Difficult Solutions: How to Resolve the Controversies over Fracking

Amber Hopkins
West Philadelphia High School

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Overview:

This unit is designed for students in an introductory chemistry class at the high school level, over a period of three weeks. Through topics covered in class, and in greater depth through independent research, students will focus on the chemicals used in hydraulic fracturing, their properties in regards to solubility, how they are being used and how they affect the environment. Aspects of this unit may be modified and applied to physical science topics for younger students. If a teacher chooses to target this unit towards younger students, more emphasis might be placed on the environmental impact than the physical mechanisms of solubility and chemical interactions.

The unit will begin with an introduction of hydraulic fracturing, providing students with an example of a real life application of a chemical solution. The introductory lesson will also touch on some of the ramifications of creating such chemical cocktails and how the residual chemicals are eventually disposed of. Following the introduction, students will delve into the mechanics of solutions and the properties of solubility. After students have developed an understanding of the rules of solubility, they will begin independent investigations into different aspects of fracking, and the chemicals used in hydraulic fracturing, as published by the Pennsylvania Department of Environmental Protection (Commonwealth).

I will implement this unit with the supplementary hydraulic fracturing project during Unit 10: Properties of Solutions unit outlined by the School District of Philadelphia. If a teacher chooses, however, to place this unit at the end of the school year (after any standardized testing), they would have the flexibility to work in as much or as little of the unit as they desire, omitting any material that they have previously covered throughout the year.

Some of the strategies that will be incorporated in order to increase motivation and curiosity include: hands-on activities, personal inquiry, the gradual release of responsibility model, ongoing formal and informal assessments, and problem-based learning.

Rationale:

One of the concepts that many of my students struggle with is the difference between a pure substance and a mixture, and the reality that most everything around is in fact, a mixture, particularly in modern, industrialized societies. I want my students to recognize the prevalence of solutions in their lives, and to begin considering that their consumption of these products affects the world around them in various ways.

Another reason that I feel science topics remain fairly inaccessible to many students is that they seem to have not mastered the scientific vocabulary. Knowing the appropriate terminology and the correct scientific definitions is critical to understanding most topics in science. Especially in science, I second Greenwood's statement, that "teachers cannot leave development of vocabulary to chance. The research is deceptively simple in that wide reading accounts for the bulk of vocabulary gain, but it cannot be assumed that all students will read widely, even if so assigned" (Greenwood, 258). Throughout this unit, students' mastery of scientific vocabulary should increase, especially use of vocabulary strategies such as the Frayer model, word webs, and daily reflections where students will check for their own individual understanding of the material.

Students also have a hard time recognizing the relevance of and applying scientific knowledge to their every day lives. I am hoping that by connecting the regular curriculum to a local issue, and presenting it in the Problem-based learning (PBL) format, they will engage more in the lessons and in researching solutions to the situation. Instead of merely focusing on scientific principles, the PBL discussion about ethics and social policy should appeal to students who favor social sciences over hard science. The awareness raised in this unit, that science has a very direct impact on the environment and peoples' lives, will hopefully invest the students more in their community, and in working to find solutions to various types of problems faced by society.

In my classroom, I have had much greater success in relating science issues if there is some type of human connection involved. My students engage much more if information is relayed to them in the form of a story, and particularly if there is some type of moral or human conflict involved. For this reason, I want to keep this unit focused not just on chemical solutions, but solutions as answers to a larger issue facing a group in our society. I am involving first-person articles and opinions, and casting students into particular roles, so that they will continue to consider the human aspect of the PBL project, as well as the scientific principles that they are mastering. Finally, I believe that students will engage in this topic, as it has a very distinct possibility of affecting students in Philadelphia, as we share a watershed with some of the areas where natural gas extraction is occurring

Background:

No one denies the benefits of living in an industrialized, modern society. However, we often take for granted these conveniences, forgetting about the costs and the effects that our consumption has on the world around us. Coal, natural gas, and other carbon-based fossil fuels are extracted from the earth's crust for burning in the production of energy. Often, mixtures of different chemicals or compounds are created to accomplish some greater task. Afterwards, the waste products are often discarded unceremoniously. It has only been recently that the issue of what to do with these waste products, and the consequences that these wastes are wreaking on the environment and human health, has been brought into the public spotlight.

Hydraulic fracturing ("fracking") is a method of natural resource extraction that has developed relatively recently. In a process engineered by the company Halliburton, the typical sequence of events is as follows: an oil company leases a parcel of land, brings in tons of equipment and trucks, and then begins the process of drilling the well. As the vertical well is drilled, it is lined with a cement casing designed to prevent ground water from being contaminated. The vertical portion of wells run hundreds to thousands of feet into the ground, and then the shaft can be turned to extend from 1000 to 6000 feet horizontally (United States). Once the entire well shaft has been drilled, frac fluid consisting of a mixture of millions of gallons of water, substantial amounts of sand, and smaller ratios of other chemicals, is injected into the well at very high temperatures and pressures. When this fluid reaches the end of the horizontal shaft, the pressure causes the surrounding shale formation to crack. The frac fluid then flows into the cracks, and the natural gas within the shale then dissolves into the frac fluid. The fluid is then extracted from the well, with natural gas being separated from the remaining fluid.

