What is Problem-Based Learning?

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Draft Summer 2014
Teachers work with local scientists to analyze the plants and animals living in the mud at the bottom of a pond in order to understand how the ecosystem is being affected by human populations.
PROBLEM SOLVING IN EDUCATION

A mechanic is trying to figure out why a car won’t start. A politician is looking for ways to get the country out of a recession. A biologist is investigating the impact of fertilizer on a river ecosystem. While, on the surface, these scenarios appear to be different, they are, at their core, very similar. In each case, someone is using a variety of skills and content knowledge to solve a real problem that has many possible solutions.

As we continue to move further into the 21st century, some problems such as pollution, deadly diseases, and water shortages will endure. Also, a whole new set of problems, most of which we cannot predict, will arise. This continually changing set of challenges will require people to be adept at problem solving, critical thinking, and inquiry skills in order to find plausible solutions to yet unknown dilemmas.

Based on this reality, 21st century educators need to focus on problem solving (Delisle, 1997). From fan belt calculations on a car, to policy analysis of state budgets, to water quality experiments, teachers should be providing students with the mental and physical skills needed to answer the unknown questions and solve the problems that will continually surround our lives.

Unfortunately, the kinds of problems that students generally encounter in school have little to do with the problems that they need to solve in everyday settings (Lave, 1988; Roth & McGinn, 1997). Whereas classroom problems posed by textbooks and teachers are typically well-structured, the kinds of problems that students face in real-world situations are mostly open and ill-structured (Chin & Chia, 2005). In this document, we will refer to open, ill-structured problems as “messy” problems.

The types of problems or scenarios presented in school are normally well-structured and have convergent solutions that engage the application of a limited number of rules and principles within well-defined parameters. In contrast, ill-structured or “messy” problems possess multiple solutions, various paths to find a solution, and fewer parameters which are able to be manipulated. These types of problems also contain uncertainty about which concepts, rules, and principles are necessary for the solution, or how they are organized and which solution is best (Jonassen, 1997). A properly designed messy problem is a key factor distinguishing problem-based learning (PBL) from other instructional models. “PBL begins when students meet an ill-structured problem” (Stepien & Pyke, 1997).
WHAT IS PROBLEM-BASED LEARNING (PBL)?

PBL is defined by VISTA as

“students solving a problem with multiple solutions over time like a scientist in a real-world context.”

This situating of learning processes in an authentic context is one of the key features of PBL (Barrows, 1994; Duch, 2001; Hmelo & Ferrari, 1997; Koschmann, Myers, Feltovich, & Barrows, 1994; Hmelo, 1998; Torp & Sage, 2002). Furthermore, by allowing students to become involved in real-world, meaningful problems, PBL helps students develop problem-solving skills through active learning rather than by passively receiving information from teachers (Gallagher, 1997; Krajcik & Blumenfeld, 2006).

Problem-based learning was first developed in the medical education field to help students develop both content knowledge and the clinical reasoning skills needed by medical professionals (Barrows & Tamblyn, 1980). PBL has since been adapted for teaching science (Allen, Duch, Groh, Watson & White, 2003; Gordon, Rogers, Comfort, Gavula, & Mcgee, 2001), and has been shown to increase students’ intrinsic motivation to become self-directed learners (Hmelo-Silver, 2004; Kelson, 2004).

Despite being an appropriate and versatile strategy for teaching inquiry-oriented science, most teachers have little experience designing and implementing PBL lessons (McDonald & LaLopa, 2006). Teachers often report that they struggle to “find PBL activities” (McConnell, 2008). In the following sections of this manual, you will learn about the basic components of PBL and how to create PBL learning environments for your own classroom in order to improve your instructional practice and increase your students’ achievement in science.
WHAT IS THE RELATIONSHIP BETWEEN INQUIRY, HANDS-ON SCIENCE, AND PBL?

Since there are a variety of definitions in the literature, it is necessary to explain how we are defining the components of PBL. Problem-based learning is a curricular approach or framework for structuring the content in a unit of study around a problem question with multiple solutions that students are solving in a real-world context. “Hands-on” and “inquiry” refer to pedagogical techniques which are used during the implementation of a PBL unit. Inquiry and hands-on science are utilized for their ability to foster appropriate behaviors needed for successful problem solving. As illustrated in the diagram below, PBL provides the overarching content organization while inquiry and hands-on science are used as instructional strategies to ensure successful implementation.

DEFINITIONS

HANDS-ON SCIENCE: Students purposefully manipulate real science materials when safe and appropriate in a way similar to a scientist.

INQUIRY: Students ask questions, collect and analyze data, and use evidence to solve problems.

PROBLEM-BASED LEARNING: Students solve a problem with multiple solutions over time like a scientist in a real-world context.
What does the research data say about the effectiveness of PBL

Much research has been conducted about the effectiveness of PBL. The table below outlines some of the research on PBL’s affect on student learning, achievement, and motivation.

