few "extension" portions build into the project itself, which can be implemented on a smaller or larger scale depending upon the amount of time devoted to the entire project. The unknown mixtures that are provided to students during the final portion of the PBL can be either a white solid powder or a clear liquid. As an extension, these unknowns provided to students for analysis could be mixtures of white solid powders or clear liquids. Certain analyses can be performed on mixtures of materials, while others would need the unknown mixture to be separated into its components before those components could then be analyzed.

Instead of giving the students only one white solid powder or a clear liquid, students could be provided with both or multiple of either. This could make for a longer analysis portion of the project. Furthermore, having a variety of unknowns will emphasize some skills that are used frequently in analysis and other skills that are more specific to particular compounds. The students will gain extended experience the more unknowns or unknown mixtures that they test.

Another extension is to give students the opportunity use instrumental analytical techniques that are commonly used in research. Options could include mass spectrometry, infrared spectroscopy, nuclear magnetic resonance, and/or crystallography. These are techniques that are more commonly used with newly discovered materials that have never been synthesized before. The techniques yield a large variety of information that can be used to identify and determine the structure of a molecular compound.

EVALUATION

Multiple Choice Questions

1. A compound that has a higher Rf value, or travels further up the chromatography paper, has more of an attraction with the:

   A) Stationary phase B) Mobile phase
   C) Solvent front D) Capillary actions

2. In mass spectrometry, the radical cation corresponding to the mass of the original compound is called the:

   A) Molecular ion B) Fragment
   C) Base peak D) Heteroatom

3. When electrons are transferred between reactants in a chemical reaction, this is called a:

   A) Metathesis reaction B) Combination reaction
   C) Decomposition reaction D) Redox reaction

4. Density is a value that measures____

   A) Moles per volume B) Mass per mode
   C) Mass per volume D) Mass per molecules

Correct Answers: 1-B 2-A 3-D 4-C

Formative Assessment Rubric

The following questions should be assessed when reviewing students' laboratory notebooks.

Criteria
Are students writing down how they performed a specific test (procedure)?
Are students recording all data, both qualitative and quantitative?
Are students recording appropriate units with quantitative data?
Are students testing a variety of compounds and noting their similarities and differences?
Are students using appropriate chemistry vocabulary when describing qualitative results?
Are students writing down questions/thoughts that they have throughout the process?
Are students documenting how their results could be used to identify and unknown?

Summative Assessment Rubric

The following rubric will be used to assess students' professional lab reports, journal articles, or toxicology reports to discuss their experiences and demonstrate their knowledge in writing, along with a

hypothesis about the likelihood that the substance was used criminally and may have led to the deaths of individuals consuming the contaminated illicit drugs.

	4 **Excellent**	**3** **Good**	**2** **Average**	**3** **Poor**
Scientific Process	Students have used creativity and insight to design and conduct scientific investigations.	Students used insight to design and conduct scientific investigations.	Students only performed scientific investigations in the exact manner that they were told.	Students did not perform scientific investigations to a level in which they could gather appropriate data.
Safety and Technique Skills	Students demonstrated exceptional skill in the safe, appropriate use of a wide variety of apparatuses, equipment, techniques, and procedures for collecting quantitative and qualitative data.	Students showed reasonable skill and safety in the use of a wide variety of apparatuses, equipment, techniques, and procedures for collecting quantitative and qualitative data.	Students showed safety and some skill in the use of a wide variety of apparatuses, equipment, techniques, and procedures for collecting quantitative and qualitative data.	Students were unsafe in the use of a wide variety of apparatuses, equipment, techniques, and procedures for collecting quantitative and qualitative data.
Writing and Communication	Students used the correct application of writing processes, scientific and technical vocabulary, and presentation formats in their scientific communication.	Students use the correct application of writing processes, some scientific and technical vocabulary, and little variety in presentation formats in their scientific communication.	Students use the correct application of writing processes, little scientific and technical vocabulary, and no variety in presentation formats in their scientific communication.	Students use the correct application of writing processes, no scientific and technical vocabulary, and no variety in presentation formats in their scientific communication.
Scientific Investigation	Students clearly documented the procedure, results, and interpretation of all tests performed.	Students documented some of the procedures, results, and interpretation of the tests performed.	Students documented very little of the procedures, results, and interpretation of the tests performed.	Students did not document procedures, results, or interpretation of the tests performed.
Unknown Identification	Students were able to positively identify their unknown or components of their unknown mixture.	Students were able to identify part of their unknown or unknown mixture or narrow the choices down substantially based on test results.	Students could narrow down the choices of their unknown or unknown mixture, but only partially.	Students were unable to identify or narrow down their unknown or components of their unknown mixture.
Chemical Explanations	Students demonstrated extensive chemical knowledge throughout their investigation and final product.	Students demonstrated some chemical knowledge throughout their investigation and final product.	Students demonstrated little chemical knowledge throughout their investigation and final product.	Students demonstrated no chemical knowledge throughout their investigation and final product.

REFERENCES

Chemical Glossary: https://go.hrw.com/resources/go_sc/mc/HC2GLOSS.PDF
Vernier pH Probe User Manual http://www2.vernier.com/booklets/ph-bta.pdf
Vernier Temperature Probe User Manual http://www2.vernier.com/booklets/tmp-bta.pdf

APPENDIX

Solubility Rules Guide

RULE	EXCEPTIONS
1. Nitrates (NO_3^-) and acetates (H_3CCOO^-) are generally soluble.	No common exception. Silver acetate, mercurous acetate, and lead acetate are moderately soluble.
2. Compounds of the alkali metals (Li, Na, K, Rb, Cs, Fr) and the ammonium ion (NH_4^+) are generally soluble.	No common exceptions.
3. Chlorides (Cl^-), bromides (Br^-), and iodides (I^-) are generally soluble.	The halides of silver (Ag^+), mercury (Hg_2^{2+}), and lead (Pb^{2+}) are insoluble.
4. Sulfates (SO_4^{2-}) are generally soluble.	The sulfates of lead (Pb^{2+}), strontium (Sr^{2+}), and barium (Ba^{2+}) are insoluble. The sulfates of calcium (Ca^{2+}), mercury (Hg_2^{2+}), and silver (Ag^+) are only moderately soluble.
5. Carbonates (CO_3^{2-}), chromates (CrO_4^{2-}), phosphates (PO_4^{3-}), and sulfites (SO_3^{2-}) are generally insoluble.	Those of the alkali metals (Li, Na, K, Rb, Cs, Fr) and ammonium ion (NH_4^+) are soluble. Many acid phosphates are soluble, i.e., $Mg(H_2PO_4)_2$ and $Ca(H_2PO_4)_2$.
6. Sulfides (S^{2-}) are generally insoluble.	Those of the alkali metals (Li, Na, K, Rb, Cs, Fr) and ammonium ion (NH_4^+) are soluble. The alkali earth metals (Be, Mg, Ca, Sr, Ba, Ra) are soluble. Cr_2S_3 and Al_2S_3 decompose and precipitate as hydroxides.
7. Hydroxides (OH^-) are generally insoluble.	Those of the alkali metals (Li, Na, K, Rb, Cs, Fr) and ammonium ion (NH_4^+) are soluble. The hydroxides (OH^-) of Ba, Sr, and Ca are moderately soluble and can be considered strong electrolytes in water. The hydroxide (OH^-) of Mg is only very lightly soluble and can be considered an insoluble substance.
8. Almost all ionic compounds containing NO_2^-, ClO_4^-, ClO_3^-, ClO_2^-, and ClO^- are soluble.	
9. All inorganic acids are soluble. Solubility of organic acids are variable.	

Solutions made from the above species, when soluble, are found to exist as charged particles and thus conduct electric current.

Density Guide

Density is a physical property of matter, as each element and compound has a unique density associated with it. Density is defined in a qualitative manner as the measure of the relative "heaviness" of objects with a constant volume.

For example: A rock is obviously denser than a crumpled piece of paper of the same size. A Styrofoam cup is less dense than a ceramic cup.

Density may also refer to how closely "packed" or "crowded" the material appears to be. Different phases of elements and compounds (solid, liquid, gas) also vary in density.
Density Comparison to Water: In chemistry, the density of many substances is compared to the density of water. Does an object float on water or sink in the water? If an object such as a piece of wood floats on water, it is less dense than water vs. if a rock sinks, it is denser than water.
The formal definition of density is mass per unit volume. Usually the density is expressed in grams per mL. Mathematically a "per" statement is translated as a division.

$$Density = \frac{mass\ (g)}{volume\ (mL)}$$

Chemical Reactivity Guide (Strong and Weak Electrolytes)

RULE	EXCEPTIONS
1. Most acids are weak electrolytes.	Common strong acids (strong electrolytes) are HCl, HBr, HI, HNO_3, H_2SO_4, $HClO_3$, and $HClO_4$.
2. Most bases are weak electrolytes.	Strong base hydroxides (strong electrolytes) are those of Li, Na, K, Rb, Ca, Sr, and Ba.
3. Most soluble salts are strong electrolytes.	Important weakly ionized salts are $HgCl_2$, $Hg(CN)_2$, $CdCl_2$, $CdBr_2$, CdI_2, and $Pb(C_2H_3O_2)_2$.

When an item is listed as a strong electrolyte, write it in ionized form in aqueous solutions. Weak electrolytes are written in molecular form in aqueous solutions.

Any given chemical reaction can be more than one type of the reactions listed below.

- Metathesis, or double displacement reactions – bimolecular exchange reactions that occur in water. These reactions have two ionic reactants where the cation and anion pairs switch and recombine. Gas formation, precipitation, and acid-base reactions are notable subcategories of metathesis reactions.

$$CaCO_3(s) + HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$ *(gas formation)*

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$ *(precipitation)*

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H2O(l)$$ *(acid-base)*

- Redox (reduction-oxidation) reactions – reactions in which electrons are transferred between reactants. The electron transfer is not shown explicitly but can be determined by determining how the oxidation number changes for an element in its reactant and product forms. The element that is being oxidized is losing electrons and is considered the reduction agent. The electrons being lost are gained by the element that is being reduced, which is considered the oxidation agent. Sometimes redox reactions can be easy to identify. Reactions where an element forms a compound, or an element is produced from a compound, are redox reactions. Reactions where a central atom gains or loses oxygen atoms are also redox reactions.

$$Fe_2O_3(s) + 3\ CO(g) \rightarrow 2\ Fe(s) + 2\ CO_2(g)$$

- Single displacement reactions are special types of redox reactions where a solid metal replaces a metal cation from its salt, forming the cations respective solid metal.

$$Zn(s) + SnCl_2(aq) \rightarrow ZnCl_2(aq) + Sn(s)$$

- Combination reactions occur when two or more reactants combine to produce one product.