These modern fracking technologies allow companies to tap into the natural fuel wells, with seemingly minimum ill effects, at least on the surface. However, many concerns are being raised about the safety precautions and regulations that will preserve the well-being of the communities around fracking sites. Groundwater contamination and air pollution are only a few of the problems that have been reported around these drill sites. The long term effects on human and environmental health, the depletion and exploitation of the natural resources, and even the long term economic consequences are all very important concerns that scholars and the public are bringing into the spotlight.

Fracking is a matter of great debate in the state of Pennsylvania and the neighboring regions. A large natural gas reserve, known as the Marcellus Shale, presents huge profit opportunity for enterprising oil companies, as huge amounts of natural gas lie within the shale formation. Oil companies are quickly moving into the Marcellus Shale, in hopes of profiting from the vast reserve. However, landowners in the area have experienced several unusual and unpleasant consequences that they attribute to the presence of and work being done by the drilling companies. Some accounts of consequences being attributed to fracking activities include people's water "turning brown and making them sick, one woman's water well spontaneously combusted, and horses and pets mysteriously began to lose their hair" (Bateman).

One of the issues at the forefront of the fracking conflict is the reality that most oil companies do not readily provide open access to the list of chemicals used in the fracking fluid. Until recently, many states did not require a list of chemicals used to be submitted at any point during the drilling process. However, on June 30, 2010, the Department of Environmental Protection in the state of Pennsylvania, published a list of chemicals used by hydraulic fracturing companies for surface and hydraulic fracturing activities, compiled from the material safety data sheets obtained from industry (Commonwealth).

The list of chemicals involved in hydraulic fracturing is very extensive. Several of the chemicals are known to cause adverse effects on human health. Other chemicals range from those found in household products to very specific industrial compounds. The frac fluid is repeatedly published as containing over 99% water and sand, with the remainder subsisting of the chemicals on this published list. One of the my goals is for my students to consider and create their own research-based opinion, whether or not these other chemicals pose a health risk to the public, even if they constitute less that 1 percent of a solution of millions of gallons of water. Also, as the list of chemicals is rather long, I will have students focus first on chemicals that they are more familiar with (hydrochloric acid, aluminum oxide, methanol, etc.), before researching the more obscure chemicals as time permits.

Once a well has been drilled, fluid pumped in, and the shale has been fractured, pressure is released, and the fluid begins flowing back to the surface as a "thick, gooey gel that is difficult to clean up", carrying with it the dissolved natural gas (Santiago-Aviles). At the surface, large holding ponds have been constructed to allow the components of the fluid to settle or evaporate, for an indeterminate amount of time. Methods for disposal of the frac fluid include trucking loads of fluid out to water purification plants, leaving fluid in holding ponds, or surreptitiously dumping it into streams or rivers. The holding ponds, openly exposed to the forces of nature, or the presence of wildlife, are one area of concern for people worried about the pollution and contamination caused by fracking. Other sources include potential breakage in the well shaft, and underground contamination of aquifers, as well as the noise and air pollution that exists on the surface.

Objectives:

I want to integrate the Marcellus Shale topic into the Unit 10: Properties of Solutions curricula designed by the Philadelphia School District. I believe that this is appropriate, as some of the teaching objectives outlined in the Planning and Scheduling Timeline include:

- Identify the parts of a solution
- Calculate molarity
- Describe/explain how polarity and temperature affect solubility
- Describe unsaturated, saturated, and supersaturated solutions, colloids, mixtures, and suspensions
- Explain how solutes affect melting and boiling points

Objectives that I would like to add with respect to the Marcellus Shale include:

- Explain what the Marcellus Shale is, where it is located, and why it is relevant
- What is hydraulic fracturing ("fracking")
- How the chemical cocktail used in fracking is a solution
- How the cocktail works (identify the purpose of combining that particular group of chemicals)
- Why the cocktail is problematic- what are some of the health, environmental, or cost issues in using these particular chemicals?
- Propose methods for cleaning up the residual fracking fluid, and separating the different components

This unit will expose students to several science and science-related careers, allowing them to see both the importance of science, as well as the broad scope of careers available to them if they choose to pursue science. For students who do not go on to pursue scientific careers, this until will have helped them develop critical thinking processes that may help them in any aspect of their lives. Completion of this unit should allow students to recognize that people and groups often have conflicting interests, and that compromises, are sometimes necessary.

The PBL structure of this unit is such that students are doing research, and coming to their own conclusions to provide a viable solution to a real life problem. There is not a simple answer, and true to life, there are several different perspectives that need to be considered. Thus, I am hoping that students will develop interpersonal skills for communicating their knowledge and their opinions in mature, appropriate ways.