### TABLE 1. PBL Research Findings

<table>
<thead>
<tr>
<th>Study</th>
<th>Findings</th>
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<tr>
<td>Sungar, S., Tekkaya, C., &amp; Geban, O. (2006) Improving achievement through problem-based learning. Journal of Biological Education, 40(4), 155-160.</td>
<td>In this study, the students in the PBL treatment group earned significantly higher scores than the control group in regard to science achievement and performance skills. Not only were they better able to organize and use relevant information, but they made stronger conclusions. PBL students believed that the cooperative approach of PBL coupled with the practical application of knowledge contributed to their learning.</td>
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<tr>
<td>Wong, K. K. H, &amp; Day, J. R. (2009). A comparative study of problem-based learning and lecture-based learning in junior secondary school science. Research in Science Education, 39, 625-642.</td>
<td>The authors found that students learning via PBL achieved higher-order learning goals, higher motivation through curiosity, and better retention in both units (42% positive change for control compared to 79% positive change for treatment in reproduction unit; 35% positive change for control compared to 162% positive change for treatment in density unit.)</td>
</tr>
<tr>
<td>Tarhan, L., &amp; Acar, B. (2007). Problem-based learning in an eleventh grade chemistry class: Factors affecting cell potential. Research in Science &amp; Technological Education, 25(3), 351-369.</td>
<td>The findings in this study according to interviews revealed that students in the PBL class were more motivated, self-confident, willing to problem-solve and share knowledge, and were more active in cooperative group activities than the traditionally-taught students.</td>
</tr>
<tr>
<td>Drake, K. N., &amp; Long, D. (2009). Rebecca’s in the dark: A comparative study of problem-based learning and direct instruction/experiential learning in two 4th-grade classrooms. Journal of Elementary Science Education, 21(1), 1-16.</td>
<td>In this study, the treatment group experienced more time on task (by 10 percentage points) and less inappropriate and non-productive behavior than the comparison group. The treatment group could better identify problem-solving strategies than the comparison group four months after treatment.</td>
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When designing a PBL unit for your classroom, it must contain a few basic components:

**TOPIC**
Content Area of PBL
Examples:
- Energy
- Geology

**THEME**
Focus area of PBL within content area selected
Examples:
- Effect of energy crisis on people and the environment (energy)
- Effect of geologic disasters on people and the environment (geology)

**SCENARIO**
Realistic situation which provides the context or framework for the PBL
Examples:
- Your region’s power station is shut down as a result of a solar event. You have been asked to assess the situation and provide alternative energy sources and solutions to problems arising from the power loss. (energy)
- An earthquake has recently struck your area. With potential for more earthquakes, you have been asked to develop a plan for protecting people and property. (geology)

**PROBLEM QUESTION**
Overarching question of PBL which poses a real scientific problem with multiple solutions
Examples:
- How do we minimize the impact on the county from the shutdown of the power station? (energy)
- How will the school plan to protect the people and property from a future earthquake? (geology)

**STUDENT ROLE**
Authentic scientific role of students within PBL
Examples:
- Students are members of the county emergency response team (energy)
- Students are members of the local geological survey team (geology)

**CULMINATING ACTIVITY**
Activity/Project which allows students to demonstrate/display/present their solutions to the PBL
Examples:
- Students present their assessment and alternative solution models to a panel of local decision makers on the power loss issue. (energy)
- Students share their disaster assessment plan with the school board (geology)
Work Flowchart for Designing a PBL Unit

Follow this flowchart when designing PBL units to ensure there is connectivity between all components of the unit.

1. TOPIC
2. THEME
3. SCENARIO, PROBLEM QUESTION, STUDENT ROLE
4. CULMINATING ACTIVITY

These three pieces of your PBL unit should be developed simultaneously to ensure connectivity throughout the unit.
Setting Up the Unit

Before you begin designing all of the lesson plans and activities that your students will complete in a PBL unit, it is critical to conduct a series of front-end analyses of the course content and context areas of your PBL unit. This analysis will equip you with a frame of reference when you are designing the instruction components to appropriately address the breadth and depth of the content and the context that your specific PBL unit is meant to accomplish. As noted in the research, without a complete cognitive map and understanding of the PBL unit, the teacher is likely to guide the student with his or her own preference of solving the problem instead of guiding the students to tackle the problem from different angles (Hung, 2009).

Identify a Topic

When you start building your unit, the first step is to identify the topic of study for your PBL. The topic refers to the overarching content area that the unit will focus on. Examples include geology, energy, forces and motion, living systems, or space systems. In many cases, unit topics are associated with a higher-level strand of the national, state, or district-level standards of learning. So, a good place to start looking for ideas for topics is your various levels of standards or curricular frameworks for your particular grade.

Along with your standards and curricular frameworks, you may also consider the following strategies and questions to help identify unit topics:

- **Past state science test data** – Which areas of the state test have students been struggling with in previous years?
- **Past benchmark assessments** – What areas have your students struggled with on past benchmark assessments you or other teachers have given?
- **Pretest** – Give your students a pretest at the beginning of the school year on a variety of content strands within your curricular framework to determine where your students are currently struggling.

Identify Standards associated with Topic

Once the topic is determined, it is essential to determine all of the science standards and benchmarks that correlate with the unit at the national, state, and/or district level. This is also an opportunity to look through standards and benchmarks for other subjects, such as mathematics, social studies, reading, language arts, music, and art, to determine the variety of subject standards you can cover within your single PBL unit and as you develop the theme of the unit in the next step.
Determine the Theme

A unit topic, such as energy, provides a good starting point for directing PBL unit development. However, it is still extremely broad and diverse in terms of helping developers and students focus on the problem that has been selected. For example, an energy unit could focus on the different types of energy that exist in the universe, or it could focus on diversifying the energy portfolio in your local area from a policy point of view. Therefore, a PBL theme must be determined to help focus the unit within the topic. Essentially, the theme of the unit outlines the societal focus of the PBL within the topic area selected. The theme will help the unit become clearer to the instructor throughout the development process, and to the students throughout implementation. Some theme examples include:

- Impact of an energy crisis on the local community and environment
- Impact of human activity on local ecosystems

Design a Meaningful Problem Scenario

As shown in the work flowchart, the scenario of the PBL unit should always be developed in conjunction with the student role and problem question to ensure connectivity and consistency through the unit. The scenario essentially outlines the story or sets the stage for students by presenting them with a description of the problem they will face and attempt to resolve. Some examples of PBL scenarios include:

- Energy: Your county is about to reduce the power output to all homes in your region for two months as the power station is being renovated. You have been asked to assess the situation and provide possible alternative energy sources and solutions to problems arising from the power reduction to all homes.
Weather: Based on previous weather-related disasters in your area, your town is looking to design and construct a model of a disaster-resistant city that could serve as a prototype for how to develop the city in the future. This city should be able to withstand natural disasters so that the people living in that area would remain safe.

