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Cultivating Future Water Scientists in the Texas Panhandle: A STEM Education Program

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Abstract

This study takes a hands-on approach to inspire middle and high school students in the Texas Panhandle about the fascinating world of water science and environmental engineering. By delving into soil properties and wastewater treatment, we aim to ignite curiosity and a deeper appreciation for water-related processes and their significance to the region's ecosystems. Middle school students will use simple tools like magnifying glasses and soil texture triangles to investigate the properties of different soil types prevalent in the Texas Panhandle, such as sandy loam and clay loam. Hands-on activities will teach them about soil components, including minerals, organic matter, water, and air. They will also create a water cycle model to visualize the movement of water through the Earth's system, exploring concepts such as evaporation, condensation, precipitation, and runoff. High school students will conduct experiments to measure the permeability of different soil types using parameters. They will analyze the data to understand how soil permeability affects water infiltration and groundwater recharge. Additionally, they will design and build small-scale wastewater treatment systems, incorporating filtration, sedimentation, and biological treatment processes. By analyzing the effectiveness of their designs in removing pollutants from wastewater, students will gain insights into real-world water quality issues. By combining theoretical knowledge with practical experience, these activities promote critical thinking, problem-solving, and data analysis skills. Students will gain insights into the challenges and opportunities associated with water resource management and environmental sustainability in the Texas Panhandle. Ultimately, this hands-on approach aims to inspire future generations of scientists and engineers to address the pressing water issues of the region and contribute to a more sustainable future. This initiative aligns with the broader goals of STEM education by developing students' analytical, teamwork, and problem-solving skills and connecting education to real-world environmental challenges specific to the Texas Panhandle.

Introduction

Water is the cornerstone of all life on Earth, serving as a critical resource for ecosystems, agriculture, industry, and human consumption. However, its availability is increasingly under threat due to a combination of global challenges, including rapid population growth, climate change, and environmental degradation. These factors are placing unprecedented pressure on freshwater systems, leading to crises in regions where water scarcity was previously manageable. This reality underscores the urgent need for sustainable water management practices to ensure the survival of ecosystems and the well-being of human populations. In the Texas Panhandle, the reliance on water resources is deeply intertwined with the region's agricultural economy, which serves as a backbone for local livelihoods and food production. Agriculture, being a water-intensive industry, amplifies the pressure on limited water supplies. The region faces a trifecta of challenges: water scarcity, soil erosion, and groundwater depletion. Water scarcity is exacerbated by erratic rainfall patterns, reduced surface water availability, and over-extraction of groundwater from aquifers such as the Ogallala, a primary water source for the Panhandle.

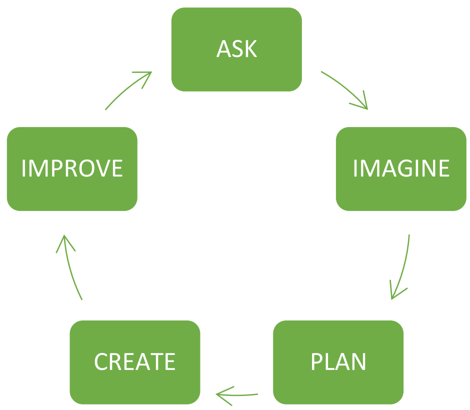

Figure 1: Engineering design process.

The process begins with Ask, where students identify a specific problem, research existing solutions, and define the challenges to build a strong foundation. Next, in Imagine, they brainstorm multiple ideas, evaluate their feasibility, and select the most promising solution, fostering creativity and decision-making. During Plan, students organize their approach by creating detailed diagrams, material lists, and step-by-step instructions, emphasizing systematic preparation. In Create, they implement their plan by building and testing a prototype, linking theory to hands-on application and assessing functionality. Finally, in Improve, students analyze their results, refine their design, and make iterative modifications, promoting resilience, adaptability, and continuous improvement. This process develops critical thinking, problem-solving, and practical skills. [1]

Quality of soil textures:

Soil texture	Holds Nutrients	Water Infiltrates	Water Holding	Aerated	Workable
Clay	Good	Poor	Good	Poor	Poor
Silt	Medium	Medium	Medium	Medium	Medium
Sand	Poor	Good	Poor	Good	Good
Loam	Medium	Medium	Medium	Medium	Medium