Strategies:

This unit is designed following the Problem Based Learning strategy. It is set up in such a way as to engage students in solving a real-world problem, while incorporating multidisciplinary topics, with particular focus in the areas of literature, social sciences, and math. Students will be exposed to science literature in their independent research, as well as more common sources of information, such as articles published in the public domain. The impact that creating different chemical solutions, especially for industrial uses such as hydraulic fracturing, has on human life, wildlife, and our planet will address topics within the social science standards. Mathematics will be integrated in interpreting and creating graphs, as well as in determining polarity, and calculating the molarity of a solution. Several Pennsylvania science standards will also be addressed throughout the unit (see appendix).

The opening lesson will introduce students to the Marcellus Shale, by showing them a clip from the documentary *Gasland*. This is intended to peak their interest as to why normal sinks are exploding in people's homes, why these people (not too far from us in Philadelphia) are experiencing health problems, etc. We will use several class periods to discuss solutions and separating solutions in a more traditional chemistry lecture style, before bringing the Marcellus Shale and hydraulic fracturing back into the picture. As a class we will examine the components of the frac solution used by drilling companies in Pennsylvania, and how problematic this solution is to the environment and the surrounding community. I will then present the fracking PBL unit to the class, where students will assume roles of different parties with vested interests in the Marcellus Shale. Students will research the issues surrounding hydraulic fracturing, from the points of view of environmentalists, oil drilling company scientists, government officials, or members of the public. Finally, the students will come together to at least one method to separate that chemical from the rest of the solution.

As part of the Problem Based Learning project, students will be looking at different chemicals used in the fracking process, how these chemicals interact with the rocks once injected into the ground, and the different separation and purification techniques currently used after the frac fluid is extracted from the ground. Lessons and activities will identify different components and properties of solutions, and I will provide a list of resources and sites for students to look for this information, but will leave a large amount of the research up to the students in an effort to help them become better independent thinkers. As part of their research within the PBL, students will also look into some of the societal and health issues raised by the components found in fracking fluid, as well as current methods of disposal, and any issues that have occurred as far as spills or contamination of natural resources.

To help students master the scientific vocabulary within this unit, use of Frayer models and word maps will be initially used, and vocabulary will be reinforced with reading articles, quizzes, and the independent research. They will be exposed to some of the policy issues regarding environmental protection through required passages that will further help students improve reading skills.

Other pedagogical strategies that will be incorporated into this unit include activating prior knowledge, student-centered collaboration, hands-on and inquiry based activities, classroom discussions, and debates. Teacher demonstrations will help students visualize scientific concepts, and the hands-on and collaborative activities appeal to kinesthetic and interpersonal learners.

Collaborative groups have been very successful for me in the past. I have found that students are more motivated when they are accountable to their peers. They also retain information better when they have to explain it to a fellow student. Students also prefer these interactions to learning something in a lecture format, or from the teacher directly, though I try to circulate and offer assistance as needed, encouraging students to stay on track.

This unit will engage students and allow them to integrate their scientific knowledge with observations made about their communities. Labs and activities will allow students to improve inquiry skills and demonstrate understanding of mathematical and scientific principles. Students may develop skills for community activism and engagement, in seeking viable solutions to local pollution problems. The Problem Based Learning (PBL) and Gradual Release of Responsibility formal of the unit will allow students to take more ownership over their work, and engage their critical thinking skills as they propose novel solutions to the PBL scenario.

As students progress through the duration of the unit, they will receive feedback from both the teacher and their peers. Regular self-evaluation will also help ensure adequate progress through the unit, and will serve as a reinforcement or mastery check in understanding the various concepts being covered.

The list of chemicals involved in hydraulic fracturing is very extensive. Depending on the time and resources available, teachers may choose to restrict student research to a limited number of the chemicals listed. Teachers may also choose to provide more information directly to the students, simplifying the individual research component of the unit. Student research will be completed through reading from scientific literature, internet sources, and classroom seminars and discussions.

Classroom Activities:

Day 1

Introduction to New Material:
The teacher will give a brief introduction to the movie, and will provide a few minutes for students to look over the worksheet and ask any clarifying questions.

Guided Practice:
Students will be given a worksheet with guided notes and questions to fill out as clip from *Gasland* progresses (see appendix - Dauray). At the conclusion of the movie, the teacher will open up a class discussion, allowing for questions and responses to be shared.

Independent Practice:
Following the class discussion, students will individually write a response, explaining their understanding of fracking and what is happening in the communities around the drill sites.

Closing:
As students finish writing their responses, the teacher will explain that this unit will be focused on solutions, and the chemistry involved. Students will understand that *Gasland* was an introduction to this topic, and that they will return to the subject of fracking after mastering some of the principles regarding chemical solutions and their subsequent properties.