Developing the Student Role
In conjunction with the development of the scenario and problem question, you should also develop the student role. This will give your students a job title and job description that they will adopt throughout the PBL unit. The overall function of the student role is to establish the students’ stake in the problem. Here are some examples of student roles and the associated unit topic:

- Energy: Students are scientists working as members of the Arlington Community Emergency Response Team
- Geology: Students are young geologists working with the Virginia Department of Emergency Management
- Weather: Students are junior meteorologists working with local civil engineers in Louisa county

When developing the student role, consider researching real positions or roles people in your community undertake as part of their careers. Consider contacting some professionals in your community to come to your classroom to discuss their careers. This will help your students understand their role better. This will also, in many cases, increase the engagement of students in their role within the PBL unit.
The problem question is one of the most important parts of a PBL unit. It is not only the ultimate unit question that the students are trying to answer, but it is also the question which will determine the level of student engagement throughout the unit. As shown in the work flowchart, it should always be developed along with the scenario and student role to ensure successful connectivity throughout the unit.

Overall, the problem question is a real scientific problem with multiple solutions. It should be stated as a question that will be solved over time by the students throughout the unit. The literature has presented that many teacher frustrations with PBL units can be traced back to the quality of the problem question (McConnell, 2008). So, in order to help you design quality problem questions for your future units, it is important to discuss the aspects of quality PBL problem questions.

**Well-Structured vs. Ill-Structured**

Problems vary on a continuum from well-structured to ill-structured (Arlin, 1989; Jonassen, 1997; Newell & Simon, 1972). According to Jonassen (1997), ill-structured, messy problems are characterized as containing vaguely defined goal states, several unknown problem elements, multiple plausible solutions, and ambiguity about the concepts or principles needed to solve them, while well-structured problems possess well-defined goal states, prescriptive arrangement of concepts and principles used, and a single definite solution. Problem questions posed by textbooks and teachers are typically well structured, whereas the kinds of problems that students face in real-world situations are mostly open and ill structured, or messy. Therefore, the kinds of problems that students encounter in school have little to do with the problems that they need to solve in everyday settings (Lave, 1988; Roth & McGinn, 1997).

In addition, scientists frequently encounter ill-structured problems that can have multiple paths to multiple solutions (Jonassen, 2011). To approach such problems, “higher-order” mental operations such as analysis, synthesis, and abstraction are key. In addition, creative thinking—the most complex and abstract of the higher-order cognitive skills according to Bloom’s taxonomy of learning skills (Krathwohl, 2002)—can allow restructuring of problems and
produce solutions through unexpected insights (Bowdenet, 2005).

In PBL, the purpose of ill-structured problems is to help students develop their ability to adaptively apply their knowledge to deal with complicated problem situations that are normally seen in real world settings (Wilkerson & Gijselaers, 1996). Students need to be reminded that there may be other ways to view a problem than the way it is presented; they can list the problem features and then try to rearrange or restructure them or look at them from different angles (Bowdenet, 2005) and to generate many ideas about possible solutions before beginning to evaluate which of them may be best (Bowdenet, 2005; McWilliam, Poronnik, & Taylor, 2008).

When developing PBL problem questions, they should be ill-structured, messy problems and contain the following characteristics:

- require more information for understanding the problem than is initially available.
- contain multiple solution paths.
- change as new information is obtained.
- prevent students from knowing that they have made the “right” decision.
- generate interest and controversy and cause the learner to ask questions.
- are open-ended and complex enough to require collaboration and thinking beyond recall.
- contain content that is authentic to the discipline.

(Adapted from Allen, Duch & Groh, 1996; Gallagher, 1997.)
Along with the characteristics of messy problems, here is a list of questions to consider when developing your own problem questions:

1. **Is the problem question appropriate for the curriculum?**
   Is the question directly related to the topic, theme, standards, scenario, and student role of the unit being developed? This should be one of the first considerations when developing your PBL problem question and is one of the main reasons for the front-end analysis discussed in the previous section.

2. **Does the problem question allow for inquiry?**
   When developing a problem question, determine if it will provide an impetus to develop the following characteristics of inquiry within the PBL:
   - Will the question promote students to ask questions?
   - Will the question cause students to think critically about the relationships between evidence and explanations?
   - Will the question encourage students to construct and analyze alternative explanations?
   - Will the question create situations where students are communicating scientific arguments?

3. **Is the problem question authentic and relevant?**
   Gaining practice addressing and applying knowledge to real-world scenarios is one of the greatest strengths of PBL units. Make sure that your students are familiar enough with the content and context of the question to be perceived as relevant and important to their lives.

4. **Is the problem question open-ended?**
   Most problems people face in the real world are not straightforward, easy, and neat. In many of these real-world cases, multiple options for developing solutions are created, discussed, justified, debated, and confirmed with others leading to a deeper understanding of the concepts at hand. By creating a problem question that is open-ended, your students will utilize the same cognitive strategies used by scientists as they work together to analyze multiple, viable hypotheses or answers to the problem.

