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Project-Based Learning-to-Go: Fog Net & Biomimicry Curriculum for High School Students

An Interdisciplinary Qualifying Project

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Project-Based Learning-to-Go: Fog Net & Biomimicry Curriculum for High School Students

An Interactive Qualifying Project

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By

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Abstract

The goal of this project was to create a project-based learning curriculum around the premise of building fog water collection nets for the Berber minority in the Anti-Atlas Mountains of Morocco and using biomimicry as inspiration for the net design. The goal of this curriculum is to get more women and students from underrepresented backgrounds interested in the field of engineering. The curriculum was developed and reviewed by professionals in the field, though implementation needs to be done to evaluate its efficacy.

Acknowledgments

I would like to thank Katy Jessop and Kyra Biederman for providing me access to their resources and their lesson plans developed for middle schoolers for a previous iteration of the PBL Fog Net project. Their previous work was a huge help for developing my own curriculum.

I would also like to thank Donna Taylor from Worcester Polytechnic Institute's STEM Education Center for reading through and providing me feedback on my preliminary lesson plans.

Lastly, I would like to thank my advisors, Professor David DiBiasio and Professor Kristin Boudreau, from Worcester Polytechnic Institute for their flexibility in allowing me to take this project in the direction of my interest, in addition to their guidance for my project's direction, which helped save countless hours and shaped the project into its current form.

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Introduction

Getting students interested in science, technology, engineering, and mathematics, otherwise known as STEM, is crucial for a variety of reasons. According to the U.S. Department of Commerce STEM-related occupations grew at a rate of 24% from 2005-2015, while occupations outside of STEM grew at a rate of 4%. STEM workers will play a key role in providing sustainable and stable economic growth into the future too, as STEM jobs are projected to increase by an additional 8.9% from 2014-2024 compared to that of 6.4 % of non-STEM employment (Noonan 2017). People with STEM degrees also earn more than those with non-STEM degrees, with workers possessing a bachelor's degree in STEM earning on average $39.28 per hour in 2015 compared to $28.34 for non-STEM bachelor's degree holders (Noonan 2017). STEM workers also tend to experience lower rates of unemployment. As a result of the 2008 economic crisis, the STEM unemployment increased from 1.9% to 5.2% before falling back down to 2.5% in 2015, However, the non-STEM unemployment rate increased from 4.8% to almost 10% before falling back down to 5.5% in 2015, still being over double that of the STEM unemployment rate (Noonan 2017).

Besides economic factors, STEM is a source of innovation, contributing to many advances in technology, computing, healthcare, construction, etc. STEM education also provides a unique skill set that is desirable in many other fields, but specifically management occupations. These traits include critical thinking, collaboration, and problem-solving skills (Noonan 2017).

Yet getting students involved in STEM is still challenging. According to a Pew Research Center survey conducted in 2017, 52% of US adults say the main reason young people don't pursue STEM degrees is that they think these subjects are too difficult. Other noteworthy responses include 23% percent saying that STEM subjects are not useful for their careers, and 12% saying simply that STEM subjects are too boring (Kennedy et al. 2020).

In the same survey, those who were interested in STEM degrees but did not end up pursuing them cited the following reasons for not pursuing a STEM degree: first being cost and time barriers (27%), second, being the pursuit of a different interest/career path (20%), and third being had difficulty in STEM classes or lost interest in STEM (14%)(Kennedy et al. 2020).

Furthermore, interest and involvement in STEM are not equal. According to the U.S. Department of Commerce, while women make up more than half of the college-educated workforce, only 25% of college-educated STEM workers are women (Noonan 2017). This disparity holds true for many non-White ethnic backgrounds too. While 29.3% of the US population is classified as underrepresented minorities (Black, Latinx, Indigenous), only 14.7% of STEM bachelor's degree holders are classified as underrepresented minorities. This disparity only increases at each degree level (Estrada et al. 2016).

One way to seed interest in STEM is to get students involved in project-based learning (PBL) revolved around STEM topics. Project-based learning is a method of teaching that stresses experiential learning through student self-management and self-discovery guided by a teacher or professor. Students are given a problem and then must research how to solve it (Kokotsaki et al. 2016). Once the students conduct their research, they are then required to provide a feasible solution and discuss their findings, usually in the form of a presentation or a report. These problems are often based on actual real-life scenarios and issues. In addition, these PBL problems are often curriculum-based to provide students with the necessary tools and information to complete the project. Furthermore, like many projects in the real world, PBL problems are interdisciplinary and require a variety of knowledge and skills in different subject areas (Solomon 2003).

Another way to promote interests and retention is to put some personal stake into what students are learning in STEM, as these are often the main motivators for students choosing a career path. There is increasing evidence that motivation and persistence for students of underrepresented backgrounds in STEM come from the goal of resolution of cultural issues that are shaped by student's cultural experiences and communities (Estrada et al. 2016). Additionally, further research has provided evidence that people from underrepresented backgrounds and women are more likely to get involved in science for the benefit of their community and society and for the pursuit of social causes that they feel have value (Seymour & Hewitt 1994)(Miller et al. 2000).