Homework:
Students are expected to look for more information about fracking online. Where is fracking taking place? Is it happening near cities, or out in the country? What other information can you find?

Day 2

Do Now:
Students will enter and respond to the following questions in their journal:
1) What is the difference between a mixture and a pure substance? Give an example of each.
2) What is the difference between a homogenous and heterogeneous mixture? Give an example of each.

Introduction to New Material:
Teacher will introduce solubility vocabulary, and will use a PowerPoint presentation to guide a discussion about how we are surrounded by substances that are actually

mixtures of different elements and chemicals. Students will follow along with guided notes. The teacher will also use questioning, and will allow students to free-associate, in order to prior knowledge and to tease out any previous misconceptions from the students (Greenwood, 259). Vocabulary words will include solution, suspension, colloid, heterogeneous, and homogenous. The main focus will be on solutions and mixtures in the liquid state, but enough emphasis will be given for students to recognize examples of solid or gas solutions. One pneumonic device that will be presented to the students to help them remember the difference between the solute and solvent in a solution: A robber broke into a store, and filled his sack with loot. When the police arrived, the robber hid the loot in a vent so that he wouldn't get caught. The sol-LOOT goes in the sol-VENT.

Guided Practice:

Students will work in groups of 2-3 students to complete Frayer models for the vocabulary words defined in the notes, providing examples and counterexamples for each word (see appendix). The teacher will then introduce the independent practice activity, instructing students that they can stir and observe solutions, but that they should not pick them up. Teacher will then allow time for students to ask any clarifying questions before beginning the activity.

Independent Practice:

Students will complete a graphic organizer (see appendix) identifying types of solutions placed around the classroom at different stations. Examples of solutions include: 1) oil and water, 2) sucrose and water, 3) food coloring and water, 4) ranch salad dressing, 5) clay and water, 6) milk, 7) salt and sugar, 8) dry rice and beans, 9) sand and water, 10) salt and water, 11) a ruby, 12) a sapphire, 13) 14-carat gold, 14) air, 15) water, and 16) brass.

Closing:

Students will complete an exit slip, with two multiple choice questions, as well as a diagram of a solution at the molecular level to check for student mastery of the material. Student will also perform a self evaluation, rating how comfortable (s)he is with the material on a scale of 1-5.

Homework:

Students will complete a bubble map, connecting each of the vocabulary words covered during the lesson.

Day 3

Do Now:

Students will enter and respond to the following prompt in their journal: Brainstorm a list of things that have poles, or polarity. What do you think it means if something is *polar*?

Introduction to New Material:

Teacher will perform the magnets and toothpicks demonstration (Kruse). Class discussion will then follow, about why the magnets clump together, while the toothpicks spread out when dumped on the table. Teacher will continue to pose questions, leading students to see that water can demonstrate similar characteristics to magnets, while nonpolar solvents (hexane, or vegetable oil) has properties that cause it to act more like the toothpicks. Further inquiry activities are suggested by Kruse, which may be included at the teacher's discretion.

Guided Practice:

Teacher will review electronegativity with the class, reminding students of the periodic trend, and will then demonstrate how to use the electronegativity values to determine whether a compound is polar or not. A large periodic table with the electronegativity values of the elements will be displayed at the front of the classroom. Teacher will work through three or four examples, and then students will work in pairs to solve 2 more problems, before finishing the worksheet independently.

Independent Practice:

Students will work independently to complete the worksheet, determining whether different chemical compounds are polar or not, based on their electronegativity values.

Closing:

Using the results from the worksheet, the class will compile a T-chart of polar and non-polar chemicals.

Homework:

Students will write several sentences, incorporating the lesson on polarity and any prior knowledge, to explain why oil and water do not mix together well.

Day 4

Do Now:

Students will enter and answer the following prompt in their journal: If you are presented with a glass of salt water, can you think of a way to separate the salt from the water? Use complete sentences to explain the steps you would take in separating the salt and water.

Introduction to New Material:
Teacher will give definitions and descriptions of various separation methods, using PowerPoint images to supplement the information. Students will follow along with guided notes.

Guided Practice:
Teacher will demonstrate how to use the methods of separation flow chart when determining how to separate a solution. Students will follow along, and the class will work through 2-3 examples together. Teacher will check for understanding, allowing time for students to pose any questions before moving to independent practice.

Independent Practice:
Students will have the list of solutions and the stations from Day 2 to look at. Using their knowledge of different separation methods, students will work in groups of 2-3 students to determine which method they would use to separate the components of each solution.

Closing:
Teacher will lead a class discussion focusing on student observations during Independent Practice. Did students see any correlation between the separation techniques they chose and the type of solution they were looking at?

Homework:
Pre-lab questions for day 5 (see Appendix)

Day 5

Do Now:
Students will assemble into their lab groups, and will discuss the pre-lab questions.

Guided Practice:
Teacher will review lab procedures and expectations, highlighting any safety concerns for this lab (i.e. hot equipment at the distillation station).