5. **Is the problem question engaging?**
   Many times educators develop units they think will be engaging to their students and grab their attention, only to find out through implementation that the idea flops from lack of interest from the students. One strategy that may help to find engaging topics includes finding ideas from current events in newspapers, magazines, news programs, TV series, and movies. These may not provide the exact events you wish to cover in your class, but they can lead you to general topics that can be explained using the science concepts you teach in your class. Another strategy involves polling the students for the types of questions and ideas that interest them. This question/idea gathering could happen at the beginning or throughout the year. Then you can always reference their responses as you begin developing new questions and units, as student interests will change throughout the year and from year to year.
6. Is the question appropriately challenging?
Many educators may think that they would not want to make the problem question too difficult for their students. However, recent research has shown that teachers reported lower satisfaction with problems that could be answered with little or no need to search for answers or explore the phenomena (McConnell, 2008). McDonald and LaLopa (2006) also noted that PBL problems often do not offer enough challenge to push students thinking, and research confirms the importance of making problems appropriately challenging. Making the problem question more complex forces the learners to work together to conduct research and investigations, while continually interpreting and applying the information to the overarching scenario. Through this process, students begin to construct their own new ideas, stretching the boundaries of their understanding of the science concepts, and spark their interest in the scientific process of inquiry.

7. Are information and resources easily available to answer the question?
This question is especially relevant for students who may be newer to PBL and have not yet learned some of the essential skills of developing solutions to a variety of problems. Conduct some basic research of your own before you begin your unit to determine what types of information your students will encounter. Also, ask the resource managers and librarians to gather information that will be helpful for the topic and theme of the problem question. Having information and resources easily accessible will increase the ease with which your students can explore the problem question.

PROBLEM QUESTION EXAMPLES

- How can we mitigate the affect of land and building development on the soil and water in our local community?
- How can we minimize the spread of invasive species and their negative impacts on Virginia’s ecosystems?
- How can we minimize the impact to the ocean environment if the energy resources are developed off the coast of Virginia?
DEVELOP CULMINATING ACTIVITY

Setting up the Unit

Determine Culminating Activity

At the end of your PBL, your students will complete a final culminating activity which you can use as the final assessment of their performance within the PBL unit. For development purposes, it is always good to develop and understand the nature and structure of the final activity the students will be working towards so that they can effectively and efficiently complete the PBL unit. This will also help you develop lessons that are continually helping your students build resources and knowledge that will be utilized during the culminating activity. One of the prime functions of this activity will be to help the students reflect on their progress within the PBL unit. Some examples of culminating activities include:

- Engaging in a presentation to the class, school administration, community members, city council, mayor, and/or parents
- Engaging in a panel discussion with other students, parents, administrators, community members
- Creating videos, podcasts, or other broadcasts summarizing their findings
- Engaging in a debate with other students, parents, administration, and/or community members
- Writing creatively on the topic, theme, scenario including all of the information collected
- Writing a proposal to school administration, city councils, elected officials, or local scientists or scientific organizations
- Building a model that demonstrates ways to address the problem question
PBL UNIT DEVELOPMENT CHECKLIST
Review and refine for continuity across all six components

**TOPIC**
OVERARCHING CONTENT AREA OF PBL UNIT

**THEME**
STATEMENT WHICH OUTLINES THE SOCIETAL FOCUS OF THE PBL UNIT

**SCENARIO**
SITUATION THAT DESCRIBES THE SCENE THE STUDENTS WILL BE WORKING WITHIN THROUGHOUT THE PBL UNIT

**PROBLEM QUESTION**
A SCIENTIFIC PROBLEM WITH MULTIPLE SOLUTIONS STATED AS A QUESTION THAT WILL BE SOLVED BY THE STUDENTS THROUGHOUT THE PBL UNIT

**STUDENT ROLE**
ASSIGNED ROLE OF STUDENTS WITHIN THE PBL UNIT

**CULMINATING ACTIVITY**
FINAL STUDENT PERFORMANCE WITHIN THE PBL UNIT
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<th>TOPIC</th>
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<tr>
<td>THEME</td>
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<td>SCENARIO</td>
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<td>PROBLEM QUESTION</td>
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<tr>
<td>STUDENT ROLE</td>
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<td>CULMINATING ACTIVITY</td>
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### PBL Unit Examples

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<tr>
<th></th>
<th>TOPIC</th>
<th>Earth Science</th>
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<tbody>
<tr>
<td></td>
<td>THEME</td>
<td>Effect of geologic disasters on people and the environment</td>
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<tr>
<td></td>
<td>SCENARIO</td>
<td>An earthquake has recently struck your area. With potential for more earthquakes, you have been asked to develop a plan for mitigating the effects of the people and property of your school and the surrounding community.</td>
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<td></td>
<td>PROBLEM QUESTION</td>
<td>How can we mitigate the impact of geologic changes on the people and property in Virginia?</td>
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<tr>
<td></td>
<td>STUDENT ROLE</td>
<td>Students are members of the local geological survey team</td>
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<td></td>
<td>CULMINATING ACTIVITY</td>
<td>Students share their school disaster plans with the school administration</td>
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<thead>
<tr>
<th></th>
<th>TOPIC</th>
<th>Environmental Science</th>
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<tbody>
<tr>
<td></td>
<td>THEME</td>
<td>Human impact on the environment</td>
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<td></td>
<td>SCENARIO</td>
<td>The school is considering registration to be assessed by the Sustainability Tracking, Assessment and Rating System (STARS). The school has hired you to go undercover as the SEA Team to evaluate the campus. You have unlimited access and the ability to make positive changes to the campus. You are to find ecological issues and make recommendations for improvement to campus before the STARS team comes for their assessment.</td>
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<tr>
<td></td>
<td>PROBLEM QUESTION</td>
<td>How can we mitigate the schools impact on the ecosystems in and around the community?</td>
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<td></td>
<td>STUDENT ROLE</td>
<td>Junior Ecological Experts as part of the SEA Team (Secret Ecological Agency)</td>
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<td></td>
<td>CULMINATING ACTIVITY</td>
<td>Presentation to a panel of students, teachers, administration, and custodial staff outlining recommendations for improvements to campus before the STARS team comes for their assessment.</td>
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</table>
A question map is a tool that helps frame a blueprint for the questions, issues, and content that you will encounter as you move forward through the PBL unit to address the problem question. By developing a question map up front, you will have a framework for structuring and organizing all of your lesson plans and activities within the unit. Furthermore, allowing students to be part of the question map development process helps to provide them with further clarity of the problem question while enabling collective efforts between students that are consistently productive.

