Title: **Chemistry & Engineering Design - Facing Local and Global Challenges**

Length of Course: **1.0 unit** (one year, two semesters or three trimesters equivalent)

Subject Area and Discipline: **Laboratory Science ("d") – Chemistry**

CTE Sector: **Engineering**

CTE Pathway: **Design**

Grade Level(s): **11-12**

Course Overview:

Through this course students will examine, explore, and experiment with a variety of Chemistry concepts in order to better understand how such knowledge can be used to engineer tools, products, or systems for using energy to meet human needs--such as water purification, energy needs for a community, and ways to store energy. Unit 1 features key assignments for understanding and carrying out the process of water purification. Unit 2 focuses on the energy needs of communities, such distillation as an effective means of purifying water with dissolved contaminants. In Unit 3, students will study the basic types of chemical reactions and how energy is released or absorbed through chemical change in order to understand different plausible energy storage solutions. Finally, in Unit 4, students will create a solution to a real world problem that will bring together all of the concepts that were studied during the course. The final challenge in Unit 4 is framed around creating sustainability related to water, food, or energy consumption in a hypothetical small village. The culminating project of the course requires students to present a report that includes CAD models or prototypes, bill of materials, and Gantt chart to achieve their selected goal. They will also present their project to an authentic audience and receive feedback. In order to demonstrate and integrate student learning of both Chemistry and Engineering design, students will be prompted to collect work samples for a portfolio that will also support them with completing their culminating project.

The project portfolio should illustrate the level of student proficiency in each chemistry based skill by documenting the application of these skills in the production of each unit project. The portfolio should contain imagery, video and written reflections rich in language/vocabulary used in both the class and the associated professional industry. As a recursive practice throughout the course, students will learn and apply documentation skills in order to create a "course notebook" chronologically recording daily progress through the course. The course notebook will be referenced recursively in each unit and should ultimately resemble a blend between traditional engineering and chemistry lab notebooks.

Unit 1: Providing Clean Water for a Community

Students will learn the chemistry of what makes water pure and such a unique, vital compound. Students will answer the questions: What is pure water, what is water contamination, and how can water be purified? Students will read current examples of how this has impacted US citizens, such as the Flint, Michigan drinking water disaster of 2015. Using the concepts of the classification and properties of matter, solutions and pH, students will design, fabricate, and then evaluate a prototype of a gravity-driven water purification system in order to purify a water sample of observable contaminants. (Unit 2 will look at how dissolved contaminants are removed). Students will first investigate commercial filtration systems and then use teacher provided resources (water bottles, cans, coffee filters, etc.) to construct their own. As part of the challenge, students will need to determine the best method for supporting their system in the vertical arrangement that gravity driven systems require. Students will sketch, then measure and properly document all purification system components, then design and fabricate a support system using 2-D CAD/CAM skills. *(Example: Students use cardboard securely hung on a wall with laser-cut parts sticking out of it. These parts will hold a funnel in place above a water bottle full of filtration material such as sand or carbon. The water bottle as well as the other components of the filtration system will also be supported by laser-cut or folded cardboard attached to the back panel.)*

Assignments

U1.1: **How is water different from other types of matter? How do we measure critical dimensions, and how do we best use a notebook to record our measurements?**