Independent Practice:
Students will rotate through different stations, practicing different separation techniques (filtration, paper chromatography, separation funnel, observing a distillation, etc. - see appendix).

Closing:
Students will use complete sentences to explain two of the separation techniques they observed in the lab, and what type of mixture for which these techniques are most effective.

Homework:
Look up the history of the Philadelphia Water Works. Try to find as much information as possible about what techniques are used to purify and process the water, and then how the water is distributed to the people in the greater Philadelphia area.

Day 6

Students will take a field trip to a local water purification plant, water-bottling company, or a similar alternative where industrial purification methods are demonstrated.

Day 7

Do Now:
Students will enter and respond to the following questions in their journal: If you put 10 scoops of NesQuik powder into a cup of milk, and your friend puts 12 scoops of NesQuik, which one of you has a more concentrated cup of chocolate milk? How do you know?

Introduction to New Material:
Teacher will discuss concentration, and give students examples with KoolAid, orange juice concentrate, strong tea vs. weak tea, etc. Teacher will give the definition of molarity, describe what it is used to measure, and how it is measured. Students will follow along with guided notes, including filling out a Frayer model for concentration. The teacher will work through examples 1-3, modeling the process for the students.

Guided Practice:
Students will work in groups of 2-3 to complete problems 4-6, directing the teacher, who is writing down their solution on the board.

Independent Practice:
Students will work in cooperative groups to complete the worksheet. Teacher will circulate, offering assistance as needed, and checking for understanding. Groups are responsible for making sure everyone has the correct answers up to problem 10. Students are responsible for finishing the remainder of the worksheet for homework.

Closing:
Students will write out an explanation of how to solve a problem for the molarity of a solution.

Homework:
Students will finish the remainder of the worksheet from the independent practice.

Day 8

Do Now:
Students will enter and respond to the following questions: What happens when you try to dissolve sugar in iced coffee? What if you dissolve it in hot coffee? Do you think sugar is more soluble in liquids at high or low temperatures?

Introduction to New Material:
Teacher introduces the inquiry lab (see appendix), and explains where all required lab supplies are located.

Independent Practice:
Students complete the inquiry lab, testing how different factors affect solubility. Teacher circulates and offering assistance as needed.

Closing:
Students will share out observations from the inquiry lab. Teacher will ask guiding questions as necessary, but students should have observed that higher temperatures, increased surface area, and increased pressure, and agitation all result in higher levels of solubility.

Homework:
Students finish the post lab questions.

Day 9

Do Now:
Students will enter, and quietly study notes for a quiz on the material covered thus far in the Properties of Solutions unit.

Introduction to New Material:
After administering the quiz, the teacher will introduce the Fracking PBL scenario (see appendix).

Guided Practice:
Teacher will lead a discussion reviewing the basics of fracking, and the issues raised in *Gasland.* Teacher will assign (or allow students to select) groups for the PBL, and allow groups to meet and distribute roles for the project.

Closing:
Each group will submit the Intro to the PBL worksheet with their initial reactions, and the role assignments for the project.

Homework:
Students will begin researching their role for the PBL project.

The remainder of the unit can be paced according to time available and teacher discretion. For best results with my students, I try to provide enough time in a computer lab for students to get the bulk of their research done, as many of my students do not have reliable computer or internet access at home. Three or four days should be ample time for the independent research, after which groups reconvene to discuss their findings and propose a solution. One to two days should be allowed for groups to put together their PowerPoint presentations, and the final day of the unit should be groups presenting their research.

Annotated Bibliography / Resources:

Bateman, Christopher. "A Colossal Fracking Mess." *Vanity Fair Magazine*. Vanity Fair, 21 June 2010. Web. 22 Mar. 2011. <http://www.vanityfair.com/business/features/2010/06/fracking-in-pennsylvania-201006>.

This article is an interesting read, good for an introduction to fracking, though maybe a little lengthy for some students.

Commonwealth of Pennsylvania. Department of Environmental Protection. *Chemicals Used by Hydraulic Fracturing Companies in Pennsylvania*. Pennsylvania Department of Environmental Protection, 30 June 2010. Web. 22 Feb. 2011. <http://www.dep.state.pa.us/dep/deputate/minres/oilgas/new_forms/marcellus/marcellus.htm>.

This pdf is the list of chemicals used by companies utilizing the hydraulic fracturing method to extract natural gas in the state of Pennsylvania.

Dauray, James. "Gasland Documentary - Student Worksheet." *Aurum Science Environmental Science Resources for Teachers*. Aurum Science, 2011. Web. 1 June 2011. <http://www.aurumscience.com/environmental/11_nonrenewable/gasland.html>.

This worksheet covers the film very thoroughly, which will help students stay engaged throughout the entire film. Sections of the worksheet may be omitted, depending on how much of the movie is viewed. I took out a few of the questions in the worksheet found in the appendix.