$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$$

- Decomposition reactions occur when one reactant produces two or more products. The reverse of a combination reaction is a decomposition reaction.

$$2\ H_2O(g) \rightarrow 2\ H_2(g) + O_2(g)$$

- Combustion reactions occur when an organic molecule burns in the presence of oxygen to form carbon dioxide, water, and large amounts of heat.

$$CH_3OH(l) + O_2(g) \rightarrow CO_2(g) + 2\ H_2O(l)$$

ALI BICER

21. SOAP MAKING AND PACKAGING

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Engagement and research	Exploration and research	Begin the lab exercise	Finish lab exercise, and collect data	Begin working on presentation	Conduct presentation

WELL-DEFINED OUTCOME

Students are told to produce a specific amount of soap to protect children in Sudan from disease. They must use their creative ability, chemistry knowledge, and mathematical skills to design soap of specific shapes and dimensions to fit into designated boxes.

TEACHER INTRODUCTION

This PBL was created for ninth grade students. Its purpose was to challenge students to use critical thinking in geometry and chemistry and to encourage students' awareness of world problems by participating in charity work.

Administrators and/or expert teachers can guide teachers who are new to PBL activities in the classrooms. Students also play a vital role contributing to the implementation of the PBL. Because students hold different skills and come from different backgrounds, teachers need to understand what their students bring to the classroom in order to provide meaningful learning. Learner centered environments provide benefits for implementing PBL by providing an understanding of each student's initial ideas about the topics. Allow students to work in groups of three or four members. Groups should be arranged by creating as much diversity as possible. Students in each group can learn from each other that can extend to culture and other diverse issues. Teachers can offer a positive contribution to the PBL by supporting collaboration, cooperation, and communication between and among groups. Teachers need to monitor all students and provide scaffolding when difficulties arise during the PBL. When teachers see the entire class needs support, they can give a short lecture to provide the information to enable students to continue their projects. Finally, teachers need to learn all the details about the projects so students can ask interdisciplinary questions.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- Use the scientific process during their chemistry laboratory investigation.
- Connect various chemistry topics in one experiment including but not limited to acids-bases, chemical reactions, chemical change, physical change, chemical equations, and features of matter.
- Realize how chemistry plays an important role in daily life.

Mathematics – The student is expected to:

- Demonstrate geometric thinking and mathematical skills and use previous mathematics knowledge to investigate geometric thinking and relationships.
- Connect three-dimensional models' shapes, volumes, and weights.
- Compare and contrast various three dimensional models' volumes by considering their weights.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 181–186.

– Estimate 3-dimensional models' weights to solve application problems that involve surface area and volume.
– Use different methods to determine measurement of geometric figures and investigate the measurement concepts to find perimeter, diameter, area, volume, and surface area.

English – The student is expected to:

– Analyze the data and ideas about previous research.
– Evaluate own team's product and the product of another team.
– Present ideas, including the ideas' weakness and strengthens in front of the audiences, and offer at least one suggestion that might make the product more effective.

Science – The student is expected to:

– Describe the influence of scientific discoveries on daily life.
– Conduct research on world issues.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

– Apply principles of relationships, chemical reactions, and physical change.
– Plan and implement investigations.

Technology

– Conduct effective internet searches; recognize reliable internet sources.
– Use appropriate technological tools to help solve the problem.

Engineering

– Use an iterative problem solving and engineering process.
– Follow appropriate strategies and procedures to solve the problem.

Mathematics

– Apply geometry to everyday experiences, other disciplines, and activities inside and outside of the school.
– Plan a cost effective budget.

STUDENT INTRODUCTION

Your school has volunteered to help the students of a rural school in the Sudan. The school administration has chosen your class because of your advanced geometry and chemistry knowledge. You are told to produce a specific amount of soap to protect children in the Sudan from disease. You and your partners must use your creative ability, chemistry knowledge, and mathematical skills to design soaps of specific shapes with certain dimensions to put the maximum amount in designated boxes. The UN will provide standard size (16in.x13in.x3in) boxes. You will be able to investigate the connection between 3-dimensional geometric shapes' concepts and real life problems. These concepts include, but are not limited to, perimeter, surface area, and volume. You will also have an opportunity to see how chemistry courses apply in your daily life by developing and creating your own soap. Because you will produce your own soap, you need to use your chemistry and biology knowledge to conduct this PBL. Your design will be neatly drawn on graph paper provided, colored, and then mounted onto a ¼ sheet of poster board. You and your partners will present to the school board your soap design and a convincing argument as to why your design will enable you to put the maximum amount of soap in the UN boxes. Another classmate will check the efficiency of your group's design, and you will check the solution and justification of another group's design. Questions and statements for students can be as follow:

- We need to put the maximum amount of soap into the boxes.
- How can we decide our soaps' shapes and sizes to fill our given boxes with as much soap as possible?
- Which geometric shapes of soap are the best choices to put the maximum amount of soap in a given box? Or how can we arrange the maximum number of soaps in a given box?
- Using 3-dimensional concepts such as volume, surface area, and total area or using highest common factor and lowest common multiple.
- Each soap's weight must be no less than 5oz, and fit within the given box.
- We can use 3D models to see which geometric shape of soap allows for the greatest amount of soaps.
- To implement the PBL, we can use two different solutions. We can measure the given box volume and choose an appropriate geometric shape. Then, fill the boxes with the maximum amount of soap.
- We can measure the given box volume and make each soap as light as is allowed, and choose the suitable cube or rectangular prism to avoid spaces between the soap.
- We can use several materials that are varied from each other in terms of their sizes, shapes, and weights.
- We can adopt this technique to estimate the best packaging for a variety of objects that provide safe traveling and maximum amount of objects.

MATERIALS USED

- Box
- Ruler
- Formula Chart (volume and area of three dimensional shapes)
- Pencils or markers
- Computer
- Olive oil
- Glycerine (one water glass)
- Water glass (capacity of at least 500ml)
- Water (6 times with water glass)
- Pot (capacity of 6 L)
- Mixer
- Bar of soap (group's preference of shape)
- Thermometer
- Wooden spoon
- Extracts to scent the soap
- Microwave Bowls
- Forms or cookie cutters

DAY 1 (50 MINUTES)

To gain students' interest for the project, the teacher starts off the project by showing YouTube videos about how to make natural soap, and how to give soaps a certain geometric shape and size. After watching the videos, the class will discuss the reason why various geometric shapes and sizes are available around the world. In order for students to see the importance of the projects, the teacher will show a video concerning the rate of yearly child mortality in the Sudan due to poor hygiene. The teacher creates an open discussion to help students understand that the more soap that is placed in the boxes, the more children we can help protect from sickness. The teacher also asks some specific questions such as which geometric shapes of soap are the best choices for the given boxes, how can we place the highest possible number of soaps in a given box, and how much weight is safe for shipment of the boxes? By asking these questions, the teacher encourages students to figure out what components play a role in designing their soaps. Shapes can be cut out of the soap once made. Simply pour the glycerine soap base into a baking pan about an inch or so deep, let it set, and have the students use cookie cutters to make their shapes. Research how to make glycerine soap http://www.marthastewart.com/335074/fruit-and-herb-soaps-how-to

DAY 2 (50 MINUTES)

Teachers should allow students to work in groups of three or four members to decide their soaps' shapes and sizes. After each group decides their soaps' shapes and sizes, the team will give a 5-minute speech explaining the reason why they chose that specific geometric shape and size. The teacher also informs students about the constraints that each soap piece's size must not be bigger than standardized soap sizes

(3.5" × 2.35" × 1.25"), and only given certain boxes (16in. × 13in. × 3in) will be used. The boxes' safety in terms of weight and packaging for traveling will be taken into account as one of this project's requirement.

DAY 3 (50 MINUTES)

Students will decide what they need for materials to produce their own soaps and package them in the most efficient way. In order to produce soap, students will gather data by researching materials online. Because one of the purposes of this project is charity, students need to adhere to the project's constraints on profit. When students decide their materials, teachers will determine whether they have enough materials to be able to produce soaps or not. After students collect their materials, they will brainstorm ideas about which geometrical shape of soap they will use. Each group member needs to write in his or her journal to demonstrate his or her understanding for the project's development. The journals should include what group members discuss, what they offer, and what they accept or reject for their project. Students need to write down in their journals about the geometric background of their products by giving importance shape of each piece of soap, height, width, circumference, radius, volume, weight, surface area, diameter, total surface, and total weight. Students are encouraged to use any objects that are similar to their soaps in volume and weight to see their model's effectiveness before they give any geometrical form to their products. They can base their calculations on the forms being used to build the shapes.

DAY 4 (50 MINUTES)

Students need to explore the chemical process of making soaps, and because there are various kinds of soaps in terms of their ingredients, students are also allowed to choose any type. Before students go to chemistry lab, they will research about their project's chemical requirements by using online resources, books, and magazines. Because there are various soaps, each has a different chemical formula. The teacher might give an example of any soap's chemical formula to guide students when it is necessary. Students should be encouraged to use ingredients that are considered safe within the environment and age appropriate.

DAY 5 (50 MINUTES)

Students will have an open discussion about the process of soap making and shape their soaps according to the best-fit geometrical model to put the greatest possible number of soaps into the given boxes. During the discussion, the teacher facilitates on the cost, efficiency, and safety of the students' products. After the discussion is over, each group will start researching about what they need to make soaps, and how to give them specific geometrical shapes by taking into account their soaps' weight, volume, and visual appeal. The teacher should facilitate by reminding students they are working for charity purposes and need to adhere to the project's constraints in order to be efficient and safe by using a minimal budget. After students gather data about their soaps, the teacher will take students to the chemistry laboratory. Lab safety procedures should be explained to students before they start making their soaps. Students start making their soaps by using the materials that they choose. The teacher should monitor closely each group's progress and scaffold when they have difficulties to follow their design way. Because making the soaps requires chemistry knowledge, the teacher should either learn soap making or partner with the chemistry teacher to be able to guide students in the chemistry part of the project.