This activity will begin with students researching the differences between mixtures, pure substances, elements and compounds. To support this work, students learn notebook usage techniques and introductory lab safety. In their notebooks, students will generate definitions of the different states of matter with examples of each. After students are able to classify different types of matter, their knowledge will be extended to understand the difference between ionic and covalent compounds and their properties. Students will demonstrate their knowledge of different bonding types by modeling the dissolving process of both compound types. Students will then specifically study the properties of water that make it unique - boiling and freezing point, ability to dissolve ionic and polar covalent substances, high surface tension, etc. Students will apply their knowledge of molecular types to understand why some compounds are not miscible in each other and can be separated by density. This will involve understanding the difference between polar and nonpolar substances in order to explain why some substances float on water and some sink in water. Students can then apply this knowledge to understand a real-world situation involving polluted drinking water (i.e. - Flint Michigan, 2015). Students will read a relevant article about a real-world example and report on the chemical issues involved. This work will result in sketches that illustrate particulate structures at both the molecular and macroscopic level (example: storyboard). This unit has students design and produce a gravity powered filtration system out of common materials such as water bottles, cans, etc. This first unit assignment has students filter water mixtures using proper funnels, beakers and ring stands. Students will then adapt common materials to fit the needs of each component of the purification process which is more complex than the process experienced in assignment 1. As students use proper lab equipment in their exploration of the properties of water and filtration , such as beakers, funnels, etc., they will identify and select comparable objects from the supplied project resources (ex: water bottles, cans, etc.) Students will learn engineering sketching techniques and then sketch the selected comparable objects in their course notebook. Students will then learn to use measurement tools (ex: calipers) and how to produce properly dimensioned part drawings in order to improve their previous sketches into drawings that meet industry standards. These dimensioned drawings of project resources (ex: water bottles, cans, etc.) will be used extensively later when students design and fabricate their water purification system using 2D CAD/CAM.

U1.2: How can the contaminants of water that are observable by sight and smell be removed using physical methods? Sketch then build a water filtration system using 2D CAD/CAM.

Students understand how basic techniques (oil-water separation, sand filtration, filter and charcoal absorption) are able to remove observable components from water. Students investigate commercially available water filter systems that utilize these techniques and document findings in their notebook. Students then demonstrate understanding of the filtration processes by using their sketches from U1:1 to sketch/design a multi-process water filtration device, similar in function to the commercially available filter, but out of common recyclables (water bottles, cans, etc.). Students advance engineering drawing skills by learning to add proper drawing annotation to sketches/drawings. Students then annotate the filter system sketch to indicate the chemical processes happening in each step and which contaminants are removed in each step. Once students have a sketched filtration system that works in theory, they will be introduced to two dimensional computer aided design and two dimensional computer aided manufacturing “2D CAD/CAM” (ex: inkscape and laser cutter). Students will apply 2D CAD/CAM skills independently to design and fabricate supports for all filtration components, ultimately creating their version of a water filtration system. They will then use their filtration system to purify a sample of teacher-provided contaminated water. After using and observing their filter perform, student groups will analyze both the water cleanliness and the filter system durability. Modifications should be made to minimize leaks, and to produce water that has the least possible amount of observable contaminants. A repeat sample will be run through the modified system. Results will be analyzed and documented in their course notebook. The filtration system and the performance of this system should be documented and discussed in the student’s course portfolio.

U1.3: Is the water pure now that it looks pure? How can we know? What would we need in order to actually test the purity?

Students will be testing the filtered water from U1.2 to determine its purity. Through discussion and research, students will learn how to test the sample for conductivity and presence of specific ions. In order to do this, students will understand the chemical changes that occur during single and double replacement reactions. They will do this by combining a series of ionic compound solutions to discover how precipitates form. Students will use the periodic table and the properties of elements to predict whether a reaction will take place. Then, they will take this knowledge and design a series of tests to identify dissolved impurities that are present in the filtered water from U1.2. Additionally, once students understand the concept of pH and electric current, students will further test for impurities by measuring pH levels and conductivity. Students will produce a written filtrate testing protocol detailing how to test for a number of soluble impurities in a contaminated sample of water in their course notebook. The protocol will include a chemical justification for each step. Then they will test their contaminated sample to determine what dissolved impurities exist and record results in their course notebook. Protocols generated in this assignment should be documented and discussed in the student’s portfolio.