Fisher, Douglas, and Nancy Frey. *Better Learning Through Structured Teaching: A Framework for the Gradual Release of Responsibility*. Alexandria: Ascd, 2008. Print.

This framework is set up for students who may be behind grade level in reading, but who are critical thinkers and problem solvers. Engaging students from the outset of a unit helps motivate them beyond their comfort level, to help them grow and progress as learners, and over time to develop habits that will make them stronger readers.

Gasland. Dir. Josh Fox. Perf. Josh Fox, Dick Cheney, Pete Seeger. HBO, 2010.

A documentary investigating fracking and the people being affected by the practices of the drilling companies.

Greenwood, Scott C. "Making Words Matter: Vocabulary Study in the Content Areas." *The Clearing House* 75.5 (2002): 258-63. *JSTOR*. Taylor & Francis, Ltd., May-June 2002. Web. 28 May 2011. <http://www.jstor.org/stable/30189755>.

This article provides several strategies for teaching content vocabulary, providing more variety than simply copying and memorizing dictionary definitions.

Introducing Students to Polar and Non-Polar Interactions through Inquiry, Jerrid Kruse. *Iowa Science Teachers Journal*, Fall 2005, Iowa Academy of Science. Volume 32 (3) p. 19-22.

This pdf provides several inquiry activities to help students make connections between phenomena they are familiar with, and interactions at the molecular scale.

Myers, Oldham and Tocci. Chemistry. Austin: Holt, Rinehart and Winston, 2004.

This is the textbook recommended in the standardized chemistry curriculum in the School District of Philadelphia. Students can refer to this as needed, particularly when looking for "official" definitions of vocabulary words.

Preston Elementary School. *Preston Elementary School*. Preston Elementary School, 12 Apr. 2005. Web. 14 May 2011. <http://preston.rialtoschools.org/download.axd?file=6b063456-21f4-4726>.

This lab worksheet allows students to design their own procedures in experimenting with different factors that affect solubility.

Santiago-Aviles, Jorge. "Frac Fluid Purification." *Marcellus Shale and Pennsylvania: Energy, Money, Trout and Drinking Water*. University of Pennsylvania. Jaffe Building, Philadelphia. 15 Feb. 2011. Class lecture

Savery, John R. "Overview of Problem-based Learning: Definitions and Distinctions." *Interdisciplinary Journal of Problem-based Learning* 1.1 (2006): 9-20. Print.

The PBL structure allows students to gain practice in solving real-world problems, where there may not always be one correct answer. Students are responsible to research, and to work in collaborative groups to provide a reasonable solution.

Trimp, Tracy. "Messing With Mixtures." *The Science Spot*. Havana Junior High, 8 May 2011. Web. 23 May 2011. <http://sciencespot.net/Pages/classchem.html>.

The Science Spot is an excellent resource for lab activities, demonstrations, and project ideas. Even though it is tailored towards middle school students, many activities can easily be tweaked for older or younger students.

United States. Environmental Protection Agency. Environmental Protection Agency. *Water: Hydraulic Fracturing*. Environmental Protection Agency, 13 May 2011. Web. 25 May 2011. <http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_hydrowhat.cfm>.

This website gives an overview of fracking, and some of the issues involved. This is a good website to direct students to, as they are working on their individual research projects in the PBL unit.

Wood, Diana F. "Problem Based Learning." *British Medical Journal* 328th ser. 326.7384 (2003). *Bmj.com*. HighWire Press, 8 Feb. 2003. Web. 2 June 2011. <http://www.bmj.com/content/326/7384/328.extract>.

This article describes the Problem Based Learning strategy, and though focused on medical education, is relevant to all curricula, particularly the sciences.

Teacher Resources

In my instruction, I have access to a Promethean board, a laptop computer, and a digital projector.

Gasland. Dir. Josh Fox. Perf. Josh Fox, Dick Cheney, Pete Seeger. HBO, 2010.
A documentary investigating fracking and the people being affected by the practices of the drilling companies.

Student Resources

Myers, Oldham and Tocci. Chemistry. Austin: Holt, Rinehart and Winston, 2004.
This is the textbook recommended in the standardized chemistry curriculum in the School District of Philadelphia.