The goal of this project is to develop a curriculum to get students interested in STEM. This will be accomplished by focusing on three things: hands-on project-based learning, avoidance of complex mathematics or other factors that scare away potential STEM students and focusing on humanitarian problems that are culturally relevant. Incorporating these 3 factors into the curriculum will hopefully maximize interest in STEM while appealing to all backgrounds.

Background

Project-Based Learning

Project-Based Learning (PBL) is a method of teaching that arranges student learning around the completion of projects. Projects are complex in nature and based on challenging real-world problems. Students develop solutions through a combination of critical thinking, design, decision making, experimentation, problem-solving, collaboration, and communication with peers and technology (Bell 2010). This method of teaching is also reliant on guided student self-management. Successful PBL curriculums achieve a greater student understanding of the course content and result in quality and realistic presentations and products (Solomon 2003).

Effectiveness of Project-Based Learning

Project-Based Learning has proven to produce better results on standardized tests compared to traditional curriculums, regardless of setting. In a diverse, inner-city school located in Boston, eighth-graders scored the second-highest in the district on the Stanford 9 Open-Ended Reading Assignment after the implementation of a PBL-based curriculum. Similar results held true for a Portland, Maine middle school. After implementation, scores saw increases of almost four times that of the state average. Similar results can be found across the United States (Thomas, 2000).

Project-based learning approaches to STEM education have also been shown to stimulate interest, especially in backgrounds less likely to pursue STEM fields. One study with 14- and 15-year-old girls in Israel showed increased interest in learning STEM-related subjects compared to their non-PBL curriculum counterparts (Barak and Asad, 2012). Another study surveyed 84 female high school students in Taiwan and showed that students who had PBL STEM curriculums showed higher levels of interest and engagement with the subject and could combine the theory and practice principles more effectively (Lou et al. 2011). Furthermore, PBL curriculums tend to motivate low-achieving students more than traditional curriculums. A study conducted by Doppelt (2003) found that STEM-related PBL helped improve the motivation and self-esteem of low achieving students and resulted in more students reaching college acceptance thresholds.

Making an Effective PBL Curriculum

To maximize the learning potential and efficacy of a PBL curriculum, it must meet two general criteria. First, students must feel as if the project is personally meaningful. It must be a task that has an empathetic stake so that they will want to do well and put in the effort. Second, the project must fulfill an educational purpose. Too often, a PBL curriculum fails to properly meet these two criteria and comes off as busy work for students, rendering it less efficacious than desired (Larmer & Mergendoller 2010). To properly meet these criteria, researchers at the Buck Institute for Education have identified 8 crucial elements that should be incorporated into each PBL curriculum. They are as follows:

1. Significant Content
2. Stimulated Curiosity
3. A Driving Question
4. Student Direction
5. 21st Century Skills
6. Inquiry and Innovation

7. Feedback and Revision
8. Public Presentation

Significant Content

To be effective, a PBL project must incorporate relevant content into students' education. A good way of doing this is looking at the state learning standards and curriculum frameworks, as these will include necessary topics students should be able to learn and understand by the end of each academic year (Larmer & Mergendoller 2010). Additionally, these are topics where student understanding will be evaluated via state assessment (Solomon 2003).

Stimulated Curiosity

To properly introduce a PBL project, it must start with a hook or something to trigger the curiosity of students. Introducing a project immediately with a packet or project outline stifles a student's innate curiosity and will be interpreted as unimportant and irrelevant. Starting with a hook that introduces the problem and gets students thinking before a formal introduction to the project, which will drive curiosity and create motivation for students to pursue research into the subject. Hooks can be a variety of different things, but the most common examples include videos, class-wide discussions, guest speakers, mock scenarios, etc. (Larmer & Mergendoller 2010).

A Driving Question

To properly provide a solution, students need to be asked the right question; one that drives their research in the right direction while maintaining the scope of the project. A good driving question is complex, open-ended, and linked to the core learning objective of the project. Without a driving question, students may not understand what they are doing or how all the curriculum components come together (Larmer & Mergendoller 2010).

Student Direction

Student choice in which direction they want to take the project is a keystone element of PBL. When students are given the power to guide the project on their terms, it gives the project meaning for them and provides ample motivation to do well (Bell 2010)(Larmer & Mergendoller 2010).

21st Century Skills

The incorporation of a wide variety of 21st-century skills into the project helps prepare students for their eventual work environments. Communication, collaboration, time management, critical thinking, and technology skills are meaningful traits that are sought after by employers, and thus generate a sense of importance for the students (Solomon 2003). PBL projects are often group projects for this reason. Frequent assessment of students' 21st-century skills by teachers and self-assessment by students is important as they progress through the project, as issues in these areas will hamper their project. (Kokotsaki et al. 2016)(Larmer & Mergendoller 2010).