Every question map can be broken down into three types or levels of questions.

The Level 1 question is generally your problem question previously developed and is the over-arching unit question that all of the other questions will work together to address.

Level 2 questions are informational questions that are needed to answer the level 1 question. These questions are generally generated by conducting a brainstorming session to determine “what do we need to know to answer the level 1 question”?

Level 3 questions are specific questions that directly address the standards, student role, and scenario of the unit. These are also the questions from which you will develop your daily lessons and activities.

Consider utilizing the following strategy to help in the development of your question maps:

- Develop a question map of your own that will help you anticipate student generated questions and help guide students towards questions that will develop appropriate activities to address the questions.
- Have students complete a KWL chart to determine what your students think they Know (K), Want to Know (W), and Want to Learn (L) about the Level 1 problem question. This will help students document information that will be helpful when developing level 2 and 3 questions.
- Set up a large blank question map with the problem question at the top of a board or blank wall. Have students write Level 2 and 3 questions on sticky notes. Then have students begin building the map by putting the sticky notes onto the blank map. As a class, work together to organize the stickynotes with questions until everyone is satisfied with the overall map.

Addition of Standards

Once the question map is set, you can identify which science content standards, along with any math and language arts standards that are associated with each Level 3 question. It is helpful to add these directly to the question map to determine if all of the standards are being met through this question map and the PBL unit as a whole.
How can we mitigate the impact of geologic changes on the people and property in Virginia?

- What forms of geologic change occur over time on Earth?
- What geologic features result from geologic change?
- How can humans control and prepare for the impacts of geologic changes?

- How does flowing water change the surface of the land?
- What geologic features are found on land?
- What geologic features are found in the ocean?
- How can we better prepare for earthquakes, landslides, and other geologic changes or natural disasters?

**Level 1 Question**
One over-arching unit question that is presented to effectively solve the problem presented in the scenario.

**Level 2 Questions**
Informational questions needed to answer the Level 1 question which results from initial "what do we need to know to answer this question" brainstorming.

**Level 3 Questions**
Questions where the content and standards are being directly addressed. These are questions around which daily activities are centered.
How do geologic changes affect the people and property in Virginia?

- How do scientists study how Earth is or has changed geologically?
- What forms of geologic change occur over time on Earth?
- What features are found on land?
- What features are found in river systems?
- What features are found in the ocean?
- What geologic features result from geologic changes?
- What forms and features of geologic change occurred in the past and/or are active today in Virginia?
- How have humans, past and present, impacted geologic changes happening in Virginia?
- How can humans control and prepare for the impacts of geologic changes?
- How have geologic changes happened in the past on Earth?

*Standards used in this example reference the Virginia Standards of Learning (SOLs)*

This space can be used for scheduling/planning purposes when working through the question map with your students.
Problem-Based Learning Unit

A Commotion in the Ocean
Grade 5 - Ocean Science

Developed by

Rose Norris
Prices Fork Elementary School

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Highland Park Elementary School

Nicole Coldren
Round Hill Elementary School

Brenda Seal
St. Paul School

Innovating Science Education Across Virginia

VISTA.GMU.EDU
**Unit Overview**

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<th>TOPIC</th>
<th>Ocean Environments</th>
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<tr>
<td>THEME</td>
<td>Oceans: Characteristics, Ecosystems, and Human Impact</td>
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**SCENARIO**

Energy resources off the east coast of North America are very valuable. One of the most significant energy issues facing President Obama is whether to allow leasing of offshore land for drilling oil and natural gas, where production has been off-limits. Scientists are investigating areas off the coast of Virginia to develop these resources. Residents and tourists on the east coast are concerned about the development of these energy resources in the Atlantic Ocean. The Bureau of Ocean Energy Management (BOEM) will offer leases for drilling of oil and natural gas, and will also offer for auction the development of wind or tidal turbine farms off the east coast. The Virginia Department of Environmental Quality (DEQ) is enlisting you and your team to determine how to minimize the impact of these energy resources on our environment. As a member of the DEQ advisory task force you will investigate the issues, evaluate the impacts of the different energy options, and inform the public.

**PROBLEM QUESTION**

How can we minimize the impact to the ocean environment if the energy resources are developed off the coast of Virginia?

**STUDENT ROLE**

Researchers: Oceanographers/Oceanologists hired by DEQ: cover a wide range of topics including marine life and ecosystems, ocean circulations, plate tectonics and the geology of the sea floor, and the chemical and physical properties of the oceans.