Appendix:

1) *Gasland* worksheet (Day 1)

Gasland

Hydraulic Fracturing in the Marcellus Shale

1. Shade in the Marcellus shale rock formation in this map.

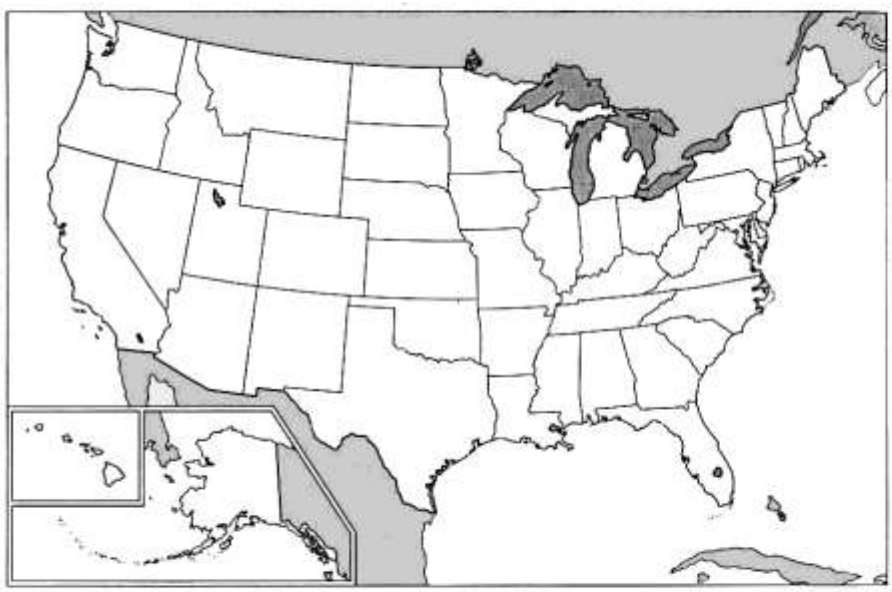


Image from vmapas.com

2. The Energy Policy Act provided exemptions for the oil and gas industries. What laws were they exempt from?

3. When was the exemption passed, and who was president?

4. Explain the process of hydraulic fracturing, as explained in the movie.

Water, Water, Everywhere

5. What health effects were experienced by the residents of Dimock, the community drilled by Cabot Oil and Gas?

6. What changes in water quality were observed?

7. What health effects were experienced by animals?

Life in the Red Zone

8. Why does the water light on fire? What is mixed with it that is combustible?

9. What is trichlorobenzene?

10. What possible conflicts of interest existed with the Vice President and some of the other politicians responsible for the exemptions to the Clean Water Act?

Easter in Wyoming

11. Why was the reverse osmosis system installed as a result of the lawsuit ineffective at filtering the water?

12. What happened when Lewis Meeks' new water well was drilled?

13. Describe the quality of the water that comes out of the Meeks' original water well.

14. What are the physical and chemical properties of glycol ethers?

15. What effects does the natural gas drilling and fracturing have on the surrounding cattle farms?

Your Land, My Land, Gas Land

16. What is Bureau of Land Management (BLM) land, and what rights does the American public have to it?

17. What is the purpose of the derrick in a drilling rig?

18. How many truckloads of hydraulic fracturing water must be brought in?

19. How much of the water injected into the well is actually recovered?

20. What is the purpose of the **flowback pits**?

21. What is the purpose of the **evaporation sprayers**?

22. What is the purpose of the **separator**?

23. What is contained inside the **condensate tanks**?

24. Ozone is a **secondary pollutant** produced from a chemical reaction between the **primary pollutants** volatile organic compounds and nitrogen oxide. What is the source of each of these two primary pollutants?

25. How do the gas wells affect the native animal populations, such as the pronghorn antelope?

Drop Everything, Clear Your Schedule

26. List and describe the neurological effects of the VOCs and other air pollutants, as described by Dr. Theo Colborn.

Contamination at Divide Creek

27. What effect did the seepage have on Divide Creek?

28. Was the company responsible fined? How much?

The Air Over Fort Worth

29. How do the air pollution emissions from the oil and gas drilling compare with the car exhaust from the entire Dallas-Ft. Worth area?

30. What two categories of toxins are released by the condensate tanks?

Louisiana

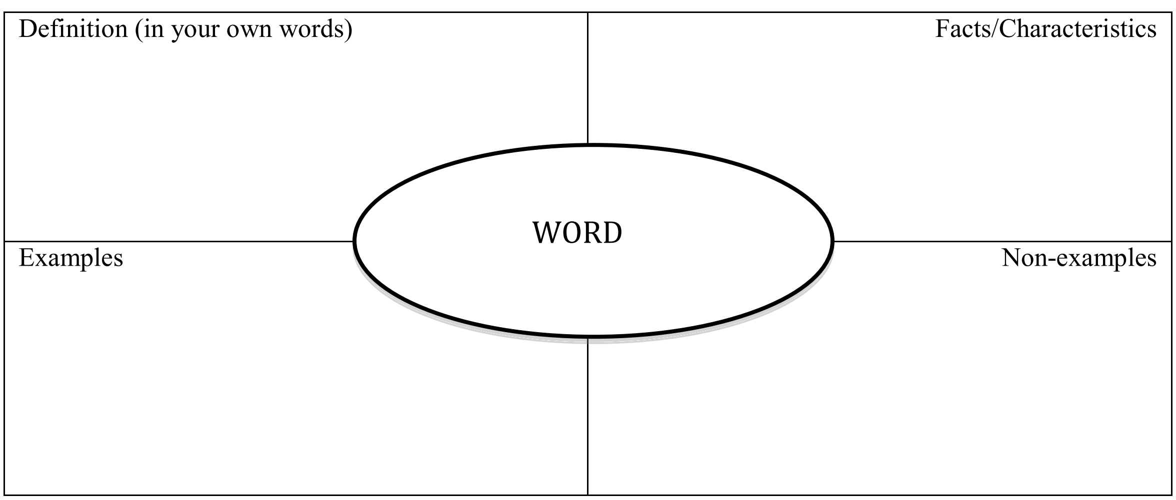
31. Explain how the storm surge from a hurricane can cause further contamination of coasts.