The Soil Texture Triangle is a tool that classifies soil types based on their proportions of sand, silt, and clay, categorizing them into types like sandy loam, clay loam, and silty clay. Each side of the triangle represents one component, and soil types are identified based on where their composition falls. Sandy soils drain water quickly but retain less moisture, while clay-rich soils hold water well but drain slowly. Silt improves water retention and nutrient-holding capacity. This triangle is particularly useful in the Texas Panhandle for understanding soils like sandy loam and clay loam. It helps students connect soil science to real-world applications like agriculture and water management through engaging activities.[2]

Figure 2: Soil texture traiangle

Sandy loam is a soil with high sand content (60-70%), providing excellent drainage, high aeration, and easy root penetration, though it retains little water and nutrients. Clay loam, on the other hand, contains more clay (20-35%) and has a fine, cohesive structure, offering excellent water and nutrient retention but poor drainage and limited aeration. Understanding these soil types helps identify their suitability for crops, water management, and fertilization needs. Sandy loam supports well-drained crops like peanuts and cotton, while clay loam benefits moisture-loving crops like wheat. This knowledge aids in optimizing soil use for agriculture and land management. Soil is made up of four essential components: minerals, organic matter, water, and air, each contributing to its ability to support plant growth and sustain ecosystems. Minerals, such as sand, silt, and clay, form the bulk of the soil and determine its texture, structure, and drainage properties, which influence how well plants can root and access nutrients. Organic matter, though present in smaller amounts, plays a vital role in improving soil fertility by providing nutrients, enhancing water retention, and supporting microbial activity essential for nutrient cycling. Water in the soil dissolves nutrients, making them available for plant absorption, while its retention depends on soil texture—clay soils hold more water, while sandy soils drain quickly. Air occupies the spaces between soil particles, supplying oxygen to plant roots and soil microorganisms necessary for respiration and decomposition. Understanding these components helps students recognize how soils function to support life, manage water resources, and maintain agricultural productivity while addressing environmental challenges like erosion and pollution. [3]

The water cycle model simplifies the movement of water through Earth's systems, highlighting four key processes: evaporation, condensation, precipitation, and runoff. Evaporation occurs as the sun's heat converts water from oceans, rivers, and soil into vapor, which rises into the atmosphere. As the vapor cools, it condenses into droplets, forming clouds during the condensation stage. Precipitation follows when these droplets become heavy and fall back to Earth as rain, snow, or hail, replenishing water in soil, rivers, and lakes. Runoff occurs when water that doesn't infiltrate the soil flows over land into water bodies, connecting terrestrial and aquatic systems. Soil plays a critical role in this cycle, influencing water absorption, retention, and movement. Sandy soils drain quickly, allowing deeper infiltration but holding less water, while clay soils retain more water but are prone to runoff. Understanding the water cycle model helps students connect these processes to soil management, agriculture, and sustainability, offering practical insights into water conservation and environmental health.

Soil permeability measures how easily water moves through soil, a property that significantly impacts water infiltration and groundwater recharge. Testing permeability involves studying how water flows through the soil's pores, either vertically or horizontally, depending on the soil's structure and texture. Permeable soils, like sandy soils, allow water to pass through quickly, making them effective for rapid infiltration and groundwater recharge. In contrast, less permeable soils, such as clay-rich soils, restrict water flow, leading to slower infiltration and potential surface runoff. By analyzing permeability, students can understand the relationship between soil properties and water movement. For example, highly permeable soils contribute to efficient groundwater recharge but may struggle to retain water for crops, whereas low-permeability soils can hold water longer but may cause waterlogging. Understanding these properties helps students grasp the critical role soils play in water management, agricultural practices, and environmental sustainability, providing insights into how different soil types influence the hydrological cycle and resource conservation. [5]

Building a small-scale wastewater treatment system is an engaging way to understand how water can be cleaned and made safe for reuse or release into the environment. This system involves three key processes: filtration, sedimentation, and biological treatment. Filtration removes large particles and impurities by passing water through layers of gravel, sand, and activated carbon, which trap debris and absorb contaminants. In the sedimentation stage, the water is left undisturbed, allowing heavier particles to settle at the bottom due to gravity, reducing turbidity and clearing the water. Finally, biological treatment uses microorganisms to break down organic pollutants. This is achieved by passing the water through a biofilter, where beneficial bacteria consume harmful substances. By constructing and observing such a model, students can see how pollutants are removed and clean water is restored, making the process tangible. This activity helps students appreciate the importance of wastewater treatment in protecting ecosystems, conserving water, and safeguarding public health, linking classroom science to real-world environmental challenges. [6]