Inquiry and Innovation

Students will find the project more tolerable and interesting if they can do some of the discovery for themselves. This includes performing their own background research for more knowledge and inspiration, running experiments to test out their projects, and developing prototypes (Solomon 2003). Students will not only produce results from their inquiries but generate more questions based on them too. The overall goal is to have students recognize that they can improve currently available technology and policy based on their own research and experimentation (Larmer & Mergendoller 2010).

Feedback and Revision

Creating a way for students to receive constructive feedback and make revisions is crucial, as this is where much of the learning happens. Through feedback and revision, students learn that a quality final product is often not produced on the first try, and that creation of a product in the real world frequently involves many iterations of design before the desired final product is achieved (Larmer & Mergendoller 2010).

Public Presentation

When students are completing the project, it becomes much more meaningful if they are presenting their results to someone besides their teacher. Students learn much more if there is something real at stake behind their project. Whether students are presenting something to their local city council, an advocacy group, or creating a prototype for someone to use, when the task is more authentic, student engagement and learning are much higher (Larmer & Mergendoller 2010).

Water Scarcity and Fog Nets in the Anti-Atlas Mountains of Morocco

The Anti-Atlas Mountains are located in the southwest region of Morocco. The area is characterized by persistent drought, government neglect, and poverty (UNDP 2014). The region only experiences an average of fewer than six inches of rainfall a year, so many communities rely on overused and contaminated wells for their water needs (Roudi et al 2002). This problem is only being made worse by climate change, as increased rates of desertification are causing wells to dry up (Dodson & Bargach 2015).

Native to the region is the Berber minority. Traditionally, they are pastoral farmer communities that are neglected by the Moroccan government. Climate change and well overuse is having a profound effect on these communities due to their dependence on water for their agriculture-based livelihood. This has led many Berbers to leave their villages and become migrant workers to support their rural families back home (Dodson & Bargach 2015).

Berber women, however, bear the brunt of this hardship. Berber women and girls spend upwards of 4 hours a day laboriously gathering water to meet their family's needs. This is time that could otherwise be used for more productive tasks, such as childcare, education, or income-generating activities. Furthermore, due to societal marginalization and traditional values, they also suffer from low social status (Dodson & Bargach 2015).

However, there is something unique about the Anti-Atlas Mountains due to their geographical location. Despite being located in an arid climate zone, for nine months of the year, September through June, the mountains are draped in fog. This is due to moisture being blown in from the Atlantic coast (Dodson & Bargach 2015). This unique property allowed for a different solution for combating water scarcity to be implemented: capturing drinking water from the fog.

Harvesting drinking water from fog is relatively simple compared to other water collection methods. The device is constructed of two key components: a mesh net, and a sturdy frame (Figure 1). As fog passes through the net, water droplets collect on the mesh and accumulate. Once enough water has accumulated, gravity pulls the water down the net and drains into gutters which lead to a reservoir.

Pipes connected to the reservoir are then run from the mountains down to the Berber villages, providing them with direct access to fresh, clean water (Domen et al. 2014).

Figure 1. Fog water net set up in the Anti-Atlas Mountains of Morocco. Photo: Leslie Dodson (Dodson & Bargach 2015).

The implementation of the fog nets provided an effective, sustainable, and context-appropriate solution to the water scarcity problem in the region. By addressing water scarcity, further humanitarian goals were also achieved. Strides were made in addressing social marginalization, poverty, loss of cultural livelihood. Berber communities now have access to clean, fresh, drinking water, and women have gained the most. They no longer must spend up to four hours a day collecting water and can focus their attention on more productive matters, and girls have an increased likelihood of entering school (Dodson & Bargach 2015).

A project of this nature is an invaluable learning opportunity, as it shows that there are effective ways to develop, design, and implement solutions while being aware of the cultural, environmental, and institutional contexts. The humanitarian nature of the project and the unique design process behind it makes the fog water harvesting nets a good basis for a PBL backdrop. STEM work based around altruistic efforts has been shown to draw more interest from underrepresented minorities and women into STEM fields (Estrada et al. 2016). This will hopefully provide meaning for the students and motivation to do well on the project, fulfilling one of the curriculum design criteria.

Biomimicry

Biomimicry is the design and production of materials, structures, and systems to mimic the functions of biological entities and processes found in nature to solve human design challenges (Biomimicry Institute

2021). Biomimicry can be seen in many things, from plane wings being modeled after migratory birds' wings to wind turbines being modeled on whale fins to bullet trains being shaped after bird beaks.

The fog water collection nets mentioned in the previous section take inspiration from the Namib desert beetle *Stenocara gracilipes*, an insect that has evolved a mechanism of coping with water scarcity in arid environments by harvesting water directly from fog (Domen et al. 2014).

The beetle *Stenocara gracilipes* utilizes its body surface chemistry and topography to collect fog water when necessary. The beetle possesses hydrophilic peaks on its back to collect the water and waxy hydrophobic valleys that allow the water to be funneled toward its mouth. The beetle takes a unique stance referred to as fog basking, facing toward the wind in a head-standing position, collecting fog water as the wind blows on their elytra, the casing that protects the wings (Figure 2). Eventually, the beetle collects enough water that it runs down to their mouth for consumption (Nørgaard & Dacke 2010).