Throwing Water on a Drowning Man

32. The results of the tests of the contaminated wastewater from Dimock produced several above-normal results. Explain what each of these measures:
    a. Conductivity –
    b. Total Kjeldahl Nitrogen –
    c. Methylene Blue Active Substance (MBAS) -

33. John Hanger, Secretary of the Pennsylvania Department of Environmental Protection describes the natural gas drilling and extraction as a "trade-off". Explain what the trade-off is. Do you believe this is a good trade? Natural gas is often described as a "transition fuel" and a cleaner-burning fossil fuel. Explain how these claims are incomplete. Given what you learned from this movie, is natural gas a fuel that we should explore and extract more of?

2) Frayer Model (Day 2)



3) Solutions Stations graphic organizer (Day 2)

Station number	Type of Mixture (pure substance, solution, suspension, or colloid)	Heterogeneous or Homogeneous?	What is the solute?	What is the solvent?	Separate After Standing? (yes or no)

4) Separating Mixtures Pre-lab questions. The following questions can be used as a pre-lab worksheet.

1. What is surface area?

2. What is chromatography?

3. What liquid is called the "universal solvent"?

4. Review the Kinetic Molecular Theory. According to KMT, what happens to the molecules in a substance when the temperature increases?

5) Separating Mixtures Lab worksheet (Day 5)

The lab worksheet comes from the Science Spot worksheet, "Messing with Mixtures" (Trimpe).

6) Factors Affecting Solubility Lab (Day 8)

This lab worksheet comes from Preston Elementary School (Preston).

7) Introduction to the Fracking PBL Project (Day 9)

Introduction to the Marcellus Shale Fracking Unit Project

You and your team are a group of scientists who have been hired by an anonymous group to investigate the hydraulic fracturing taking place in Dimock, Pennsylvania. Your job is to produce as detailed and unbiased an account of the effects of hydraulic fracturing before, during, and after the drilling process. Work with your group of scientists to suggest a plan for the future, based on your analysis.

As you complete this project, keep in mind the motives behind each of the groups involved with the fracking in Dimock. Can you come up with a plan that keeps all of the stakeholders happy, or do some group(s) have to compromise? How realistic is your solution for the future? When your group has completely developed your plan, prepare to present it to an audience that includes individuals from the public, environmentalists, government, drilling companies, and your anonymous funder. Create a Powerpoint presentation explaining all of your research and the steps you would advise for moving forward concerning Dimock, the Marcellus Shale, and hydraulic fracturing.

Initial reaction and notes:

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____
____
____

Now that you've met your group members, decide who is going to do which job.

_____________ 1- scientist from the drilling company- responsible for knowing about the drilling process, the main chemicals used, and why those particular chemicals

______________ 2- environmentalist- responsible for researching effects of fracking on the environment (air, water, wildlife, etc.)

______________ 3- representative from the government- should research and be familiar with laws involving companies drilling in the Marcellus Shale region, as well as what concentration levels of fracking chemicals are considered legal

______________ 4- concerned citizen- considering signing a lease for a company to drill on their land- responsible for seeing what information is readily available to the public

Content Standards:

The Pennsylvania Academic Standards for Physical Science, Chemistry, and Physics addressed in this unit include the following:

3.1.12. E: Evaluate change in nature, physical systems, and man made systems.

3.2.10.B: Apply process knowledge and organize scientific and technological phenomena in varied ways.

3.2.12.C: Apply the elements of scientific inquiry to solve multi-step problems.

3.4.10.A.2: Explain the repeating pattern of chemical properties by using the repeating patterns of atomic structure within the periodic table.

3.4.10.A.8: Apply knowledge of mixtures to appropriate separation techniques.

3.4.10.A.9: Understand that carbon can form several types of compounds.

3.4.10.C.3: Explain fluid power systems through the design and construction of appropriate models.

3.5.12.B: Analyze the availability, location, and extraction of earth resources.

3.5.12.D: Analyze the principles and history of hydrology.

3.8.10.A: Analyze the relationship between societal demands and scientific and technological enterprises.

3.8.10.B: Analyze how human ingenuity and technological resources satisfy specific human needs and improve the quality of life.

3.8.12.C: Evaluate the consequences and impacts of scientific and technological solutions.