Unit 2: **Energy Needs of the Community:** Students will study the process of distillation as an effective means of purifying water with dissolved contaminants. As the distillation process requires a lot of energy, students will use the distillation process as a means to study energy needs and challenges involved in supplying a community with pure water. In addition, students will use the distillation process as a medium to quantify and analyze the energy supplied from various energy sources. As

a brief overview, students will observe the distillation process using traditional lab equipment (burner, hot plate, condenser, etc.) and record the resulting temperature versus time graph in their notebooks. Students will then use various energy sources to distill contaminated water samples and again record the temperature vs time graphs. Students will compare the temperature vs time graphs. The comparison will be used to instruct students on both the amount of energy necessary to distill contaminated water, and the amount of energy supplied from various energy sources. Students will then learn about the condensing process then use understandings to design and fabricate a condenser using 3D-CAD/CAM. (Extension: use a programmable controller to monitor the solution temperature and use this data as an input and to then control outputs to indicate which liquids are being condensed. Advanced extension: Have the controller aim the condenser exit tube into various containers based on the solution temperature, dividing the mixed solution into collections of pure).

Assignments

U2.1: Boil off water and create temp/time graphs related to phase change. See impurities left in the beaker.

As a class, students generate ideas for how to separate impurities from contaminated water, such as that filtered in unit 1, from the dissolved impurities. In an attempt to relate the coming activities to the world around them, students look at real world examples of evaporation (Example: salt ponds). Students discuss and record the energy source for these real world instances of evaporation (ex: the sun) in an effort to begin thinking about alternative sources of energy besides traditional lab equipment. Next, students boil off their filtrate from Unit 1 using traditional lab equipment to remove water and examine the impurities left behind. Students create a heating curve (temperature vs. time) in their course notebook showing the energy needed to change the phase of water from liquid to gas as well as from solid to liquid. Students will use sketches in their course notebook to model the molecular changes that occur during state change. Students will also annotate their sketches, applying drawing documentation skills learned in assignment U1:1, to describe the intramolecular forces. In analyzing these curves, students address the difference between temperature and energy as well as the steps necessary to condense gases back into liquids.

U2.2: Creating temp/time graphs of various chemicals. (Combustion) Design and build a cook stove.

Students will investigate transfer of energy by looking at chemical reactions that produce energy. As an introduction, students will brainstorm ways that they use energy in their everyday lives and will then think about how that energy is generated.

Students will then observe a series of demonstrations (reactions that generate heat (exothermic), absorb heat (endothermic), generate light, etc. and analyze the flow of energy (conservation of energy). Students will be able to describe chemical processes in terms of writing balanced reactions and differentiate them from physical changes. After students have written balanced equations, they will use stoichiometry to calculate the amount of energy they expect to generate from a reaction based on given amounts of reactants. Students will look at combustion reactions specifically. They will be given masses of specific fuels and use the combustion reactions to calculate (mole conversions/stoichiometry) the amount of heat that should be released. Students will then use that initial mass of fuel to heat water and determine how much of the heat was actually transferred to the water. They will compare their theoretical calculations (Joules/mole) to the actual data to determine the efficiency of fuel source and analyze for sources of error. This will all be completed in the course lab notebook. After demonstrating an understanding of combustion reactions as a means to release energy, students will research examples of traditional stove devices and study how ignition, oxygen and fuel are combined to release heat energy. Students will then sketch a design of a small cook stove that could be used to provide heat to the water distillation system used in the previous assignment. The designed stove should be made out of resources determined at the teacher's discretion (ex: clay, metal can, etc.) for the purpose of converting stored energy from a provided energy source (ex: peanut, wood chip, etc) into heat energy as effectively as possible. Students will demonstrate their understanding of the combustion process by defending their stove design decisions (such as oxygen intake hole diameter, stove size based on fuel requirements, etc.) with relevant chemistry related reasoning. Students will further demonstrate their understanding of combustion and energy flow by diagramming and annotating energy flow on this design sketch as well. The resulting cookstove design (or the fabricated cookstove) should be documented and discussed in the student's portfolio. (optional extension: build and test the cookstove)