Figure 2. (left) the Namib desert beetle, Stenocara gracilipes, in a stance referred to as fog basking. (right) close up of the unique surface topography of the Stenocara gracilipes that facilitates fog water collection. Photos: asknature.org

There is also a variety of other mechanisms that other organisms have evolved to cope with their low rainwater environments, as shown in Figure 3 below.

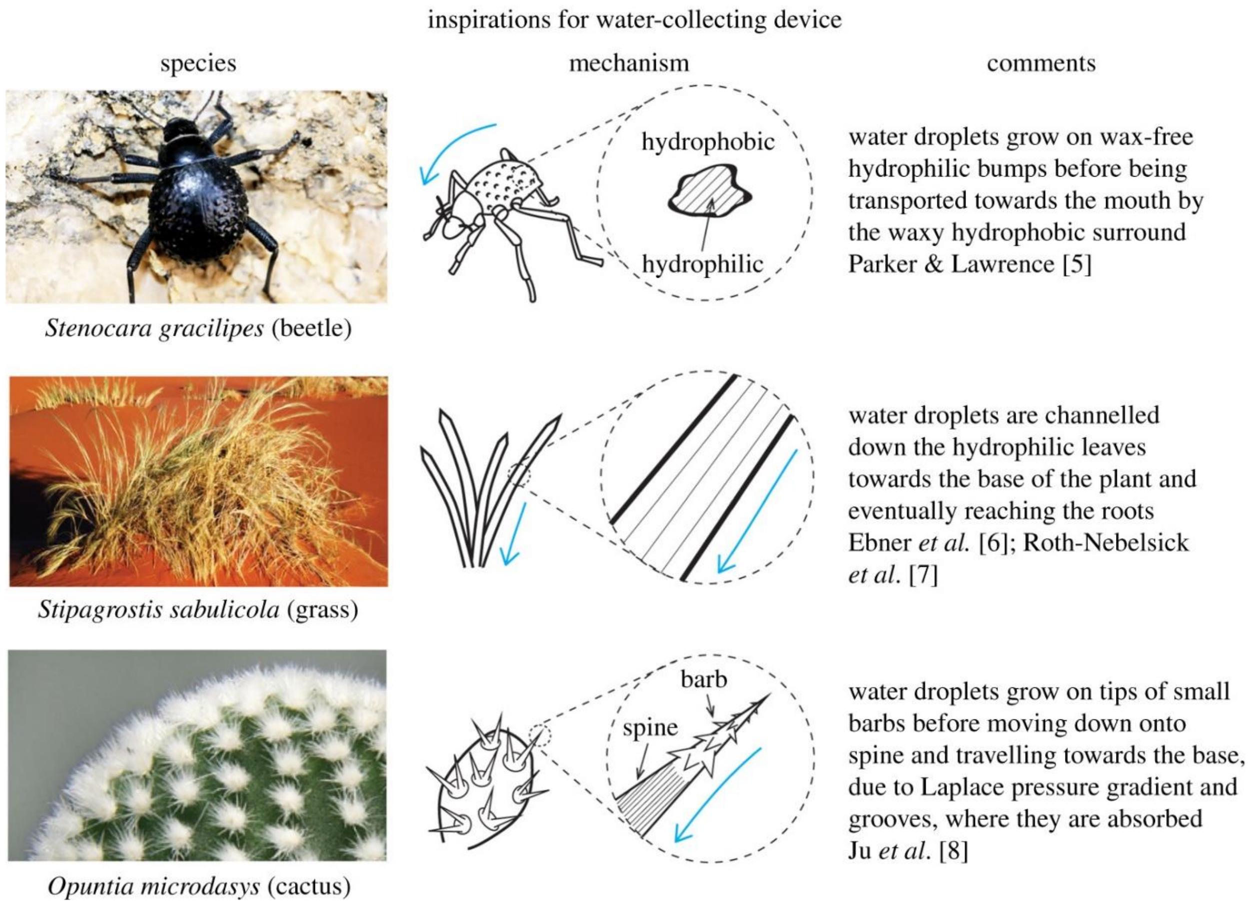

Figure 3. Examples of water collection mechanisms present in different organisms. Figure from Gurera, D. and Bhushan, B. 2019. Designing bioinspired surfaces for water collection from fog. Phil. Trans. R. Soc. A. 377:20180269

Nature has solved many of the problems that humanity is currently facing, especially regarding cost-effective water collection; however, the designers of the human world often do not have much biology experience. By taking a step back, observing nature, and performing some research, inspiration for innovative design can be found.

This is the second backdrop to the development of the PBL curriculum. Incorporating biomimicry as one of the keystones of the projects enables students to understand that biology is a significant source of engineering inspiration. In addition, students will be able to research organisms as a foundation for their design rather than complex mathematical derivations, fulfilling more of the curriculum design criteria.