DAY 6 (50 MINUTES)

As the final duty of each group, students will measure the weights of their packaging. Finally, each group will explain their design benefits and drawbacks in terms of their soaps' geometrical background in front of the classrooms.

EXTENSION

Instruct students to present their models in front of the classroom; the rest of the class will give scores by taking into account the number of soaps, the box's weight, and the attractiveness and safety of the packaging. Students write in their personal journals after each of the project meetings. Their journals should include but are not limited to students' feelings, contributions, what they learn and think is important, and what previous information they used to solve questions or problems. The teacher will

gather students' personal journals after each project meeting. Then, the teacher will return each student's journal and address both the individual and group's problems. This is aimed at extending students' learning as the teacher will: a) come up with various solutions that students have not considered while conducting the project, and b) try to correct any misconceptions and misunderstandings in the disciplines of mathematics and science by providing further detailed explanations. This helps teachers understand what students know, and how their initial ideas need to be changed or developed. Then, teachers can be ready to correctly assess both individual student and group development.

EVALUATION

Presentation Rubric for group's scientific background

Scientific Background	**Exemplary 4**	**Mastery 3**	**Proficient 2**	**Introductory 1**
Chemistry Background	All chemical calculations and element selections are correct, and the use of elements is calculated to produce best quality soap.	The necessary elements and chemical calculations are correct. However, the use of chemical elements is not correct to produce best quality soap.	Only an attempt was made to gather the appropriate elements, and the use and chemical calculations are incorrect.	All chemical calculations written are incorrect, and the elements included in the soap are not satisfactory to produce soap.
Mathematics Background	All geometric and mathematical formulas were used in the most appropriate way to determine how much soap could be placed into the given boxes.	Most of the mathematical and geometrical formulas were used in an appropriate way to calculate how much soap could be placed into the given boxes.	Only an attempt was made to decide which geometrical and mathematical formulas needed to be used to determine how much soap could be placed into the given boxes.	All geometrical and mathematical formulas are incorrect, and the model demonstrates a lack of calculations for determining how much soap will fill the given boxes.
Biology Background	Group's product is totally safe for both human and animals.	Group's product is not safe for human use, but it is safe for animals and can be used for cleaning purposes.	Group's product is not safe for human use, but it is safe for animals.	The group's product is not safe for either human or animal use.

Scientific background of group's model

Quantitative features of group's model	**Level 3**	**Level 2**	**Level 1**
The number of soap pieces in the given boxes	Group put more than 20 soap pieces in the given boxes.	Group put between 10 and 20 soap pieces in the given boxes.	Group put less than 10 soap pieces in the boxes.
The total weight of the box when filled with soap.	The weight of the box is more than 5 kg.	The weight of the box is between 3.5kg and 5kg.	The weight of the box is less than 2.5kg.
Attractiveness and safety of the packaging	The design is appealing and is totally safe for travelling.	The design is appealing but not safe for travelling.	The design is not appealing and not safe for travelling.
Total			

Journal Checklist

Journal Checklist	From first day through last day (circle one)
Roles and responsibilities for all members	2 1
Individual contributions, feelings towards project	3 2 1
Enough details about every phase of project	3 2 1
Hypothesis that predicts best geometrical soap shape, and justifies the choice	5 4 3 2 1
Relationship with the previous topics, and appropriately using them	5 4 3 2 1
Uses various sources, and analyzes data correctly	4 3 2 1
Reports enough scientific backgrounds such as formulas, equations, and so on	5 4 3 2 1
Summarizes what they learn as new	3 2 1
TOTAL	/30

Multiple Choice Questions

1) Which of the following divisions gives us the number of soaps that we can put in the given boxes?

A) Floor space of boxes/ floor space of soaps
B) Box's volume/one soap volume
C) Floor space of boxes/one soap volume
D) Box's volume/floor space of soaps

2) Which of the two following ingredients do you need to make soaps?

i) Oil ii) Glycerine iii) HCI iv) NaCI

A) i and ii B) ii and iii C) iii and iv D) i and iv

3) One rectangular prism's edges are measured as 60cm, 80cm, and 100cm. We would like to fill the rectangular prism with the largest possible cubes that all have the same volume. How many cubes can we put into the rectangular prism?

A) 30 B) 40 C) 60 D) 80

4) How many rectangular prisms that all have the same dimensions of 9 cm, 15 cm, and 30cm do we need to make the smallest cube?

A) 90 B) 180 C) 270 D) 360

5) When Ali counts his marble two at a time, three at a time, and four at a time, he has one marble left. If we know Ali has more than 30 marbles, at least how many marbles does Ali have?

A) 63 B) 60 C) 45 D) 48

Correct Answers: 1-B 2-A 3-C 4-B 5-A

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TECHNOLOGY

JORDAN WALKER

22. EMOTION, TECHNOLOGY & THE BODY

The Role of Each in Technological Communication

SCHEDULE AT A GLANCE

Day 1	Days 2–3	Day 4	Day 5
Discussion on causes and kinds of emotions	Research on emotions and their role in communications	Design and complete an experiment that implements the scientific method	Continue experiment from Day 4
Day 6	Day 7	Day 8	Days 9–10
Design the device	Planning and development, complete drawing journal	3D Printing	Presentations

WELL-DEFINED OUTCOME

Using a computer program and a 3-D printer, students will design a device that will transfer emotions across a chosen form of technological communication (text messaging, e-mail, one social media outlet, etc.) through a simple circuit system.

TEACHER INTRODUCTION

This PBL is designed for on or above level students. Communication and emotions are familiar concepts to students – they communicate and feel some emotion nearly every minute of every day. Therefore, incorporating communication with science and technology should help students relate to the issue on a personal level. Before assigning this PBL, students should know how to design and complete an experiment, collect and record data, use at-home body and vital sign monitors (heart monitor, blood pressure monitor, etc.), research using credible internet and print sources, and use technology (computers, phones, etc.). This PBL should enhance students' understanding of the body's role – emotionally – in producing good communication and technology's role in helping and hindering the transfer of emotions across technological communication.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- Describe and apply the steps of the scientific method.
- Research the body's role in producing emotions that effect communication.
- Design and complete an experiment that will monitor/measure certain bodily functions.
- Record and analyze data collected through experimentation.
- Analyze and interpret the emotions people produce in relation to the recorded data.

Technology – The student is expected to:

- Report how emotions are lost through technology.
- Exhibit skills in computer use and presentation programs.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 189–196.

– Design a technological device that will transfer emotions across technology.
– Correctly use sensitive equipment to gather accurate and relevant data.

Communication – The student is expected to:

– Research and analyze the role of emotions in communication.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

– Apply knowledge of the body systems to the body's production of emotions and communication.
– Determine hormones, systems, and environmental factors that lead to the development of emotions.

Technology

– Apply knowledge of technological medical devices (vital sign monitors).
– Use technology (computers, etc.) to produce organized data delivery.
– Apply technology (computers, 3D printers, etc.) to develop the final product.

Engineering

– Apply knowledge of circuits to develop the final product.
– Determine what simple circuit system will best work in the design of the product.

Mathematics

– Collect and analyze data based on real-world settings.

STUDENT INTRODUCTION

People communicate everyday either face-to-face or over some form of technology (text, e-mail, social media, etc.). Although communication through technology is quick and easy, it leaves out a very important component of communication – emotion. The loss of emotion alters the messages we send – causing people to misinterpret and misread important messages, which could be avoided if emotions were present. In this PBL, you will investigate the presence of emotions in communication between people, the body's role in producing emotion, and the role technology plays in preventing and causing the loss of emotions. An experiment will be conducted to include data collection techniques that capture items such as heart rates, body temperatures, and other vital signs that play a role in conveying emotions. You must consider how the body operates to produce emotion and how the body's vital signs are affected by emotion. The idea is for students to design a device that will attach to the body and will measure the vital signs that could convey particular emotions. For instance, students could design a ring that detects information about heart rate and blood pressure, which could indicate anger, stress, and fear. The device could then connect to an app that multiple people could connect to and retrieve the emotions detected from the person wearing the ring. This would allow the recipient of the ring to identify some possible emotions that could play a role in the communication. Students do not necessarily have to pick only one or two emotions; they can choose to have their devices detect multiple emotions. Students should research and think beyond the vital signs we consider day-to-day (e.g., heart rate, pulse, etc.). This project will link together several subjects: science (the experiment process and the body), technology, and communications. A technological advancement of this kind could potentially allow the benefits of face-to-face communication to be maintained across multiple forms of communication.

MATERIALS USED

– Computers
– Composition journals

- Computer program to design the device
- Access to email (if chosen as media outlet to design a device for)
- Access to social media (if chosen as media outlet to design a device for)
- 3-D printer
- Access to print sources for research
- Vital sign sensors such as heart rate monitors, blood pressure monitors, thermometers, etc.
- Cell phones
- Access to text messaging (if chosen as media outlet to design a device for)
- Access to phone calls (if chosen as media outlet to design a device for)

DAY 1 (45 MINUTES)

Introduce the project by asking students if emotions are present when they engage in face-to-face conversations. Have students explain how they see the presence of emotions and what kind of emotions they experience and witness. Then, in small groups, ask students to discuss what they think causes emotions. This discussion should lead students to surface the science concepts (the body's vital signs) that are affected by emotions. If help is needed, ask some questions to get students thinking about the science behind emotions. Some sample questions are:

- Which of the body's vital signs do you think allow emotions to be detected?
- Name some emotions that you witness when you partake in face-to-face communication.
- How do you know that someone is angry? Sad? Happy?
- What are some emotions that you see when communicating face-to-face that you do not see when you are text messaging?
- Why do you think emotions play such a large role in communicating and understanding messages as intended by the sender?

The teacher should then assign the following introductory story for students to read. The story is designed to help the students relate to the project on a personal level.

Introductory Story

You are a high school student and your parents have told you it's time to get a job. At first, you felt sad about having to spend your summers working rather than swimming, sleeping, and shopping. That was until you heard about a summer job opening at the local zoo, a dream job for a young animal enthusiast like yourself. Not only would you help with some animal care, but you would also be a tour guide for small groups of children ranging from kindergarten to 8th grade. Although you would not be caring for the children, the job would require you to have good presentation skills and be able to engage the children throughout the tours.