**CULMINATING ACTIVITY**

Develop a report for the Virginia Department of Environmental Quality. Your report could include presentations, videos, interviews, and other forms of communication to address concerns, trends, and workable solutions for the impact of offshore energy resources.
UNIT BACKGROUND

This 5-9 week unit was created for 5th grade classrooms to address VA standards 5.5, 5.6, and 5.7 on ocean systems. The scenario and problem question for this unit are focused around developing strategies to minimize the impact to the ocean environment if the energy resources are developed in the ocean off the coast of Virginia. To do this, students will work through a number of other questions to help them develop their ideas.

First, students will learn about the general process of different forms of energy production.
Lesson 1: Student will research how oil and natural gas is found and extracted & how wind and tidal power is utilized & discourse findings.

Next, students will explore the geologic characteristics of the ocean.
Lesson 2: Students will use data to analyze depth and graph the structure of the ocean floor and then use this data to develop a model and topographic maps of different physical characteristics.

Next, students will explore the physical characteristics of the ocean water.
Lesson 3: Students will analyze the relationship between temperature and depth in the ocean.
Lesson 4: Students will explore salinity and changes in water pressure through the ocean.
Lesson 5: Students will inquire about what causes waves and tides and explore how the ocean water moves.
Lesson 6: Students will explore how we could get energy from the ocean using water turbines and currents.

Next, students will examine the ocean ecosystem.
Lesson 7: Students will examine what types of organisms live in the ocean, the different zones they live, the characteristics of each zone, and the survival strategies organisms use to live in these ecosystems.
Lesson 8: Students will explore energy flow in a food chain and web. How does understanding marine food webs help us to minimize the impact from energy extraction on this ecosystem.

Next, students will examine the land and ocean relationships.
Lesson 9: Students will explore the relationship between the oceans and land using stream tables.
Lesson 10: Students will investigate the impact on coastlines from storms and develop strategies for minimizing their impact on these ecosystems.

Finally, students will examine the human impacts on the ocean.
Lesson 11: Students will examine endangered species and the processes for how organisms become endangered.
Lesson 12: Students will explore how developing energy resources affects our oceans and beaches. Using all of their research and experimental data, they will develop a plan to minimize the impact of the development of these resources off the coast of Virginia.

UNIT RESOURCES

Bureau of Ocean Energy Management: www.boem.gov
BOEM Virginia: http://www.boem.gov/State-Activities-Virginia/
Virginia Department of Environmental Quality: www.deq.virginia.gov
Marine Mapping and Data Tools: www.marinecadastre.gov
NOAA Ocean Education Resources: www.education.noaa.gov
How can we minimize the impact to the ocean environment if the energy resources are developed off the coast of Virginia?

What are the geologic characteristics of the ocean?
- What is underneath the ocean water? SOL 5.6 a
- How deep is the ocean? SOL 5.6 b
- What percentage of the Earth is covered by oceans? SOL 5.6 b
- How do we find oil and gas under the ocean? SOL 5.6 a

What are the physical characteristics of the ocean?
- Why is the ocean salty? SOL 5.6 b
- How do oceans move? SOL 5.6 b
- What changes in the ocean as it gets deeper? SOL 5.6 a, b
- How can we get energy from the ocean? SOL 5.6 a, b

What are ocean ecosystems?
- What is an ocean ecosystem? SOL 5.6 c
- What plants and animals are in or near the ocean? SOL 5.5 c
- Why do some animals live in deeper water than others? SOL 5.6 c

What is the human impact on oceans?
- What do storms do to the coast and the energy resources? SOL 4.6
- What organisms are endangered and why? SOL 5.7
- How does our watershed affect the ocean? SOL 4.9
- How does developing the energy resources affect our oceans and beaches? SOL 5.7 f, g
- What is the relationship between the oceans and the land? SOL 5.7 f
Invasives in Virginia
Grade 4 - Life Science

Developed by

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Falling Branch Elementary School

Melissa Martin
Round Hill Elementary School

Teri Ford
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Innovating Science Education Across Virginia
**Unit Overview**

**TOPIC**
Life Processes (4.4) and Living Systems (4.5)

**THEME**
Impact of Invasive Species on Virginia Ecosystems

**SCENARIO**
Researchers of the Virginia Department of Conservation and Recreation (DCR) have noticed a lot of non-native species, also known as invasive species, in Virginia. You have been hired as an Educational Research Assistant for DCR. Your job is to identify invasive species in your county/state and educate the people in your community on how to prevent and manage the spread of invasive species, therefore reducing the negative effects on Virginia’s ecosystems.

**PROBLEM QUESTION**
How can we minimize the spread of invasive species and their negative impacts on Virginia’s ecosystems?

**STUDENT ROLE**
Educational Research Assistant
Virginia Department of Conservation and Recreation

**CULMINATING ACTIVITY**
Develop a management plan and way to educate your community about invasive species and ways to prevent and manage the spread of invasive species, therefore reducing the negative effects on Virginia’s ecosystems.

**Unit Resources**

VA Dept. of Recreation & Conservation: www.dcr.virginia.gov
Invasives in Virginia: www.vainvasivespecies.org
National Invasive Species Council: www.invasivespecies.gov
Unit Background

This 5-9 week unit was created for 4th grade classrooms to address VA standards 4.4 and 4.5 on life processes and living systems. The scenario and problem question for this unit are focused around identifying, understanding, analyzing, and managing invasive species in the local area. To do this, students will work through a number of other questions to help them develop their management plan for what they find within the community.