U2.3: **Students will now take their 'clean' water from Unit 1 and learn how to remove the dissolved contaminants using the process of distillation. Students will apply the concepts of 3D modelling and measurement tolerance to fabricate a condenser.** Students will learn about boiling point and melting point and how they vary depending on the compound. In this assignment students will design a distillation system for purifying the clean water that they generated in Unit 1 using combustion. Based on knowledge of phase change, students will design a distillation system to separate alcohol from water. Students will also be asked to take into account the energy involved in this process and strive to make their system as energy efficient as possible as well as be able to justify their choices with respect to energy flow. Students will also research real world applications of this. Students also learn about the process of removing energy from a vapor to condense vapors into liquids. Until now, students have released energy from an energy source to add heat to a liquid, converting the various liquids into vapors, separating out the water contaminants. The vapors have simply evaporated. Now students learn about condensers, how they work and how this process captures the purified liquids rather than allowing them to escape. Students learn about 3D modeling and measurement tolerances related to creating water tight seals and hose fittings in order to fabricate a condensing device to cool the vapor produced in the distillation process. Students will produce (ex: 3D print) a condenser that fits tightly around the tube/hose exiting the distillation apparatus that also has an input and an exit hole for cooling water to enter and exit through supplied hoses. The condenser produced here should be documented and discussed in the student portfolio.

Unit 3: Providing food for the community In this unit, students will consider how energy is generated and stored for human use and growth. Students will study the basic types of chemical reactions and how energy is released or absorbed through chemical change. Specific reactions (ReDox) that can be harnessed to release energy to do work will be studied through an investigation and production of a battery used to light an led or power a fan. Next, students will shift their focus to how humans get the energy they need through food. Students will study important biochemical molecules vital for life. That information will be connected to how these nutrients are provided and how they can be renewed via composting practices. Initially, students will experiment to make a loaf of bread. This will include both qualitative and quantitative analysis of the ingredients and the products and the chemical processes involved in the process. Students will analyze the processes involved in producing bread to create a detailed Bread Bill of Materials, Task list, Task dependency, and Gantt Chart. Students will then use proportional reasoning to scale this information in order to make predictions regarding features of a bakery capable of supplying bread to their community.

Assignments

U3.1: Types of chemical reactions and how they relate to energy (conservation of mass):

Students will compare different types of reactions and group them based on similarities and differences including whether energy is absorbed or released (exothermic vs. endothermic). They will then do a real life scavenger hunt where they look for each type of reaction (single replacement, double replacement, combustion, redox, synthesis, decomposition) in their lives and create a poster presentation. Students will do a gallery walk and give feedback on other student work. Images of the poster presentation should appear in the student portfolio. Students will then research nuclear reactions and discover how energy from nuclear reactions is used to generate electricity through producing steam to turn a turbine. Students will also compare the efficiencies of nuclear power in comparison to chemical reactions. As this work is in theory only, students will produce a pamphlet supporting what they feel to be the best means of generating electricity in their community. The pamphlet should be documented and discussed in the student's portfolio.

U3.2: How do we store the energy we need? How does a battery work? What are the components? What types of batteries are there?
Students will construct a battery from simple materials. They will demonstrate an understanding of the chemistry behind batteries (oxidation reduction reactions) by producing a properly labeled drawing of the complete system/process in their course notebook. Students will explore how different materials, therefore different reactions, produce different voltages and are therefore able to produce different amounts of electrical energy. Students will use data collected in order to design a set up that will turn on a low voltage LED bulb and provide a written summary of design, theory and results. Result will be documented in a the course notebook.

U3.3: What are the main components of foods that provide energy and nutrition for humans? (CALORIMETRY) Students learn about the role of carbohydrates, proteins and fats in energy storage and usage for humans. Students learn about their chemical structure and how to test for them. Students should also conduct an energy analysis of the components to measure the relative energy content of each. This could include burning a given mass of carbohydrate, protein or fat and capturing the energy in a soda can calorimeter. Students will write up a report of their procedure and findings in their course notebook. They will include a bond energy analysis as well. As students learn about these molecules, students will create a spreadsheet-driven Bill of Materials including columns documenting chemical properties and characteristics. The information from these spreadsheets should be included in the course notebook.