Before telling all your friends that you have the coolest summer job ever, you will have to go through an interview process, complete an application, submit a purpose statement that tells why you feel you are capable of doing the job well, submit references, and participate in a phone interview before advancing to the face-to-face interview at the zoo. Although this is a rigorous process, it is all worth it for a chance to spend your summer going to the zoo EVERY day. After submitting all your information, the zoo manager calls you to set up a time for your phone interview. The date is decided. It will take place two days from now. For the next two days, you spend hours practicing and crafting answers to possible questions, because you know that you must do well on the phone interview to advance and have a shot at getting the job. When the day arrives for the phone interview, you await the phone call from the zoo manager all day. At 3 p.m. on the dot, he calls. He asks you questions, some of the questions you had prepared for, but you're nervous because you have never done a phone interview before.

When the phone interview is over, you run to tell your parents how excited you are that the interview went so well. Now, all you have to do is wait three days to hear if you advanced to the face-to-face interview. It felt like five weeks of waiting, but three days later, the zoo manager called to tell you that you advanced. However, he said, "While I was very impressed with your statement of purpose and what your references had to say about you, I need to make myself clear when I say that the phone interview did not go as well as I would have liked. You did not seem very enthusiastic about the opportunity. Therefore, the face-to-face interview will be crucial in determining if you are the best fit for the position. I look forward to seeing you in a week for your interview."

Wow, what a bummer! You thought the phone interview had gone so well. After thinking about it, you realize that your nervousness had covered up your enthusiasm for the job. You wish so badly that the manager would have been able to sense the nerves, so he might understand why your enthusiasm had not

shown quite so bright. Fast-forward one week. You arrive at the zoo ready for the most important interview of your young life. One hour later, you walk out of the zoo office having rocked the interview and landed the best job ever.

Three weeks into the job, you are guiding a summer camp of children through the zoo, telling them about all the fascinating animals. Thirty minutes into the tour, you realize there are three children with special needs who have a really hard time communicating. You don't know if you are engaging them, and they are being a bit disruptive. You feel nervous because you want them to enjoy their time at the zoo just as much as the other children, but you don't know what emotions they are feeling – bored, excited, sad, etc. After leaving the zoo for the day, you can't stop thinking about the children with special needs and the need to know their emotions to determine how to best engage them. This also leads you to think back to your phone interview when you wished so badly the manager would have been able to read your emotions through the phone to know you were nervous. When you get home, you grab your computer and begin doing some research on emotions and communications. You then think it would be brilliant if there was some sort of technology that would have allowed your emotions to be transferred through the phone to the zoo manager and that would allow you to know what emotions children with special needs are experiencing.

You explore all different things that cause emotions, as well as all different types of communication. At the end of the summer you have compiled so much information that you take it to your STEM teacher when you start the new school year. You ask her if you can do a project that might allow you to develop your ideas so you can possibly use what you develop next summer at the zoo doing the BEST job on the planet.

The teacher will then present students, either in print or electronically, with the following article to read. http://www.huffingtonpost.com/2014/03/15/words-and-communication-r_n_4966581.html. Then, the teacher will show the video, located within the link to the article, to get a better idea of how emotions are present in communication. During this phase of the project, the teacher will also place the students into small groups of four or five students each.

DAYS 2–3 (75 MINUTES EACH DAY)

In the next two class periods, the teacher will instruct the students to conduct research on emotions and how they play a role in communications. The research will not be intensively guided. The idea is for the students to gather information that is not explicitly in front of them; they should dig deep. The research should include both electronic research and print research. Students will also need to brainstorm about how they plan to design and carry-out an experiment to collect necessary data. The circuit system concept will also need to be researched. Students will determine how the simple circuit system will be used to transfer emotions. That is, they will research different types of simple circuit systems and determine which is best for their group to use in the design of their product. During the exploration phase of the project, students will choose the communication outlet that they plan to design a device for.

DAY 4 (75 MINUTES)

After researching and brainstorming, students will design and complete an experiment that will allow them to engage in the experimental process, the scientific method, the causes of emotions, detection of emotions, and the use of bodily monitors. The monitors will present another form of technology from which students can learn more about how emotions affect the body. Students are expected to use their knowledge of the scientific method to develop an experiment that will provide them with the information that (found through their research) they will need to design and develop a product that will convey emotions. Students will explicitly use the steps of the scientific method: 1) ask a question, 2) research, 3) hypothesize, 4) test the hypothesis, 5) study data, and draw conclusions, and 6) communicate results to others.

DAY 5 (75 MINUTES)

Students will continue the experiment they began on day four. At this time, each group member should record data from the experiment. Individually, students will write a paper detailing the data they discovered in their experiment. Each student will write their OWN paper so every student takes away a

complete understanding of what they did and learned through the experimental process. The paper should include a detailed explanation of the experiment, stating how the experiment was designed and why the group chose to design it the way they did. The paper should be grammatically correct, free of any spelling errors. The paper is an important component because it requires the students to debrief after the experiment. The paper does not necessarily have to be done during the 75 minutes class period. The teacher can assign the paper and expect students to turn it on day six or seven.

DAY 6 (75 MINUTES)

After designing and carrying-out the experiment, students will design their device using a computer program that is available to them (i.e. a design program such as InDesign). They will use the information they gathered in their experiments to determine which of the body's vital signs they want to measure. This will be dependent upon the emotions they want to detect. The idea is for students to design a device that will attach to the body and will measure the vital signs that could convey particular emotions. For instance, students could design a ring that detects information about heart rate and blood pressure, which could indicate anger, stress, and fear. The device could then connect to an app that multiple people could connect to and retrieve the emotions detected from the person wearing the ring. This would allow the recipient of the ring to identify some possible emotions that could play a role in the communication. Students do not necessarily have to pick only one or two emotions; they can choose to have their devices detect multiple emotions. As students design their device, they should keep a journal of drawings that show the stages of development.

DAY 7 (60 MINUTES)

At this stage, students should be deep into the planning and development phase. Day seven should be the point at which students are nearing the final stage of development (i.e. the simple circuit system that students will use in the design of their device should be chosen and implemented). At the end of this stage, students will turn in their complete journal of drawings (as accurate to the real design as possible – accounting for limited drawing skills). The journal of drawings is important because it gives the students the opportunity to get a complete visual of their ideas and design before producing the final product using a 3D printer. The drawings should include labels and should be organized. If parts of the drawings need an explanation, students should write a short explanation.

DAY 8 (60 MINUTES)

Once students have designed their device using the data collected from their experiments and knowledge about circuits from their research, they will print their devices using a 3-D printer. They will then have a tangible product. The students will be expected to properly use the 3D printer, as demonstrated by the teacher. Improper use of the printer would include being irresponsible and damaging the equipment. This will teach the importance of being careful and courteous when working with equipment.

*NOTE: The time allotted for this day could vary depending on the availability/access to the 3D printer.

DAYS 9–10 (75 MINUTES EACH DAY)

After the device is printed, students will prepare a presentation to deliver to the class and, potentially, to outside guests. The presentation should not merely be students standing in front of the audience with their device. Students should display a detailed description of their research, experiment, and thoughts and ideas that went into the design and completion of their final product. They should include original visual aids (i.e. graphs and charts). The presentation should explicitly state the function of the device, background information about the method(s) used to produce the final outcome, and an analysis of how the experiment and data were used to design the device. Students' creativity should be easily seen. The presentation should be professional, as if the product was being pitched to investors or superiors. To properly prepare the presentation to the above specifications, students should use the assignments outlined throughout the PBL (experiment data, experiment analysis paper, journal of drawings, notes, and the final product). These assignments and other materials should greatly aid the students in the planning and preparation of the presentation.

EXTENSION

For advanced student

Students could incorporate a more advanced circuit system, opposed to the simple circuit system outlined in the well-defined outcome.

For students who finish early

Students could research other bodily monitors that are not available to them and explain how their product might change if the other monitors were part of the experiment.

EVALUATION

Experiment Rubric

	9 points	**6 points**	**3 points**	**0 points**
Scientific Method *1. Formulate question* *2. Conduct research* *3. Hypothesize* *4. Test hypothesis* *5. Analyze data and draw conclusions* 6. *Communicate results*	Students use all six steps of the scientific method.	Students use four of the six steps of the scientific method.	Students use two of the six steps of the scientific method.	Students use less than two of the six steps of the scientific method.
Originality of Design	Students displayed excellent thought and creativity in the design of their experiment. All ideas were original.	Students displayed good thought and creativity in the design of their experiment. Most ideas were original.	Students displayed some thought in the design of their experiment but lacked creativity and originality.	The experiment does not exhibit original ideas or thoughts. It seemed to rely mostly on outside experiments.
Use of Monitors	The experiment incorporates the use of multiple monitors that measure the body's vital signs, and they were all pertinent to the project.	The experiment incorporates the use of multiple monitors that measure the body's vital signs, and most of them were pertinent to the project.	The experiment incorporates the use of one monitor that measures the body's vital signs, and it was pertinent to the project.	The experiment did not use monitors or used monitors that were irrelevant to the project.
Data Analysis	Extensive data analysis is shown throughout the project. Data is evaluated using appropriate methods and valid conclusions are drawn.	Some data analysis is shown throughout the project. Data is evaluated using appropriate methods and valid conclusions are drawn.	Some data analysis is shown throughout the project. Data was not evaluated using appropriate methods, and some conclusions are invalid.	Very little data analysis is shown throughout the project. Data was not evaluated using appropriate methods, and some conclusions are invalid.

Device Rubric

	6 points	3 points	0 points
Device Production	The device was produced using a 3-D printer, and the product turned out as it was designed.	The device was produced using a 3-D printer, but the product did not turn out as it was designed.	The device was not produced using a 3-D printer, and the product did not turn out as it was designed.
Circuit System	The device incorporates a circuit system of some kind. The group displays a clear understanding of the circuit system it chose to use.	The device incorporates a circuit system of some kind. The group displays somewhat of an understanding of the circuit system they chose to use.	The device does not incorporate a circuit system.
Wearability	The design of the device allows for it to be easily worn on one's body.	The design of the device allows for it to be worn on one's body, but it does not easily attach or stay attached.	The device cannot be worn on one's body.
Display of Emotions	Emotions are very easily readable from the device. The emotions are also easily communicated through the device (i.e., with one glance, by simply listening, etc.)	Emotions are somewhat readable from the device. The emotions are communicated through the device (i.e., with one glance, by simply listening, etc.).	Emotions are not readable when looking at the device.
Depth of Thought	The device clearly displays deep thoughts and original ideas based on the experiment that was conducted.	The device displays some deep thought and ideas based on the experiment that was conducted.	The device severely lacks deep thought and original ideas.