Methodology

The activity begins with students learning about the Soil Texture Triangle, a scientific tool that helps classify soil types based on their proportions of sand, silt, and clay. The triangle visually represents how different combinations of these three components result in soil types like sandy loam, clay loam, or silty clay. Students collect soil samples from the Texas Panhandle, known for its diverse soil types such as sandy loam and clay loam. They analyze these samples to determine the percentage of each component using methods like sedimentation tests or sieving. Once they have the data, students plot the results on the texture triangle to identify the specific soil type. This hands-on activity helps them understand the significance of soil classification and its implications, such as how texture affects water retention, drainage, and aeration. By making theoretical concepts tangible, students not only improve their analytical skills but also develop an appreciation for the complexity of soil science and its importance in agriculture and environmental management.[1] Students then delve deeper into the four essential components of soil: minerals, organic matter, water, and air. They investigate how minerals such as sand, silt, and clay determine soil texture and structure, influencing its permeability and ability to support plant roots. Through simple experiments, such as adding water to soil samples and observing drainage rates, students explore the role of air in soil, which creates pore spaces necessary for root growth and microbial activity. Additionally, they measure how much water different soils can retain, highlighting the differences between sandy loam, which drains quickly, and clay loam, which holds water more effectively. This step not only teaches students about the physical and chemical properties of soil but also fosters critical thinking by encouraging them to draw connections between soil composition and its behavior in various environmental conditions.[3] In the final step, students link their findings to real-world applications, exploring how soil texture and components influence environmental processes and agricultural practices. They discuss how sandy loam’s high permeability makes it ideal for crops that require well-drained soils, such as peanuts and cotton, while clay loam’s excellent water retention benefits moisture-loving crops like wheat and sorghum. Students also analyze how soil properties affect groundwater recharge, erosion, and sustainability. For instance, they learn that sandy loam supports rapid water infiltration but may lead to nutrient leaching, whereas clay loam can prevent water loss but risks waterlogging. By engaging in discussions and applying their knowledge to practical scenarios, students understand the role of soil management in addressing challenges such as water conservation, sustainable farming, and environmental protection. This step emphasizes the importance of informed decision-making in agriculture and land use, preparing students to tackle future challenges with a solid understanding of soil science.[4]

Permeability is a measure of how easily water flows through the pores in soil, which directly impacts water infiltration and groundwater recharge. This concept with relatable examples:sandy soils, with large, connected pores, have high permeability, allowing rapid water movement, while clay soils, with small and compact particles, show low permeability, restricting water flow. Similarly, the**.** Porosity (the total volume of pores) influences water storage, while the connectivity of these pores determines permeability. For instance, sandy soil may not store much water due to larger, poorly retaining pores, but it allows fast infiltration, making it ideal for crops requiring well-drained soils. Understanding permeability teaches students how soil affects water availability for plants and ecosystems.

The provided materials outline practical experiments to measure soil permeability. This method uses funnels filled with soil types like sand, clay, and gravel. Students pour a fixed amount of water into each funnel and measure the time taken for water to pass through. This activity visualizes differences: gravel, with large particles, allows water to flow quickly, while clay slows water movement due to its tightly packed structure. Additionally, students calculate porosity by measuring the volume of water retained in different soils after infiltration. These experiments reveal how soil particle size, structure, and connectivity influence water movement. Students can analyze data to understand how high-permeability soils facilitate groundwater recharge, while low-permeability soils retain water for longer, aiding drought-resistant crops.

Figure 3: Demonstration of porosity and permeability using recycled bottle filters with varying sediment layers.