First, students will learn how we identify invasive organisms and determine how they reproduce.
Lesson 1: Students will collect, identify, classify, and research real plants and animals from pictures and from samples they collect in the field.
Lesson 2: Students will design an experiment to test the different components of photosynthesis to understand variables that influence how different plants grow.
Lesson 3: Students will grow, measure, pollinate, and dissect fast growing plants.
Lesson 4: Students will observe seed/spore development and dispersal.
Lesson 5: Students will measure the length and mass of kudzu to experiment with the conditions needed for dormancy.

Next, students will explore where invasives are located in Virginia.
Lesson 6: Students will collect, identify, and map invasives within their community along with researching the dispersment of invasives across the state.
Lesson 7: Students will build and observe a habitat including invasives to consider the practical parameters or constraints within the system.
Lesson 8: Students will design an experiment to test the migration of invasive species within an ecosystem to determine how the invasives could have traveled to Virginia.
Lesson 9: Students will design an experiment to test beak adaptations to help them understand how adaptations could help a species thrive in Virginia.

Students will then look at the effects of the invasives in the state of Virginia.
Lesson 10: Students will select, research, and present the positive and negative impacts of a specific invasive organism.

Finally, students will explore how we can manage invasive species in the state.
Lesson 11: Students will explore and design methods for monitoring and managing invasives. Culminating Activity: Students will use their research and experimental data to develop a management plan that will educate the public on the control of invasive species in Virginia, and present their plans to a panel of local and regional experts.
How can we minimize the environmental impact of invasive species in Virginia?

Where are they located in Virginia?

What are their effects?

How can we manage them?

How do we identify invasive organisms and determine how they spread and grow.

What are invasive plants and animals?

What are native plants and animals? Virginia Resources SOL4.9b

How do invasive plants grow? Photosynthesis SOL 4.4a,c

How do invasive plants reproduce and spread? Pollination, structure, Dormancy SOL 4.4a,b,c

Where are the habitats of native and invasive species? Niche, populations, communities, ecosystems SOL4.5 b,c

How did invasive species get here? Migration SOL4.5

Did invasive organisms come naturally or were they brought here? Human influence SOL 4.5

What adaptations do they have that allows them to thrive in Virginia? Adaptations SOL 4.5

Does each region have specific resources that attracts or repels these organisms? VA resources SOL 4.9

What are the positive and negative impacts? Niches, habitats, flow of energy SOL 4.5

Why should we care?

Are they causing problems in our streams? Watershed SOL 4.9

How are they monitored? Human Influences SOL 4.5

How can we get rid of them? Human Influences SOL 4.5

Do they have natural predators? Food chains/webs SOL 4.5

What resources does Virginia have to resolve these problems? VAresources SOL 4.9
Problem-Based Learning Unit

VISTA
VIRGINIA INITIATIVE FOR SCIENCE TEACHING AND ACHIEVEMENT

Virginia Watersheds
Grade 6 - Water and Matter

Developed by

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Carroll County Middle School

Claire Guzinski
Stonewall Jackson Middle School

Teri Blankenship
Andrew Lewis Middle School

Kevin Agee
Stonewall Jackson Middle School

Innovating Science Education Across Virginia

VISTA.GMU.EDU
### Unit Overview

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<th>TOPIC</th>
<th>Water &amp; Living Systems</th>
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<tr>
<td>THEME</td>
<td>Human Impact on Water and Living Systems</td>
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### Scenarios (This Unit Has Multiple Scenarios Based on Location)

1. Because of easy access to I-77 Carroll County has been selected as a proposed site for the Southwest Virginia Regional Landfill. Where in Carroll County could this landfill be built that would mitigate the effect on the New River Watershed? You are to present your findings to Carroll County Supervisors on the cost/benefits of facility.

2. The city of Roanoke is considering the construction of a new reservoir to serve the SE community. The proposed location of the new reservoir is beside the Roanoke River on what used to be an Indian Settlement. You have been tasked to assess the impact of this project on the community, and develop a cost/benefit analysis. You will present your findings to the town council.

### Problem Question

How can we mitigate the effects of human activity on the community and Virginia watersheds?

### Student Role

Student Environmental Scientists with the Southwest Virginia Water Authority

### Culminating Activity

Develop a report for the County Board of Supervisors. Your report could include presentations, project demonstrations, videos, interviews, debates and other forms of communication to address the pros and cons of this landfill or reservoir project.
Unit Background

This 5-9 week unit was created for 6th grade classrooms to address VA standards 6.1, 6.4, 6.5, 6.7, and 6.9 on water and matter. The scenario and problem question for this unit are focused around developing strategies to mitigate the impact of human activity on Virginia watersheds from either landfill or reservoir development. This unit has two scenario options that will both work for the same unit. This is an example of modifying scenarios to appropriately fit your particular location. As students work through the selected scenario a number of other questions will be addressed to help them develop their ideas and mitigation plans.

First, students will learn about the basics of water, watersheds, and water quality testing.
Lesson 1: Student will experiment with atom builders to understand the different elements, molecular attractions, and solvent characteristics of water.
Lesson 2: Students will learn and experiment with water quality testing and use this knowledge to conduct water quality analyses in the field.
Lesson 3: Students will explore watersheds and where the water comes from?

Next, students will explore the environmental impacts of this reservoir/landfill project.
Lesson 4: Students will analyze and experiment with landfill/reservoir designs and their potential impact on the physical and chemical characteristics of the watershed system.
Lesson 5: Students will explore what organisms will be affected by the development of the landfill/reservoir and investigate how these organisms will potentially be affected by the development.
Lesson 6: Students will explore the topography of the region to determine potential locations for development that would mitigate the impact on the environment.