Presentation Rubric

Engage Audience	**(10 pts)** Group creatively engages audience during presentation through use of videos, questions, etc. (some kind of audience participation).	**(5 pts)** Group engaged some, but not all, of the audience members during the presentation. Creativity was lacking in ways to include the audience.	**(0 pts)** Group includes no audience engagement during presentation.
Use of Sources	**(20 pts)** Group effectively and accurately incorporates the use of sources into the presentation of its experiment and device. Uses at least three sources, both print and electronic, using proper APA citations.	**(10 pts)** Group incorporates the use of sources into the presentation of its experiment and device. Uses exactly two sources,both print and electronic, using proper APA citations.	**(5 pts)** Group uses only one source and it may have been lacking creditability. APA citations are not properly used.
Background Knowledge	**(30 pts)** Group included complete background discussion about how/why it designed the device. The group shared information about what it learned about emotions and the body's role in producing emotions.	**(20 pts)** Group included background discussion about how/why it designed the device, but there were times when the discussion was not complete. The group did not share information it learned about emotions and the body's role in producing emotions.	**(10 pts)** Group includes limited to no background information about how/why it designed the device like it did.

Device and Experiment	**(30 pts)** The presentation creatively presents the device AND the experiment. The group demonstrated the use of the device or gave a clear explanation of how it is used.	**(20 pts)** The presentation accurately presents the device AND the experiment, but it lacked creativity. The group did not demonstrate the use of the device. It is unclear how to use the device.	**(10 pts)**The presentation did not present both the device AND the experiment. The presentation did not demonstrate or explain how to use the device.
Overall Presentation	**(10 pts)** The overall presentation is neat, grammatically correct, and appealing to the eye. Group members acted and dressed (neatly) professionally.	**(5 pts)** Most, but not all, of the presentation was neat, grammatically correct, and appealing to the eye. The presentation contained a few errors. Most group members acted and dressed (neatly) professionally.	**(0 pts)** The overall presentation was messy and was not effectively edited. Group members did not act or dress (neatly) professionally.

Students should display a detailed description of their research, experiment, and thoughts and ideas that went into the design and completion of their final product. They should include original visual aids (i.e. graphs and charts). The presentation should explicitly state the function of the device, background information about the method(s) used to produce the final outcome, and an analysis of how the experiment and data were used to design the device. Students' creativity should be easily seen. The presentation should be professional, as if the product was being pitched to investors or superiors.

Team Evaluation

The teacher should evaluate the groups as he/she sees fit. This PBL does not include a rubric for this evaluation. The evaluation should be dependent on the teacher's philosophy on group member evaluations (i.e. do the group members evaluate each other or does the teacher evaluate each group member?). This should be considered before beginning the project.

REFERENCES

Guidance in producing the objectives came from the following sources:
- The Texas Education Agency http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112c.html
- The Huffington Post Article: http://www.huffingtonpost.com/2014/03/15/words-and-communication-r_n_4966581.htmlt
- Reference for Steps of the Scientific Method: http://www.sciencebuddies.org/science-fair-projects/project_scientific_method.shtml

NATHAN MCCALLUM

23. GAME OF CHARGING

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Days 4–5
Engagement and introduction of project. Watch videos.	Research the charging process and design mechanism.	Engineer, test, and revise the charging mechanism.	Presentations and final challenge/ contest.

WELL-DEFINED OUTCOME

Students will design the least expensive cell phone charging mechanism that produces the highest possible voltage on the cell phone battery.

TEACHER INTRODUCTION

This project is designed for middle school students and aims to give them a better understanding of the battery charging process. In this project students will work in groups to engineer their own battery charging mechanisms, present their mechanisms to the class, describe the process they used to create them, and demonstrate how their engineered chargers work. At the end of this project the students will have a contest to determine the group that made the least expensive battery and whose battery held the longest charge with highest voltage.

After the students are introduced to the assignment, they will research the various ways an inexpensive battery charging mechanism can be created from items the teacher provides in a box. The box provided by the teacher will have materials that are both useful and not useful for creating a charging mechanism. The box will function like a store whereby students buy items from the box to create their charging mechanism. Students must the record the number of items they purchase, the price at which each price was purchased, and then calculate their total cost. The items provided for the students to use will be logged on a price sheet, and any items the students bring in on their own must be given to the teacher for inventory and pricing.

In this project students will need to understand the specifics behind what produces an electrical current and how each one of their items can contribute to the charge of their batteries. Students will keep experimenting and testing their items to maximize the highest voltage they can get on their batteries in an attempt to win the contest at the end of the project. This might lead students to exchanging or buying new items, but their ultimate goal is to minimize the cost of the charging mechanism while at the same time maximizing the voltage reading.

Some limitations to the project are that the students may not have a phone or any type of device with a rechargeable battery. In this case the teacher could provide a battery.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- Discuss processes of electrochemistry.
- Describe the process of the charging system.
- Compute voltage of a battery.
- Describe the amps of and a battery's life span.
- Describe how electricity flows from the capacitor to the mechanism in need of charge.
- Conduct research on the process of electricity going through different products such as fruit and metals.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 197–200.

Mathematics – The student is expected to:

- Work with basic finances, in buying items from a store and learning how to budget.
- Perform basic addition and subtraction operations with money.
- Optimize the voltage within the battery constructed.
- Minimize the cost of constructing the battery.
- Compare numerical values and determine the differences among them.

Engineering – The student is expected to:

- Build a capacitor or circuit that will be connected to a battery and then charge it.
- Use basic household supplies to create a battery charger that will produce an electrical current to measure voltage on a battery.

Technology – The student is expected to:

- Build a circuit for the purpose of charging a phone.
- Explore batteries used in cell phones.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science:

- Students will make observations to provide evidence that sound, light, heat, and electric currents can transfer energy from place to place.
- Students will identify and describe a variety of energy sources.
- Students will discuss energy in its forms (i.e., mechanical, chemical, electrical, radiant, thermal, and nuclear).
- Students will discuss that energy can be quantified and experimentally determined.

Technology:

- Students will put their knowledge of common day cell phone charging and all of their modern technology charging mechanisms to understand their project.

Engineering:

- Students will use prior knowledge of how their charging mechanisms are built to engineer their own.
- Students will use knowledge of the flow of electricity and apply it to engineering a battery charger.

Mathematics:

- Students will apply knowledge of basic financial processes, such as working with whole dollar amounts and change and adding and subtracting through their transactions with the classroom store.

STUDENT INTRODUCTION

We use our phones constantly to check emails, text, talk, or surf the web. Basically, we use our phones to find anything we want, and that is why cell phones are so important to us. We all know that using our phones constantly will deplete its battery and sometimes this happens more often than we would like. In this project you will explore the concept of charging a battery and make a battery charger that can charge a cell phone from simple materials that conduct a current. Students will explain their understanding of how the object they created charges the cell phone battery and why their engineered product is sufficient. Students in this project must also keep track of their spending and attempt to minimize the amount of money spent on supplies. Creativity is a key element in this project.

MATERIALS USED

- Charger Materials:
  - Produce (Fruit/Veggies)
  - Soda can (full)
  - Water bottle (full)
  - Salt
  - Copper Plates (e.g. pennies)
  - Zinc Plates (e.g. galvanized nails)
  - Paper Clips
  - Coins
  - Insulated wire
  - Alligator clips
- Voltmeter
- Play money

DAY 1 (50 MINUTES)

A good way to show students how fun electrochemistry can be is through the basic concept of creating a battery charger. An engagement activity that motivates this idea is the Mintyboost™ activity from the Adafruit© company (http://www.adafruit.com/products/14). Using this activity the teacher can create a portable charger in front of class by buying the cheap materials from the Adafruit© site. This activity may be slightly more advanced than what the students will create, but it will give the students a better understanding of a circuit and how charges are created, which in turn may help students generate ideas for their projects. Other fun and cheap motivating activities are videos of how a phone can be charged. These videos will surface with a quick Internet search with key words "charge a battery with vegetables." Below are some results of YouTube videos that surfaced with the key word search:

- https://www.youtube.com/watch?v=GhbuhT1GDpI (03:21)
- https://www.youtube.com/watch?v=PuiPDBA3XZI (03:09)
- https://www.youtube.com/watch?v=f2JJH8EM9AI (02:54)

After the introductory activities are complete, go over the requirements for the project and explain the requirements of the presentations for the last two days of this project (see rubrics in Evaluation section). Provide possible supplies and encourage students to get creative. Give students the prices of the supplies that you will provide and explain price ranges for relatable items that students bring in that are not on the price list. Put students into groups and give students the same amount of play money to buy products from the teacher store. The amount of money you give each group will depend upon the cost of each item on the price list – give the students enough money to buy what they want, but make it so they can only buy about one-fourth to one-third of the items on the list. Force them to make decisions about what they want to purchase. If the students find supplies elsewhere, remind them that they must have them inventoried and added to the supply list. The students will still have to use their play money to purchase the items they bring in.

DAY 2 (50 MINUTES)

Model to students a charger you have made from the supplies on the supply list and share with them the decisions you made when buying and using the materials. Stress the importance of minimizing the cost of supplies and maximizing the voltage reading. Then, have students break into their groups and begin researching and designing their chargers. Remind students they can only buy products from the materials box with their play money. If students finish the research and design process, they can begin creating their chargers. Remind students to test their voltage with the teacher's multimeter and keep track of supplies and money they are spending. These will all be important elements in their presentations.

DAY 3 (50 MINUTES)

Have students get into groups and continue working on their projects. If at the end of this day the groups still don't have a high enough voltage – or even a charge – they can work outside of class but their final

product must be ready by the start of Day 4, the day presentations are scheduled to start. Remind students that for full credit, the battery must hold a charge during the presentation. Students must also report the final cost of the product and record the voltage for the contest.

DAYS 4–5

Each group will give their presentation and demonstrate their charging mechanism.

EXTENSION

The teacher can challenge students who finish early by excluding some items from the supply box. The teacher can also allow students to buy more supplies so the battery will produce a higher voltage. Taking it even farther, the teacher can challenge the students to create a portable charger that will fit into a compact carrying case. If possible, the students can create the compact carrying case with a 3-D printer.