Methods

The goal of this project was to develop a project-based learning curriculum around the creation of a fog water harvesting net with the incorporation of biomimicry. To achieve this goal, I developed the following research objectives:

1. Learn what professors have found effective for retaining student interest in STEM subjects and Learn what prospective students feel stimulated their interests in STEM
2. Develop preliminary curriculum and lesson plans based on research
3. Have preliminary curriculum reviewed by professionals in STEM education
4. Development of the PBL-to-go fog unit from readily available technology

1. Learn what professors have found effective for retaining student interest in STEM subjects and learn what students feel like stimulated their interests in STEM

As someone with no previous knowledge in STEM education, I wanted to know what activities professors found that stimulated their student's interest in STEM and what activities to avoid. To find out this information, I decided to interview an expert in the field of project-based learning, former WPI Biomedical Engineering professor, Glenn Gaudette, Ph.D. I set out to learn about the activities Professor Gaudette found to keep his students interested in his class content and asked for his opinion on some ideas for activities based on my own STEM background to incorporate when developing my curriculum. Thus, I developed a set of informal interview questions based on the following:

- How would you go about starting a PBL project?
- What would be the best way to introduce and incorporate biomimicry into the curriculum?
- How do you keep students engaged when you are teaching?
- What activities do you feel help students keep themselves on track?
- What do you think I should avoid when developing my curriculum?
- To understand the fog water harvesting capability of the net, students will need to understand the wettability of a material. Do you think an exercise like a simplified contact angle lab, like something we do in the Biomedical Engineering department, would be good to incorporate into the curriculum?

With this information, I know what activities and exercises I should include when developing my curriculum from the perspective of an educator.

However, it is also important to consider things from the other perspective. What do students feel got them interested in STEM and motivated to pursue it? I wanted to find out what other students found as effective sources for engaging them in STEM, in addition to what they felt started to dissuade them too. As someone currently pursuing a bachelor's degree in a STEM field, I wanted to reflect on my own experiences and discuss the thing I felt cultivated my interest in STEM and what stifled it. Thus, I developed a set of interview questions and follow-up questions for myself. They are as follows:

- Is there a specific class, project, extracurricular or other activity that got you into STEM?
- Do you have a favorite project from high school STEM classes/extracurriculars?
    - Why is that your favorite?

    - What made that project different from other class projects?
- Were there any STEM classes that dissuaded your interest
    - What made that class dissuade your interest
    - What would have made it better?
- What schoolwork did you enjoy the most?
- Did you have a lot of group projects?
    - What's your opinion of them?
- Did you have experience with project-based learning at all?
    - If yes, what did you think of it?

With my reflection of what got me involved in STEM, I utilized the information to include activities that students themselves enjoyed in the curriculum and avoid practices that dissuaded interest. This way, the curriculum makes use of observations from the perspective of an educator and a student, to hopefully maximize learning potential.

2. Develop preliminary curriculum and lesson plans based on research

Writing a curriculum was something foreign to me. To properly develop a PBL curriculum, the first thing to do was conduct some research. I developed a list of research topics based on recommendations from my interviews and topics I thought would be relevant to the development of such a niche project. They are as follows:

- Curriculum Writing Methodology
- Project-Based Learning Components
- Massachusetts STEM Learning Standards
- Project-Based Learning Curriculums/Lesson Plans
- Relevant Topics to the Curriculum
    - Wettability/Contact Angle, Biomimicry, etc.

Research on the following topics provided me enough information to write a preliminary curriculum, which is composed of a unit outline and multiple lesson plans. Reading curriculum writing methodology literature showed me how to properly write a curriculum and where to start. Project-based learning components informed me what I need to incorporate into my curriculum to make it effective. Reviewing the Massachusetts learning standards ensured that the curriculum meets topics relevant to student's education. Looking at other project-based learning curriculums and lesson plans helped me properly lay out my curriculum, in addition to providing me with inspiration for activities. Lastly, research into the topics relevant to the curriculum ensured that the project is feasible and that the correct information is being taught.

3. Have preliminary curriculum reviewed by professionals in STEM education

As a student of Worcester Polytechnic Institute, I have access to WPI's STEM Education Center. The goal of the WPI STEM Education Center is to collaborate with PK-12 educators to provide more students with access to quality STEM education. The overall goal is to broaden students' participation in and pursuit of STEM fields, especially to those who have been excluded historically excluded based on gender, race, or socioeconomic background (WPI STEM Education Center, 2021). I reached out to Donna Taylor, a member of the STEM Education Center, to provide feedback on my preliminary curriculum, as she is an expert in the development of project-based STEM curriculums. While the research was extensive, having another set of eyes with experience in the field and provide me feedback will only further strengthen the curriculum and its efficacy.

4. Development of PBL-to-go fog unit from readily available technology

For students to be able to complete the curriculum, a machine that generates enough fog to be collected on the net in a feasible amount of time will be needed. While a current fog unit prototype exists in WPI's Goddard Hall Chemical Engineering Laboratory that easily fulfills this (Figures 4,5,6), easy transportation to a classroom and replication of the device is not very feasible. This is due to the fog unit be comprised of bulky voltage regulators, multiple fan arrays, custom-made acrylic construction, and an expensive mist atomizer. Furthermore, cost also inhibits the reproduction of the fog unit. The current prototype in the Goddard Hall Engineering Laboratory has an approximate cost of $1500 – 2000 due to the cost of the components and the skilled labor required for construction by a machinist and electrical engineer.