Next, students will explore the economic impacts of the project.
Lesson 7: Students will research budgets for developing this project and identify organizations to complete the construction.
Lesson 8: Students will experiment with economic methods for filtering water associated with project.
Lesson 9: Students will research and debate/discourse to determine how the city/county will pay for the project and how the money that will be generated be used.

Finally, students will explore the cultural/community impacts of the project.
Lesson 10: Students will investigate any potential impacts on the community that the development of the project may create or affect throughout the project and after its creation.
Lesson 11: Using all of their research and experimental data, they will develop a plan to minimize the impact of the development of the landfill/reservoir.

Unit Resources

VA Dept. of Recreation & Conservation: www.dcr.virginia.gov
Virginia Department of Environmental Quality: www.deq.virginia.gov
Virginia Department of Game and Inland Fisheries: http://www.dgif.virginia.gov
Designing Lesson Plans

Once the question map is completed, you can begin working on the lesson plans for the PBL unit. Each lesson plan in a PBL unit is associated with a particular level 3 question or set of questions from the map already created, and enough lessons are needed to address all of the level 3 questions developed.

When developing your lessons, start by outlining the background of the lesson. This includes the level 3 questions being addressed, the standards, and aspects of the overall lesson. Once the content is determined, identify any student misconceptions that may be brought to the classroom while studying these topics. Note that there are many online resources which have lists of common misconceptions for particular content areas. It is extremely helpful to be conscious of the types of misconceptions your students may bring into the classroom before you begin instruction in order to address these at the appropriate times throughout the lesson. You will also want to consider any safety concerns of which you will need to be aware while working on this topic, although this may be easier to determine once all of the activities are planned.

Once the basics of the lesson are determined, identify the set of activities you will use to conduct the lesson. Within each activity, determine the time and materials you will need to conduct the lesson. Next, determine some basic guiding questions that can be used to drive instruction on this topic. Guiding questions are ideally prepared ahead of time and are developed with the consideration of specific forms of scientific discourse during their development, based on the topic being studied. Furthermore, throughout your activity plans, it is important to include these guiding questions at the appropriate places in the plan so you can effectively use them when needed.

For each activity, you will also want to determine appropriate methods of differentiation to assist all learners for each activity. Then, as a final component, determine how you will check or assess for student understanding during each activity. Remember to utilize both informal and formal forms of assessments and checks for understanding throughout any particular lesson.
### Lesson Plan Components

**Lesson Background**

- **Unit Title:** Title of your PBL unit
- **Level 3 Question(s) Addressed:** Which question(s) on your question map will this lesson address?
- **Date(s):** Dates or time frame in which it will be implemented
- **Content Standard(s):** Which content standards does this lesson address?
- **NOS Aspects(s):** Which Nature of Science (NOS) aspects will this lesson address?
- **Misconception(s) to Address in this Lesson:** What misconceptions may your students have before, during, and after this lesson that you should be aware of before starting this lesson?
- **Safety Concern(s) in this Lesson:** Are there any safety concerns that you and your students should be aware of while working on this lesson?

### Activities

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<thead>
<tr>
<th>#1</th>
<th>Title of Activity</th>
<th>Time</th>
<th>Materials</th>
<th>Guiding Questions</th>
<th>Plan</th>
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<th>ELL Modification</th>
<th>Check for Understanding</th>
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- **#1**
  - **Title of Activity**
  - **Time:** Approximate time needed to complete activity
  - **Materials:** Materials needed to prepare for activity
  - **Guiding Questions:** If needed, prepare a series of questions which will promote appropriate discussion and discourse based on the level 3 question(s), standards, and tenets of the lesson
  - **Plan:** Develop the order of events for this activity. Include guiding questions previously developed that are applicable for each section of the plan. Identify anticipated student responses for each guiding question.
  - **Differentiation:** Determine methods of differentiation for this activity
  - **ELL Modification:** Identify any activity modifications that will help these students meet the objectives
  - **Check for Understanding:** Decide how you will check in with the students during this activity to monitor their understanding

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<th>#2</th>
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- **#2**
  - **Title of Activity**
  - **Time:** Approximate time needed to complete activity
  - **Materials:** Materials needed to prepare for activity
  - **Guiding Questions:** Prepare a series of questions which will promote appropriate discussion and discourse based on the objectives, standards, and tenets of the lesson
  - **Plan:** Develop the order of events for this activity. Include guiding questions previously developed that are applicable for each section of the plan. Identify some anticipated student responses for each guiding question.
  - **Differentiation:** Determine methods of differentiation for this activity
  - **ELL Modification:** Identify any activity modifications that will help these students meet the objectives
  - **Check for Understanding:** Decide how you will check in with the students during this activity to monitor their understanding
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<tr>
<th>WHAT DO YOU THINK YOU KNOW?</th>
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Safety Plan for Condu

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<th>WHAT IS OUR QUESTION?</th>
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# Conducting Experiments

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<th>WHAT ARE THE RISKS TO STUDENTS AND TEACHERS?</th>
<th>HOW DO WE PREVENT SAFETY MISHAPS?</th>
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The Virginia Initiative for Science Teaching and Achievement (VISTA) is a statewide partnership among 60+ Virginia school districts, six Virginia universities, and the Virginia Department of Education. Its goal is to translate research-based best teaching practices into improved science teaching and student learning for all students at all levels. VISTA investigators are researching what elements best support teachers as they help students learn. The initiative is also working to build a community of practice across the Commonwealth. VISTA is funded by a five-year, $34 million grant from the U.S. Department of Education through the Investing in Innovation (i3) program, which includes a $5.7 million private sector matching requirement.

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