EVALUATION

	Outstanding	**Acceptable**	**Needs Improvement**
Research	The research is related and shows clear understanding of the content and how the project works.	The research is acceptable and connects the content to the project but inadequately.	The research is absent and fails to show the connection of content to project.
Project	The project shows evidence of creativity, inventiveness, and uniqueness in its build. It shows that the project went beyond what is expected.	The project shows some originality and creativity, but still incorporates too many other ideas and influences. Lacks originality.	There is no originality to the project and it is as if the project was a copy of other group's concept.
Presentation	All the points were clear, sensible, and presented with confidence. The audience could easily follow the information, and students responded accurately and promptly to audience's questions.	Some messages are clear and thought out and some of it was presented with poise. Audience could somewhat follow the information and had trouble gaining a perspective of the message. Most questions asked by the audience were correctly responded to.	Messages were unclear lacking thought and presented without confidence. The audience could not follow the presenter and audience was not engaged in presentation.
Reflection	Reflection has a lot of response to issues raised in class. Student growth has progressed tremendously and this reflects in their work and from examples provided.	Reflection conveys a good sense of personal growth and this is shown in work to an acceptable degree.	Reflection conveys no personal growth or response to issues raised in class. Students are limited in demonstrating ability to reflect on own work.
Teamwork	It is clear that all students actively collaborated, and the results were phenomenal.	There is some evidence of students' collaboration; overall results were good.	Little to no evidence of collaboration, and overall, the project needs major improvements.

REFERENCES

https://www.adafruit.com
https://www.youtube.com/watch?v=GhbuhT1GDpI
https://www.youtube.com/watch?v=PuiPDBA3XZI
https://www.youtube.com/watch?v=f2JJH8EM9AI

NUTRITION AND GENETICS

HYUNKYUNG KWON

24. EAT HEALTHY AT FAST FOOD RESTAURANTS

SCHEDULE AT A GLANCE

Day 1	Day 2	Day 3	Day 4	Day 5
Engagement with discussion	Exploration and research healthy food guidelines.	Research restaurant menus	Work on presentations	Presentations (5–10 minutes each group)

WELL-DEFINED OUTCOME

Make a food choice that does not exceed the recommended daily calories and total fat (saturated, unsaturated, and trans) intake for a teenager.

TEACHER INTRODUCTION

People need to make choices about the foods they eat everyday. There are many types of foods, and different food choices impact people's health in different ways. What impact do these choices have on people's health now and in the future? What food choices will allow people to keep healthy bodies? What impact can food choices have on the quality of your life?

This PBL focuses on the different types of fat in the diet, especially how unhealthy fat affects a person's health, and the importance of eating a healthy diet by including a variety of foods from each food group. Students will learn that healthy eating relies on grains, fruits, and vegetables for the majority of food selections.

Students will need some prior knowledge of one's general health and healthy choices to be successful in this project. Students in middle school typically learn about healthy and unhealthy dietary practices. In this PBL, students will work cooperatively to solve a problem that requires them to use their knowledge of the food pyramid and healthy eating guidelines. Students will apply mathematical thinking and calculations to make healthier menu choices at a fast-food restaurant.

This project should begin after learning about calculations dealing with fractions because it requires addition, subtraction, and multiplication of fractions. Students will be involved in a quick activity to review these calculations before they begin their project. This lesson requires students to extrapolate information, draw conclusions, and defend their conclusions.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Mathematics – The student is expected to:

- Use addition and subtraction to solve problems involving fractions.
- Model addition and subtraction situations involving fractions with objects, pictures, words, and numbers.
- Communicate mathematical ideas using language, efficient tools, appropriate units, and graphical, numerical, physical, or algebraic mathematical models.
- Draw inferences, make conjectures, and construct convincing arguments.
- Identify and apply mathematics to everyday experiences, to activities in and outside of school, with other disciplines, and with other mathematical topics.
- Select tools such as real objects, manipulatives, paper/pencil, and technology or techniques such as mental math, estimation, and number sense to solve problems.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 203–208.

English – The student is expected to:

- Produce a multimedia presentation involving text and graphics using available technology.
- Communicate with peers in groups and in class size to discuss important topics.
- Follow the research plan to collect data from a range of print and electronic resources (e.g., reference texts, periodicals, web pages, online sources) and data from experts.
- Paraphrase the major ideas and supporting evidence in formal and informal presentations.
- Draw conclusions from a variety of data sources to analyze and interpret systems.
- Give an organized presentation with a specific point of view, employing eye contact, speaking rate, volume, enunciation, natural gestures, and conventions of language to communicate ideas effectively.
- Participate in student-led discussions by eliciting and considering suggestions from other group members and by identifying points of agreement and disagreement.

Health Science – The student is expected to:

- Make responsible food choices in various products, using scientific information and evaluating the impact of research on it.
- Conduct research on the food pyramid, food types, and food quantities to see how food choices impact one's healthy body.
- Analyze healthy and unhealthy dietary practices.
- Explain the importance of a personal dietary and exercise plan.
- Analyze health information and products.
- Make healthy choices from selecting healthy snacks.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Research and analyze information about the food pyramid, food types, and food quantities to determine how food choices impact one's healthy body.

Technology

- Create and present a PowerPoint® presentation.

Mathematics

- Addition, subtraction, and multiplication of fractions to calculate how many fats are consumed.
- Model addition and subtraction situations involving fractions with words and numbers to make convincing arguments during the presentation.
- Compare the numbers while determining the nutritional value in each food to make the best food choice for their chosen friend in the scenario.
- Communicate mathematical ideas using language, efficient tools, appropriate units, and graphical or numerical mathematical models.

STUDENT INTRODUCTION

Your friends Sarah and Daniel have been gaining weight and feeling unhealthy from eating fast food at every meal. You have realized that their poor food choices have resulted in weight gain and unhealthy bodies. Because they do not know how to cook, they promised themselves that they would buy a nutritious (focusing on grains, fruits, and vegetables) meal with the $8 they each have to spend on dinner. The restaurants around them where they can dine out are Panda Express, Dominos, and Subway. You want to help either Daniel or Sarah to make it possible to buy a healthy meal at only one of these fast food restaurants that is well balanced and minimizes the intake of unhealthy fat. You will not have to consider the amount of carbohydrates, protein, vitamins, sugar, etc. You will only have to consider the number of calories and the amount of total and saturated fat. Sarah has already eaten one-half of the recommended daily total fat and saturated fat intake and has consumed 1200 calories. Daniel has

consumed two-thirds of the recommended daily total fat and saturated fat intake and has eaten food containing 1500 calories.

Conduct research on the food pyramid, healthy food choice guidelines, and menus of each restaurant from the websites listed in the resource section of this PBL. Learn about reasonable amounts of daily calories, total fat intake, and saturated fat intake for Sarah and Daniel through class and group discussions. Make a food choice for Sarah or Daniel that does not exceed the recommended daily calories and grams of total fat and unsaturated fat. Be prepared to make convincing arguments to present and defend your food choices in a PowerPoint® presentation format to a panel of health professionals in a week. Make sure to include all the calculations and visuals (e.g., food pyramid, menu, food choice, etc.) in your PowerPoint presentation®.

MATERIALS USED

- Scenario
- Internet and computer lab access
- Microsoft PowerPoint®
- Grading rubrics
- Group contribution log
- Group contribution log checklist
- Student resources sheet
- Construction paper
- Markers
- Rulers
- Journal book

DAY 1 (50 MINUTES)

The teacher begins the project by placing different pairs of pictures showing one person that represents a healthy food choice and one that represents a poor food choice. The teacher should not explain what the pictures mean or why they have been placed in the classroom. The teacher will place students in groups of 4 or 5. Students will explore the pictures for 5 minutes as a group. After exploring, the teacher will engage students by starting a discussion about their observations about the pictures and their perspective on what the pictures seem to represent.

Remind students that there are many types of foods, and different foods impact people's health in different ways. Have students think and discuss in groups about the following questions:

- What impact do these choices have on a person's health now and in the future?
- What food choices will allow people to keep healthy bodies?
- What impact can food choices have on the quality of your life?
- Is it possible to eat healthy at fast-food restaurants?

Following the discussion of these questions, reconvene the students as a class and share ideas. The teacher should create question prompts like the following:

- What are the some benefits and possible harms to your health from different types of food?
- How do food choices impact people's healthy body?

The teacher will now read the scenario for students. "Your friends Sarah and Daniel have been gaining weight and feeling unhealthy from eating fast food every meal. You have realized that their poor food choices have resulted in weight gain and unhealthy bodies. Because they do not know how to cook, they promised themselves that they would buy a nutritious (focusing on grains, fruits, and vegetables) meal with the $8 they each have to spend on dinner. The restaurants near where they can dine out are Panda Express, Dominos, and Subway. Your team wants to help either him or her to make it possible to buy at only one of these fast food restaurants a healthy meal that is well balanced and minimizes the intake of unhealthy fat. Sarah has already eaten one-half of the recommended daily total fat and saturated fat intake and 1200 calories. Daniel has consumed two-thirds of the recommended daily total fat and saturated fat intake and has eaten foods containing 1500 calories."

The teacher will now read the task for the students. "You will need to research about the food pyramid, healthy food choice guidelines, and menus of each restaurant from the websites listed on the resource list, which will be provided to you. Learn about reasonable amounts of daily calories, total fat, and saturated fat intake for Sarah and Daniel through class and group discussions plus research from websites. Make a

food choice that helps Sarah or Daniel that does not exceed the recommended daily calories and grams of total fat and unsaturated fat. Be prepared to make convincing arguments to present and defend your food choices in a PowerPoint® presentation format to a panel of health professionals in a week. Make sure to include all the calculations and visuals (e.g., food pyramid, menu, food choice, etc.) in your PowerPoint® presentation."

After reading the scenario and tasks to students, handout to students the resource sheet, group contribution log example sheet and PowerPoint® presentation rubric. Remind students that the group contribution log should be in the same format as the example in their journals. Explain that at the end of each day of the project one person will record in the group contribution the progress made during the day, any challenges the group encountered that day, and the plan for the next day. One person should make sure that every other member of the group should check off at least once for agreement or disagreement of what they accomplished. Remind students that they will have 3 days of class periods to research, create, and prepare their presentations.