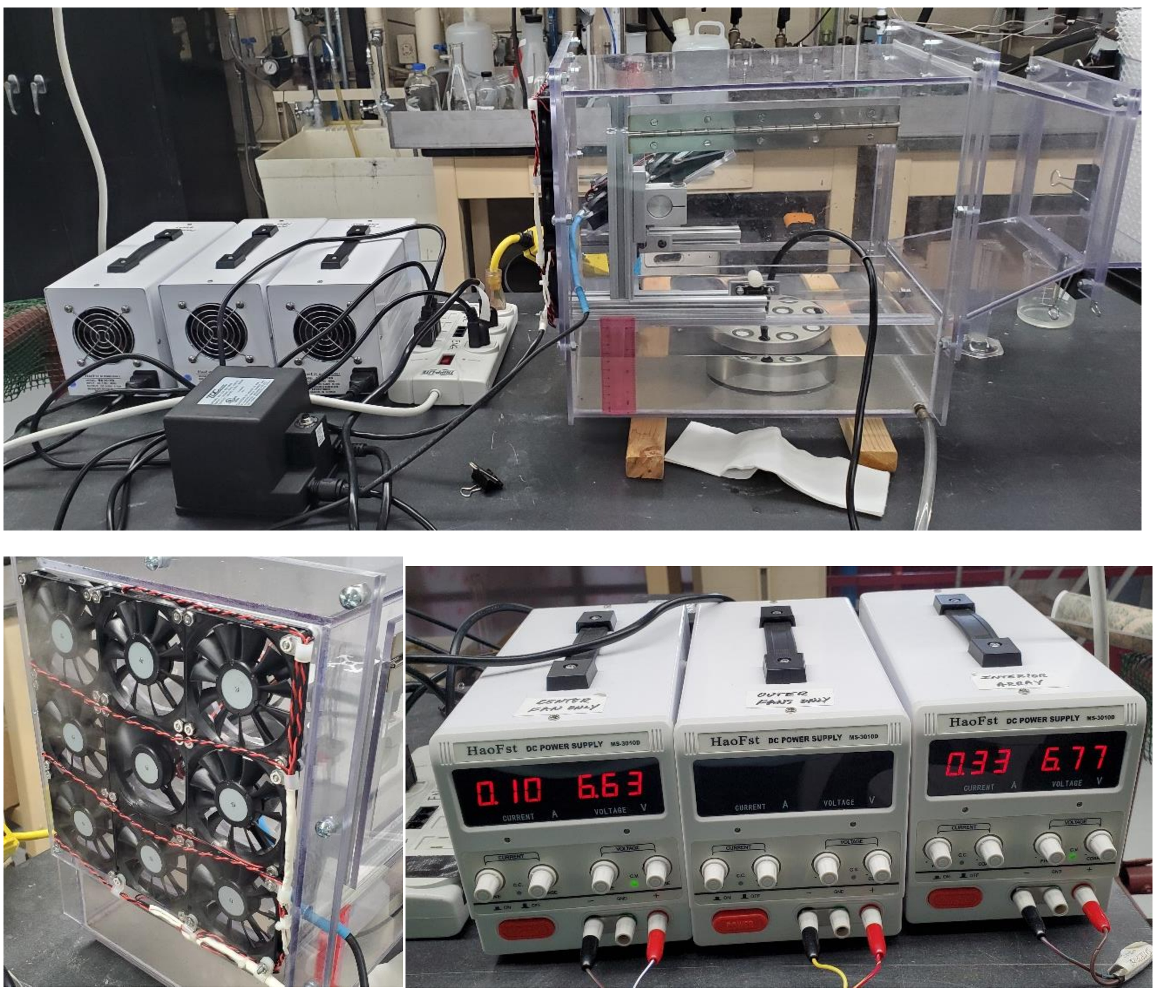

Figure 4. The Fog Unit. Composed of three voltage regulators connected to three different fan arrays (inner array, outer array, and center only), a twelve-disc ultrasonic atomizer, acrylic housing, and funnel to contain and direct the fog. Multiple fan arrays allow and voltage regulators allow for the creation of different fog wind velocities and flow patterns.