U3.4: Chemistry of making food (bread, or some other food that requires multiple interdependent processes, ex: pancakes, peanut brittle). How can bread-making be described using a spreadsheet-driven Gantt chart in order to maximize the efficiency and reproducibility of the product?
Students will be given a basic bread-making recipe. Students will learn about different chemical properties and reactions that occur during the bread-making process. Students will support this discussion by creating a spreadsheet-driven bill of materials with columns detailing bread ingredient, chemical properties of each, etc. Chemistry related bread making topics may include but are not limited to: the generation of gases (including gas laws), gluten formation (polymerization), energy content of fats and carbohydrates, how the molecular-level structure leads to the observable 3D structure, how the molecular-level structure of the pan impacts the baking of the bread, etc. Before performing the experiment (making the bread), students create a spreadsheet-driven Gantt chart to learn the concepts of task and time management. After following the Gantt chart to prepare the recipe once, student will choose an independent variable in the recipe (including the process) to change in order to optimize a chosen aspect of the bread (dependent variable) (Example: add baking soda/powder or increasing yeast to increase bread rising as measured by air bubble diameter or bread height). Students will also record and compare the actual process versus their planned process and amend the Gantt chart as necessary. They will then use the amended chart in combination with the bill of materials to hypothetically scale the process up to a size capable of producing bread for every member of their community every day. Students produce a numerically driven experimental report and presentation demonstrating the bread-making process. The presentation and report should include the data collected during the experimental process as well as scaled data for a hypothetical bakery capable of supplying bread in their community. (Example data: employee count, energy consumption, oven capacity, ingredients needed, etc.) The experimental report will be documented and discussed in student's project portfolio.

U3.5: Soil testing. What does soil need to support plant growth? Intro to programing, model closing control loop using sensors inputs (ex: temperature probe) and outputs (ex: fan)
Students learn about the components in soil that are necessary to support plant growth (soil structure, nitrates, phosphates, and pH). Students will apply Le Chatelier's principle to be able to understand the importance of the ph test and how soils could be modified with respect to their pH levels as water is in constant equilibrium with the production of hydrogen and hydroxide ions. Students will apply their knowledge of pH

and ions from unit 1 and extend it to understand how pH is quantified with respect to solution concentration (molarity) and pH calculations. They will then learn to test for the components required for plant growth using chemical tests as well as nutrient probeware. This testing technology will be used in the next assignment where students will program a system to monitor characteristics of a composter and then take action based on what the sensors read. All students will measure the characteristics necessary for an optimal soil using both chemical and probeware methods and then individual student groups will test another soil sample from the community (i.e. from school garden, student homes, etc). Students will produce a report/presentation comparing the chemical analysis of a soil sample with the equivalent probe technology-based test results. This presentation should be documented in the portfolio. Student groups should each study different soil samples with different characteristics and present this information to the class so that all students understand different soil qualities.

U3.6: The nutrients and energy humans need from their food must be recycled through the environment.

Getting nutrients back into the ground is vital to support plant growth which provides these nutrients and energy. Composting is an ideal process for conserving the matter and energy in a sustainable and low-pollution manner. Students will learn more specifically about decomposition reactions touched on earlier in assignment 1. Students will also consider the various materials that could be used to house their compost in order to optimize the conditions for the composting. This will involve understanding the various properties of different groups on the periodic tables - metals, nonmetals and metalloids. If time allows, student groups can research specific crops that provide ideal nutrient sources for a sustainable community. That information could be utilized to maximize the design of the compost.

Students will design and build a composting system that can be continually monitored for some key characteristics such as temperature and moisture content. They will need to research the types and proportions of substances that are needed in order to produce the ideal soil learned about in Lesson 5. Students will need to study kinetics in order to understand the importance of temperature, concentration and catalysts on controlling the rate of reactions.