DAY 2 (50 MINUTES)

Review multiplication, addition, and subtraction involving fraction as a class. Some example problems are: a) 1/4 + 3/5, b) 1/5 – 1/8, c) (35)(– 2/3).
Tell students the goals of this project are the following:

- To work cooperatively as a group using class time efficiently.
- To apply their knowledge of healthy food choices to select a balanced dinner that contains low amounts of saturated and trans fat at one fast-food restaurant.
- To use their mathematics skills to determine the amount of food needed and evaluate the food choices made by their group members.

Explain that not all fat is created equal. Fat can protect our organs, keep us warm, and store energy. Some fats, like unsaturated fat, are healthy for the heart; but other fats, like saturated fats, can damage arteries and lead to heart disease over time. Trans-fat does the most damage and should be avoided. The U.S. *Dietary Guidelines* recommend that children and teenagers consume between 25 and 35 percent of calories from total fat (unsaturated, saturated, and trans-fat) and no more than 10 percent of their calories from saturated fat. Tell students to take their journal out and record the following:
The midrange limits for total daily fat intake for adolescents are as follows: .

1. Girls 11 to 14 years old: About 65 grams per day of total fat with 20 or fewer grams of saturated fat
2. Boys 11 to 14 years old: About 80 grams per day of total fat with 25 or fewer grams of saturated fat.

Students will be put into groups of 4 or 5. Students will now head to a computer lab. They will research individually. They will first go to the website http://www.choosemyplate.gov/food-groups, which gives the healthy food guidelines. There are other websites available, and they can be located easily by searching for "food pyramids." At this website, students will look and examine the different food groups and the total amount of daily calories a person needs at certain ages and by gender. The purpose for this website is to receive explanations of how the five food groups are building blocks for a healthy diet and to determine the right number of calories that Sarah and Daniel would need in a day.

DAY 3 (50 MINUTES)

Students will access the computer lab to research about the restaurant menus and prices. Remind students that they should be completed researching by the middle of class time and should start preparing their PowerPoint® presentations after their research is completed.

DAY 4 (50 MINUTES)

Students will continue to work on completing their PowerPoint® presentations by checking the presentation rubric. They will practice their presentations within their groups.

DAY 5 (50 MINUTES)

Each team will be given five to ten minutes to present their presentations to a panel of health professionals. The students will be graded based on the points outlined in the summative assessment rubric.

EXTENSION

Below are a few ideas that can be added to the PBL at the discretion of the teacher:

- Write a journal of your food consumption for a day and analyze how nutritious your food choices were by comparing them to the healthy eating guidelines.
- Visit the local shopping center or the mall and record the following in your journal: Names of fast-food restaurants, Menus that include vegetables and fruits at each restaurant, and menus that provide information about low fat, no fat, or low in saturated or trans-fat. After students have recorded the required information, determine which restaurants offer the healthiest eating options. Then, determine which restaurants are the least and most expensive to eat at.
- Imagine you are an owner of a restaurant, where it is important to have healthy food options. You get to create healthy menus that this restaurant will serve. Design and create 5 different menu options and include the amount of total fat, saturated fat, calories etc. Once you have your five created food options, make a paper menu for customers.
- Assume it is impossible to eat healthy at fast-food restaurants. Make suggestions about healthy food choices and a physical activity plan for Sarah or Daniel, which can keep them healthy while they dine out at fast-food restaurants.

EVALUATION

Group Contribution Log Checklist

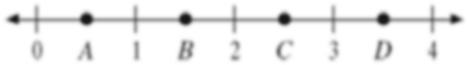
Dates are listed	/5
Descriptions are detailed	/10
Accurate journal setup	/5
Approval from one of group member (agree/ disagree)	/10
Total	/30

Presentation Checklist/Rubric

Title of Presentation: Name of Group: Name of Reviewer:					
Expectations	**Excellent 4**	**Good 3**	**Fair 2**	**Poor 1**	**Missing 0**
1) The presentation is well delivered with poise, confidence, eye contact, and appropriate pacing.					
2) The presentation is well organized and easy to follow.					
3) Visual aids and/or handouts are clear and contribute to the presentation.					
4) All mathematics is calculated without error.					
5) Information about the food pyramid and healthy eating guidelines is accurate.					
6) The amount of dollars spent does not exceed the limit ($8).					
7) A clear picture or chart of the connections among food types, food quantities, and dietary roles is provided.					
8) A well-constructed argument to defend your food choice is clearly delivered.					
9) Evidence from the online research is cited and supports the stated argument.					
10) A strategy for collecting, organizing, and analyzing the data from the measure is described.					
11) The presenter is able to provide thoughtful responses to any questions asked by the panel.					

Multiple Choice Questions

1. Which point shows the location of 3/2 on the number line?



A) A
B) B
C) C
D) D

2. $\frac{1}{4}+\frac{3}{5}=$

A) $\frac{4}{9}$ B) $\frac{4}{20}$ C) $\frac{17}{20}$ D) $\frac{4}{3}$

3. Kellogg's uses a scale of 1 serving equals 100 grams of cereal. How many grams of cereal are represented by 5 servings in this brand?

A) 20 grams
B) 500 grams
C) 100 grams
D) 50 grams

4. The weekly milk order for Subway includes 35 gallons of non-fat milk and 20 gallons of chocolate milk. What is the ratio of the number of non-fat gallons to chocolate gallons in Subway's weekly milk order?

A) 2:1
B) 5:3
C) 7:4
D) 9:5

Correct Answers: 1-B 2-C 3-B 4-C

RESOURCES

Healthy Food Guidelines:
- http://www.choosemyplate.gov/food-groups
- http://www.helpguide.org/articles/healthy-eating/healthy-eating.htm,
- http://www.hsph.harvard.edu/nutritionsource/

Food Pyramids: Google search "food pyramids":
- http://en.wikipedia.org/wiki/Food_pyramid_(nutrition)
- http://www.eufic.org/article/en/expid/food-based-dietary-guidelines-in-europe/

Restaurant Websites:
- Panda Express: https://order.dominos.com/en/assets/derived/pdf/DominosNutritionGuide.pdf
- Dominos: https://www.subway.com/Nutrition/Files/NutritionValues.pdf
- Subway: https://www.subway.com/Nutrition/Files/NutritionValues.pdf

MAKENNA ARCA AND JENNIFER G. WHITFIELD

25. SURVIVAL OF THE FITTEST

Flying Hamster Genetics

SCHEDULE AT A GLANCE

Days 1–2	Days 3–4	Days 5–6	Days 7–8
Present scenario research; brainstorm trait; begin field journal	Make hamsters from selected traits	Survival of the fittest when disaster strikes	Calculation of allelic frequencies

WELL-DEFINED OUTCOME

Students will use probability and statistics to maximize reproductive success given the repercussions of a disaster. They will keep a Darwinian-style journal for the duration of the project and, using this data, will create a report including the implications of genetic drift on the resulting generation of flying hamsters.

TEACHER INTRODUCTION

This PBL will challenge students to recognize implications of Mendelian inheritance and population genetics over a span of eight class periods. Students will research common mammalian traits and inheritance patterns and as a class will decide on traits to study in the class's population of flying hamsters. They will construct 3D models – from potatoes and other items – of their own flying hamsters based on randomly selected genotypes. Their task will then be to maximize reproductive success in their selection of a mate from the population of flying hamsters in the class after a disaster strikes and the hamsters are left stranded in a novel environment.

OBJECTIVES

This PBL will allow students to develop the following knowledge and skills in each of the identified areas below.

Science – The student is expected to:

- Construct an accurate karyotype for his or her flying hamster.
- Apply Mendelian laws to predict and calculate phenotypic and genotypic ratios of offspring.
- Analyze an emergency situation to act in the best interest of the population.
- Present post-disaster litter statistics.
- Compile a report on the implications of genetic drift and its effects on population genetics.
- Practice planned and deliberate investigation of the natural world through stimulation of natural events.
- Recognize the significance of meiosis with respect to sexual reproduction and analyze and evaluate how the elements of natural selection, including inherited variation and genetic drift result in differential reproductive success.

Mathematics – The student is expected to:

- Gather data, conduct investigations, and apply mathematical concepts and models to solve problems in other disciplines.
- Apply, compare, and contrast probabilities to make and justify decisions about risks in the project and as an extension, in everyday life.
- Report results of statistical studies, including selecting an appropriate presentation format, creating graphical data displays, and interpreting results in terms of the question studied.

M. M. Capraro et al. (Eds.), A Companion to Interdisciplinary STEM Project-Based Learning, 209–214.

Technology – The student is expected to:

- Use Google Maps to identify the location of the disaster.
- Use Excel® to calculate the probabilities of genetic events.
- Apply probability tools to solve problems.
- Investigate how the concepts of discrete mathematics are related to relevant problems and significant questions.

STEM CONNECTIONS

This PBL will reinforce and strengthen the following concepts and skills already learned by the student.

Science

- Reinforce Mendelian inheritance, prediction of possible outcomes of various genetic combinations such as monohybrid crosses, dihybrid crosses and non-Mendelian inheritance.
- Students will recognize the significance of meiosis to sexual reproduction and analyze and evaluate how the elements of natural selection, including inherited variation and genetic drift, result in differential reproductive success.
- Students will differentiate between planned and deliberate investigation of the natural world through stimulation of natural events.

Technology

- Students will use Excel® to generate probabilities, present data, calculate the probabilities of genetic events, and apply probability tools to solve problems.
- Students will investigate how the concepts of discrete mathematics are related to relevant problems and significant questions.

Mathematics

- Students will gather data, conduct investigations, and apply mathematical concepts and models to solve problems in other disciplines.
- Students will apply, compare, and contrast probabilities to make and justify decisions about risks in the project and as an extension, in everyday life. Students will report results of statistical studies, including selecting an appropriate presentation format, creating graphical data displays, and interpreting results in terms of the question studied.

STUDENT INTRODUCTION

A new species of flying hamsters has emerged at the Woodland Park Zoo in Seattle. Authorities at the zoo have agreed to trade half of the flying hamster population for a baby panda from the Beijing Zoo. Beijing has a similar climate to that of Seattle, and the hamsters are expected to adjust easily to their new home. You will begin this project by researching dominant-recessive traits, and as a class, you will decide on five traits to focus on in your population of hamsters. You will produce a model of your individual hamster based on genotypes you randomly select from a paper bag. Once the hamsters arrive at their new home, the class will be responsible for proving to Beijing authorities that this was a worthwhile trade by producing a viable F1 generation. Keep in mind Beijing's humid climate and the abundance of bamboo that will be present in their new habitat at the zoo.