This methodology offers students in grades 6-12 an engaging opportunity to bridge scientific theory with real-world applications. By exploring soil permeability through hands-on activities, students gain a deeper understanding of soil's role in agriculture, water management, and environmental sustainability. It emphasizes the agricultural importance of matching soil types to crops, demonstrating that sandy soils are ideal for crops requiring good drainage, while clay soils retain water for moisture-dependent plants. The Porosity knowledge to environmental conservation by highlighting how permeable soils reduce surface runoff, prevent erosion, and improve water quality. These activities also illustrate the critical role of permeability in groundwater recharge, which is vital for regions facing water scarcity. By participating in these experiments, students develop critical thinking, problem-solving, and analytical skills while fostering teamwork and curiosity. This approach not only reinforces theoretical knowledge but also inspires a greater appreciation for sustainable resource management, preparing students for advanced STEM studies and careers.

Students learn about the water cycle, a fundamental natural process that describes how water moves continuously through Earth's systems. This cycle includes four main stages: evaporation, where heat from the sun turns water from oceans, rivers, and lakes into vapor; condensation, where the vapor cools and forms clouds; precipitation, where water falls back to the surface as rain, snow, or hail; and runoff, where excess water flows into rivers and oceans or infiltrates the soil. Students gain an understanding of how solar energy drives this cycle and why it's critical for maintaining life on Earth. They also learn how the water cycle is interconnected with climate regulation, soil health, and freshwater availability. By linking these processes, students understand the role of the water cycle in supporting ecosystems, agriculture, and water management systems This hands-on activity demonstrates key processes of the water cycle, specifically focusing on evaporation, condensation, and collection. The jar represents a simplified model of Earth's water cycle, with water inside mimicking surface water exposed to heat. As the water warms, it releases vapor, simulating the process of evaporation. The ice on the lid acts as a cooler surface, much like high-altitude clouds, causing the rising vapor to condense into liquid droplets, demonstrating condensation. These droplets then collect on the lid or fall back into the jar, representing precipitation. This interactive experiment allows students to visually grasp how water transitions between phases in the natural cycle. By mimicking real-world processes, the activity fosters a deeper understanding of the water cycle's dynamics and emphasizes its importance in maintaining environmental balance.

Figure 4: Experimental model demonstrating key phases of the water cycle-evaporation, condensation, and precipitation.

The water cycle model directly connects to STEM education by teaching students the scientific principles of Earth's hydrological system while highlighting its real-world applications. Through these experiments, students develop critical thinking, problem-solving, and data analysis skills as they explore the relationships between water movement, soil properties, and climate. For instance, understanding how water infiltrates soil or contributes to runoff helps them appreciate the importance of water conservation and sustainable land use. These lessons from the Soil Properties and water cycle also emphasize the global challenges of managing water resources in agriculture, mitigating climate change impacts, and protecting ecosystems. By connecting classroom activities to real-world challenges, students are encouraged to think creatively about solutions, fostering a deeper appreciation for science and its relevance to everyday life. This approach not only builds knowledge but also inspires future careers in STEM fields and environmental stewardship.

Students gain a comprehensive understanding of wastewater treatment by constructing small-scale systems that incorporate sedimentation, filtration, and biological treatment. This activity introduces key processes such as sedimentation, where solids settle due to gravity, reducing turbidity and preparing water for further purification. Filtration follows, using layers of gravel, sand, and activated charcoal to remove finer particles and chemical pollutants, helping students measure turbidity changes and understand how filtration improves water clarity. Finally, biological treatment utilizes microorganisms to metabolize organic pollutants in aerated environments, converting waste into harmless byproducts like water and carbon dioxide. Through hands-on activities, students design, test, and optimize these treatment systems, fostering critical thinking and problem-solving skills while connecting engineering principles to real-world applications. By observing the transformation of water throughout these stages, students develop STEM skills and appreciate how wastewater treatment protects public health, conserves resources, and ensures environmental sustainability for a cleaner future.

Figure 5: Materials for simulating wastewater treatment processes: sedimentation, filtration and biological treatment

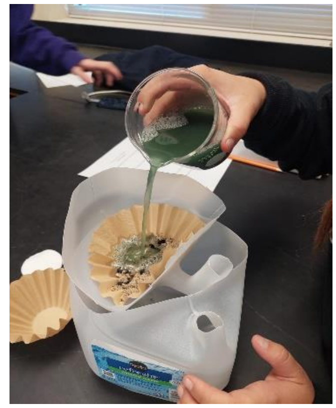

Figure 6 : Hands-On demonstration of filtration in a wastewater treatment process

Result and Analysis

The survey results show varying STEM topic understanding across grades, with older students (8-12 grade) demonstrating stronger comprehension of concepts like the water cycle, soil texture, porosity, and permeability compared to younger students (6-7 grade). Hands-on activities, like constructing wastewater treatment systems, proved most engaging, with 34 middle school students reporting vast knowledge. Older students (23 vast knowledge) excelled in applying theoretical concepts, while younger students benefited from experiential learning. These findings highlight the need for age-specific teaching approaches, combining foundational activities for younger students and analytical challenges for older ones, to enhance STEM learning and inspire future interest.