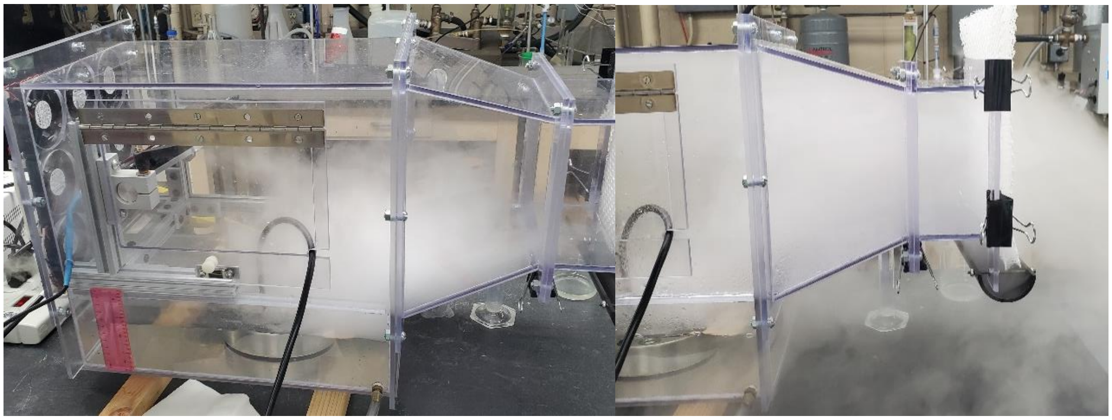

Figure 5. Fog unit generating fog for collection via net

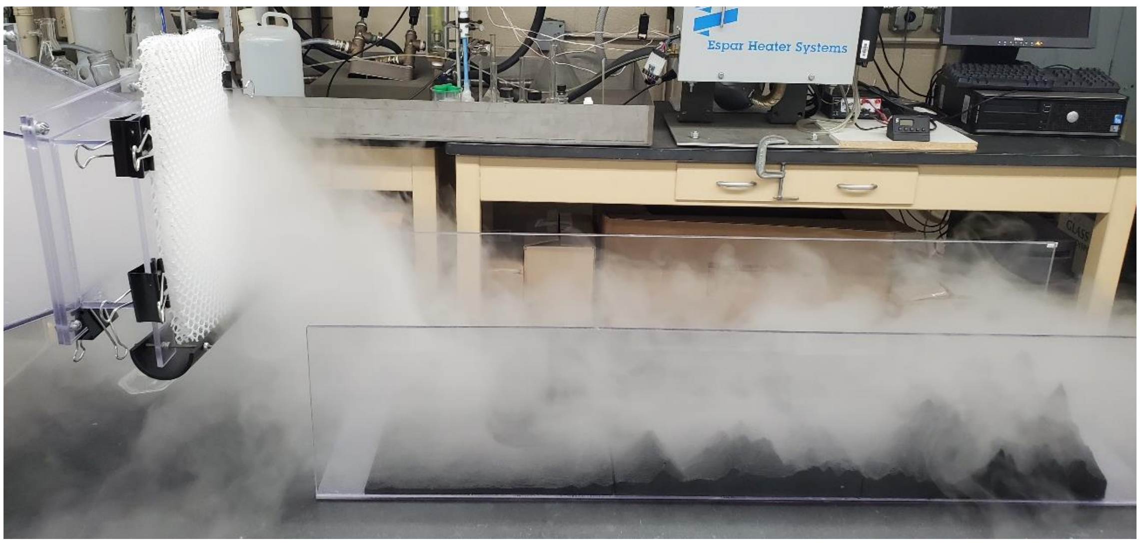

Figure 6. Movement of fog out of the unit onto a 3D printed mountain diorama

Therefore, there is a need to develop a prototype to test the efficacy of the PBL Fog Net-Biomimicry Curriculum in a classroom setting. The prototype fog unit needs to meet the following criteria:

- Be readily transportable
- Relatively cheap to produce
- Generate enough fog to allow for measurable water deposition
    - Larger water deposition is more ideal for student engagement
    - Produce a minimum of 1 mL of water
- Produce measurable water deposition in a reasonable amount of time
    - Faster water deposition is more ideal for class time usage
    - Have a maximum collection time of twenty minutes

Wind velocity/weather patterns will not be an area of focus for the curriculum, so there is no need for multiple fans or voltage regulators, which will drastically simplify the design. To begin, the prototype will be designed based on the original fog unit. This will then be tested to see if measurable water deposition is observed. If not, improvements and changes will be implemented to move in this direction.

Findings

Interview Responses

Interview with Professor Glen Gaudette

My interview with professor Gaudette resulted in these takeaways:

- Think specifically about the objectives you want students to take away from the curriculum
  - Students should be able to understand….
  - Students should be able to perform….
- To incorporate the biomimicry aspect, get students to think about what organisms are good at collecting/releasing water
  - Deserts are barren and dry environments, yet some organisms still thrive there. What mechanisms/structures/behavior have they evolved that lets them accomplish this?
- Ranked order lists are something that helps students methodically break down ideas or where to begin their research
  - These are especially useful in group scenarios
- Focus on collaboration and provide all the necessary tools to supplement this work
  - Whiteboards, shard online documents, group tables, etc.
- Start with a hook, this will generate a lot of initial interest in the project
- Look for hands-on active learning exercises, these will maintain student interest the best
- Avoid complex mathematics/principles, especially if you are only introducing a topic
  - "This is a spot that I feel we as educators fail, we scare students away from STEM fields by having all of these high-level mathematics and science principles from start, rather than invoking interests with more introductory critical thinking exercises."
- Utilization of a contact angle lab is ideal, it is a hands-on active learning exercise and relevant to what they are learning, even if they just perform qualitative comparisons
  - every student has access to a camera now via their phones, so they all have the capability of taking contact angle measurements.