MATERIALS USED

- Computers with internet access
- Potatoes
- Sweet potatoes
- Googly eyes
- Foam
- Glue
- Paper bags with paper alleles in them (trait bag)

- Karyotype handout (see Evaluation section)
- Google Maps
- Microsoft Excel®

DAYS 1–2 (5O MINUTES EACH DAY)

The teacher will explain to students that they have been tasked with accompanying a population of novel flying hamsters from Seattle to Beijing. Once they arrive in Beijing, they will have to prove the worthiness of this new species by successfully breeding an F1 generation. To do so, the focus must be on five traits. Each trait is inherited in a dominant-recessive fashion, and the genes coding for the traits are located on a separate chromosome. At this point the teacher should show some videos on dominant and recessive traits and the properties of alleles. Some possible videos are given below:

- https://www.youtube.com/watch?v=5XuiboCs0TA (04:45)
- https://www.youtube.com/watch?v=bjkB5cqXdlY (05:32)
- https://www.youtube.com/watch?v=NWqgZUnJdAY (0:16:03)

During this project students will be charged with researching various traits that might be beneficial for hamsters living in Beijing. The teacher may suggest coat color, wing shape, fur versus bare skin, or any other traits to get students brainstorming. Allow students to brainstorm and keep a running list of traits they may want to include in this species' genome. Some research on Beijing's climate may also be necessary if students are not already familiar on what it will be like to live in Beijing. Once brainstorming slows or reaches a lull, allow students to discuss the proposed traits and decide on five traits on which to focus for their flying hamster population. Once traits are selected, the class will choose which version of each trait will be dominant and which will be recessive. Alleles can be designated A, a, B, b, C, c, D, d, E, and e for simplification. The teacher will make 5 "trait bags" for each trait the class chooses (e.g., eye color, wing shape, skin covering, etc.) and place designated alleles in each bag. For example, if "A" is a dominate eye color and "a" is recessive eye color, the teacher will put capital "A" and lowercase "a" in the eye color bag. The number of paper alleles in each bag should be twice the total number of students in the class, but the teacher may decide how many dominant versus recessive alleles to include for each trait.

At this point, it is critical to stress the importance of keeping a journal throughout this process. Beijing Zoo authorities are very strict and will want detailed accounts of each hamster's journey from Seattle to China.

DAYS 3–4 (50 MINUTES EACH DAY)

Next, the teacher will allow each student to choose two paper alleles (letters) out of each "trait bag". Based on the genotypes selected from the bag, each student will create a model of their hamster using a potato as the body and whatever other accessories are needed to correspond to the selected traits. Finally, each student will complete a karyotype by indicating dominant or recessive alleles on each chromosome using specified colors (see Evaluation section for flying hamster karyotype worksheet). For example, if blue was code for dominant and red was code for recessive and the student's genotype for trait B was Bb, one of the chromosomes in the pair coding for trait B would have a blue colored band and the other chromosome would have a red colored band. To conclude this portion of the project, administer the Meiotic Events Review Quiz (see Evaluation section) to ensure students have a firm grasp on Mendelian Inheritance as it relates to sexual reproduction before continuing on with the project.

DAYS 5–6 (50 MINUTES EACH DAY)

Disaster strikes! While the plane carrying the class and hamsters was somewhere over the Pacific, it was struck by lightning and crashed on a remote island located at a location the teacher will give as geographic coordinates. Students will use Google Maps to locate the scene of the accident, and the teacher will guide students into a discussion of this new habitat in which the hamsters will now be forced to survive. In this new environment, certain genotypes will be unviable in the F1 generation. Based on this new environment and phenotypes alone, each student must find a mate for their hamster. This has turned into a survival of the fittest scenario, and the goal is to maximize reproductive success.

After selecting a mate, student pairs will complete Punnett squares for each trait using their hamsters' genotypes. Using these Punnett squares, they will calculate genotypic and phenotypic probabilities for each trait, and based on these, they will calculate maximal possible reproductive success given the genotypes of their hamsters. Partner pairs will then put their paper alleles into a bag and simulate a

breeding of however many hamster babies they choose. They must choose the litter size before beginning their mating simulation. Each "mating" will consist of randomly selecting one allele from each of the two hamsters' genotypes. The selected two alleles will constitute the baby hamster's genotype for that trait. This will be repeated for each trait, and the entire process will be repeated for each flying hamster offspring.

DAYS 7–8 (50 MINUTES EACH DAY)

Students will compare predicted allelic, genotypic, and phenotypic frequencies with actual allelic, genotypic, and phenotypic frequencies using Microsoft Excel®. They will generate charts in whatever format they think best communicates their findings. Given allelic frequencies from the F1 generation, student pairs will calculate allelic, genotypic, and phenotypic frequencies for the F2 generation. These frequencies will be used to determine whether it will be possible for the population to reach Hardy-Weinberg equilibrium.

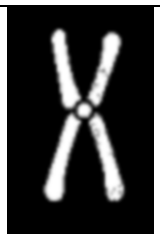
EXTENSION

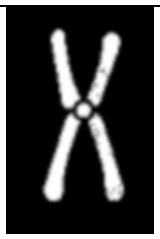
Instruct students to compile a final reflective report in whatever format they choose integrating data and observations from their notebook with their findings and success in the Survival of the Fittest competition. Ask students to address questions such as:

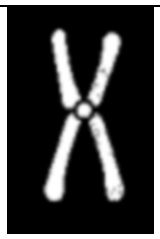
- In what ways are population genetics predictable?
- How can the stability of population genetics become disrupted?
- Is it possible for a disadvantageous allele to persist in a population? If so, how?
- Has what happened to the flying hamster population ever happened to a real population before? Find and present an example.

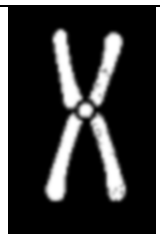
EVALUATION

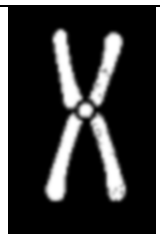
Flying Hamster Karyotype


Chromosome A


Chromosome B


Chromosome C


Chromosome D


Chromosome E

Darwinian Journal Rubric

Component	0 points	2.5 points	5 points
Organization	The student does not have dates or complete reflections/data recorded.	The student's reflections and data and/or questions are recorded but not organized or dated.	The student's observations are clearly organized and dated. Reflections and data are thorough and complete.
Detail	Little or no detail is given about events occurring throughout the PBL. Entries are not present for each day.	Entries are present for each day but give minimal detail and do not include well thought out reflections or questions.	The student's observations are well detailed and thoughts/reflections or questions are present.
Integration	Nothing relates to concepts covered throughout the PBL.	One or two concepts related to Mendelian Inheritance or inheritance patterns are included.	Several, if not most, entries relate concepts discussed to the events that unfolded throughout the PBL.

Final Reflective Report Rubric

Presentation Medium: Written Visual Video Other:

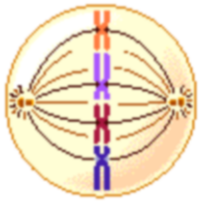
Component	0 Points	1 Point	2 Points	3 Points
Essential Questions ***(provided in assignment instructions)***	The student does not answer any of the questions.	The student provides answers to some questions.	The student provides adequate answers to each question.	The student provides well thought-out answers to all questions.
Understanding of Content	The student does not mention any content.	The student mentions content but does not demonstrate understanding.	The student demonstrates some understanding of content, but does not fully address project topics.	The student demonstrates thorough understanding of all topics included in the project.
Critical Thinking and Application to Real-World Problems	The student does not make any connections between the project and real-world events.	The student attempts to relate project results to real-world problems.	The student clearly addresses a real-world problem and relates it to project content.	The student demonstrates critical thinking in relating and applying specific project content to a real-world problem.
Communication and Organization of Ideas	There is no flow and no communication or organization of ideas.	The student communicates ideas but in an unorganized manner.	The student communicates ideas and organizes them in a coherent fashion.	The student communicates ideas and conclusions in an organized, neat, and professional manner.
Self Evaluation	The student does not address problems encountered during the project nor any ideas for improvement.	The student mentions problems encountered but does not address ways in which he or she could improve.	The student discusses challenges encountered during the project and provides some suggestions for improvement.	The student provides an in-depth analysis of individual performance and detailed ways in which performance could be improved.

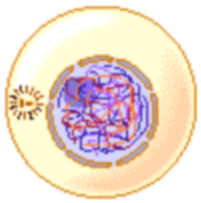
Additional Comments/Feedback:

Meiotic Events Review Quiz

1. While not dividing, which of the following best represents what your hamster's chromosomes look like? (Circle the best choice.)

A) B) C)





2. Which phase of the cell cycle is displayed in the answer to question 1? _____

3. When one of your hamster's cells enters Anaphase II, ____ sister chromatids are present.

A) 5 B) 10 C) 20 D) unknown

4. What types of cells undergo meiosis? (Check all that apply)

☐ cardiac cells
☐ muscle cells
☐ sperm cells
☐ skin cells
☐ ova
☐ gametes
☐ None of the above.

5. At the beginning of Meiosis II, cells are _____.

A) haploid B) diploid

6. Meiosis of one of your hamster's cells would produce _____ daughter cells with _____ chromosomes each.

7. If somehow your hamster lost the right chromatid of chromosome 2, what would happen to the hamster's phenotype?

8. The purpose of meiosis is to produce _____.

9. Your hamster is _____ for wing shape.

A) homozygous dominant B) homozygous recessive C) heterozygous

10. All chromosomes are the same size.

A) True B) False

Correct Answers: 1-B 2-Interphase 3-B 4-sperm cells, ova, gametes 5-A 6-4, 5 7-Answers will vary 8-gametes 9-Answers will vary 10-B

REFERENCES

Chin, Greg. "Properties of Alleles." *Education Portal.* 2013. http://education-portal.com/academy/lesson/dominant-versus-recessive.html#lesson

The McGraw Hill Companies. "Simulation of Genetic Drift." http://highered.mheducation.com/sites/dl/free/0072835125/126997/animation45.html