	Total Students = 36		Total Students = 23	
	6-7 Grade		8-12 Grade	
	Vast Knowledge	Little bit knowledge	Vast Knowledge	Little bit knowledge
1. Well management and Ground water sustainability	23	13	21	2
2. Does nature producess new water-Water Cycle/ Hydrological Cycle	15	21	22	1
3. Ground Water Quality or aquifers filtration	0	36	23	0
4. Which activity attractive for the students or They newly learned	34	2	22	1

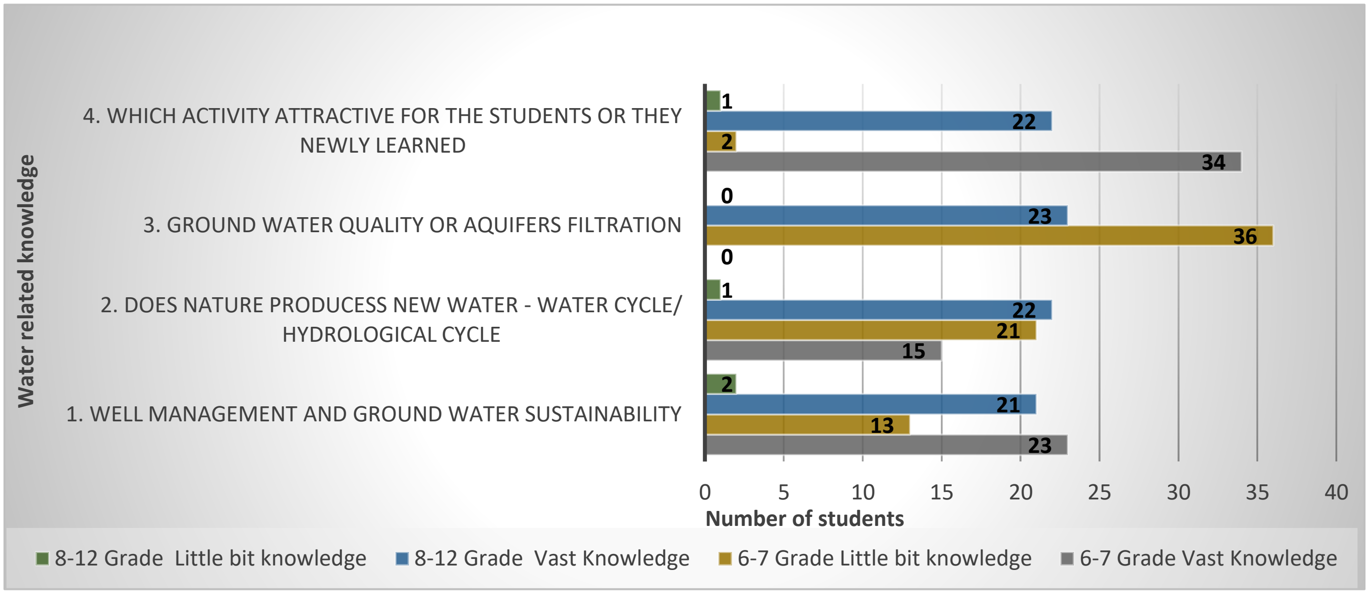

Fig 7: Water and soil-related knowledge assessment for 6–7 & 8-12 grade students in STEM education.to solve real-world problems

Conclusion

This program serves as a catalyst for inspiring the next generation of scientists and engineers to tackle critical water challenges at both regional and global levels.. These activities foster a deeper understanding of water management issues, from addressing water scarcity to improving groundwater recharge and pollution control. Students learn to think critically, analyze data, and work collaboratively . By connecting education to environmental challenges specific to the Texas Panhandle, this initiative not only addresses local issues but also prepares students to innovate sustainable solutions on a global scale.

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