Students will also learn to incorporate the technological measurement equipment used previous unit as an input to a programmable controller (ex: Arduino). Students learn to program their programmable controller to control a system output that impacts the process of composting (ex: open/close an irrigation valve, turn on/off air circulation fan, etc.) Ultimately, students combine monitoring technology and controlling outputs in order to create a system that continuously monitors one (or more) critical compost factor (ex: moisture, nitrates, phosphates, temperature, etc.) and to then take appropriate action when determined necessary. (ex: turn on a fan when the container is above ideal temperature)

Unit 4: Culminating project combining water purification, energy, food to help create a self-sustaining village

In this unit, students will create a solution to a real world problem that will bring together all of the concepts that were studied during the course. This challenge will be framed around creating sustainability related to water, food, or energy consumption in a hypothetical small village. Students will present a report complete with CAD models or prototypes, bill of materials and Gantt chart to achieve their selected goal. They will also present their project to an authentic audience and receive feedback. Examples of topics that students might choose to address include: handling compost, planning a community garden, making enough food to feed the community, or energy or waste management.

Assignments

U4.1: Identify a real world problem related to making a community sustainable and design a solution.

Students will identify problems associated with sustaining a community as it relates to topics addressed in this course (water purification, energy sources, energy storage, or food). They will research the problem from both a chemistry and engineering design perspective. Students will identify a professional in the field and interview this person to better understand what will be necessary to accomplish. The students will write a persuasive essay that argues the importance of addressing the issue chosen and proposes a possible solution using a combination of chemical and engineering design knowledge.

U4.2: Plan your culminating project.

Students will identify the design constraints of their problem. These parameters will be used as key characteristics against which their end product will be compared. These might include cost, size, availability of materials, etc. Once these constraints have been approved, students will then use their knowledge of Gantt charts to generate a series of steps and benchmarks for implementing their proposed solution.

In addition, students will research and create a materials list that includes cost analysis for the implementation of their proposed solution. Each step of their proposed solution will need to be justified from both a chemical and engineering perspective.

U4.3: Carry out and revise your plan

Students will implement their project plan. During this phase, students will continue to maintain their course notebook. As part of this implementation, students will submit rough drafts of the elements required in U4:4 in order to document their progress. This may include summary notes, product development information, testing data, revisions, obstacles and their progress as it relates to their Gantt chart. Students will receive both teacher and peer feedback.

U4.4: Present your solution to a panel/authentic audience. Complete portfolio

Students will present a multimedia presentation of their final product which will describe the problem they are solving, the chemistry concepts involved, the engineering process and an analysis of the effectiveness of the project. The audience members (peers, instructor, community members) will provide feedback on the presentation and viability of the plan.

Textbooks

NOTE: Include list of Primary and Secondary Texts. Make sure to note the books that will be read entirely and those that will be as excerpts. Textbook information is not necessary if your course is a Visual and Performing Arts, Advanced Placement or an International Baccalaureate course. Online texts or non-standard text materials should include a link to the online text.

Textbook

Title: District approved Chemistry Book

Edition:

Publication Date:

Publisher:

Author(s):

URL Resource(s):

____

Usage: ______ Primary Text ______ Read in entirety or near entirety

(Be sure to list any additional textbooks that are used for the class.)

Supplemental Instructional Materials

Water Contamination Articles
Flint, Michigan
http://www.freep.com/story/news/local/michigan/flint-water-crisis/2016/01/29/epa-high-lead-levels-flint-exceed-filters-ability/79540740/
http://www.theatlantic.com/business/archive/2015/07/dont-drink-the-water/399803/
New Jersey
https://www.tcnj.edu/~unbound/article.php?id=96

Soil Resources
http://extension.psu.edu/business/start-farming/soils-and-soil-management/soil-quality-introduction-to-soils-fact-sheet
Soil Moisture Sensor
http://www.vernier.com/products/sensors/sms-bta/?search=moisture&category=autosuggest

How to Start a composting with a school:
http://www.greenmountainfarmtoschool.org/wp/wp-content/uploads/Guide-to-Staring-a-School-Compost-Program.pdf
https://www.gardenorganic.org.uk/sites/www.gardenorganic.org.uk/files/resources/fflp/composting.pdf

Chemistry of Bread-making:
http://www.rsc.org/images/BreadChemistry_tcm18-163980.pdf