Self-Reflection

My reflection as a student who pursued STEM resulted in the following takeaways:

- I enjoyed my elective STEM classes the most, as they were very project-heavy and hands-on in comparison to requirement classes.
  - Organic chemistry labs and forensics science labs specifically
- I disliked STEM classes that taught toward standardized tests, like AP Exams
  - The classes were mostly lecture-based, the content felt like unexciting busywork
  - Project topics were usually assigned, resulting in a lack of motivation to put quality work into projects
    - incorporating more interesting projects and different kinds of learning media into the curriculum would help

        - I would also have liked to see more class discussions and scenarios
- If groups projects are not stimulating, some students can end up doing much more than their fair share of the workload while others slack off
- Projects that had real-world value were more enjoyable
    - In organic chemistry, we synthesized salicylic acid, the active ingredient in aspirin, which I thought was interesting and relevant.

Curriculum and PBL Research

Fortunately, many useful resources for the development of classroom curriculum and lesson plans are available for free. For the development of a curriculum, The Institute for Arts Integration and STEAM put together a start to finish guide on how to properly develop and assess a curriculum (Riley 2020).

In addition, websites such as TeachEngineering.org, a library of planned/module curriculums for teaching STEM to K-12 students by the University of Colorado Boulder's Engineering Department have been an immense help for providing examples on how to write STEM lesson plans and what hands-on activities for students should look like.

Furthermore, asknature.org is full of biomimicry-based educational resources for K-12 students, which could prove as an invaluable resource as students conduct their research into biomimicry and water collection mechanisms found in nature.

Extensive peer-reviewed research has also been done on PBL curriculums, showing their effectiveness, benefits, and what components are necessary for a PBL curriculum. Information on the critical components of PBL peer-reviewed literature can be found in the Background section of this paper.

Standards must be included in PBL curriculums. Standards are crucial topics set by the state to prepare students for success in college, career, and life that must be covered by educators. Students must demonstrate their knowledge of these subjects as they will be evaluated via statewide and nationwide assessments. After reviewing the Massachusetts Department of Education Science, Technology/Engineering Curriculum Frameworks revised in 2016, I identified the following standards that could be met by the Fog Net-Biomimicry Curriculum (Massachusetts DOE 2016). They are as follows:

- HS-ESS3-1. Construct an explanation based on evidence for how the availability of key natural resources and changes due to variations in climate have influenced human activity.
- HS-ETS1-1. Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society.
- HS-ETS1-2. Break a complex real-world problem into smaller, more manageable problems that each can be solved using scientific and engineering principles.
- HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, aesthetics, and maintenance, as well as social, cultural, and environmental impacts.
- HS-ETS1-5(MA). Plan a prototype or design solution using orthographic projections and isometric drawings, using proper scales and proportions.

- HS-ETS1-6(MA). Document and present solutions that include specifications, performance results, successes and remaining issues, and limitations.
- HS-PS2-6. Communicate scientific and technical information about the molecular-level structures of polymers, ionic compounds, acids and bases, and metals to justify why these are useful in the functioning of designed materials.
- HS-ETS2-4(MA). Explain how manufacturing processes transform material properties to meet a specified purpose or function. Recognize that new materials can be synthesized through chemical and physical processes that are designed to manipulate material properties to meet a desired performance condition

I incorporated the information from my research and developed it into a preliminary curriculum.

Feedback from STEM Education Center

After reading through the preliminary curriculum, STEM education expert Donna Taylor provided me with the following feedback:

- Standards are the pieces that educators are required to teach and assess.
    - The Fog Net project is the vehicle by which teacher will use to meet these standards; it is not the primary focus for them
    - The objectives and assessments should focus on the standards identified
- Pay attention to both the content and skills required by the standards.
    - If there are too many standards or they don't match up closely enough, take them out.
- Have students make connections to their own lives
    - Have they ever been without water or clean water?
    - Have they heard local stories or stories in the US about the lack of water access?
    - Have they ever been to the mountains?
        - What's it like there?
    - Have they ever seen fog collection nets before?
        - What do they look like?
        - What can they be used for?
- Assume that many students have never been to the mountains, many may have never seen or used a net before, etc. Allow them to have some conversation about this and make connections so they are more invested.
- Make activities specific to the context, edit them to fit into the scope and topics of the curriculum if possible
- When designing, be sure to build in time for feedback and redesign and retest if possible. It is through failure that learning occurs.
- Incorporate a presentation component. During the presentation, students should not only talk about the fog net but refer back to the standards identified and bring components of this into their presentation.

After receiving this feedback, I removed two standards from the curriculum, HS-ETS1-5(MA) and HS-PS2-6, which are the following:

- HS-ETS1-5(MA). Plan a prototype or design solution using orthographic projections and isometric drawings, using proper scales and proportions.

- HS-PS2-6. Communicate scientific and technical information about the molecular-level structures of polymers, ionic compounds, acids and bases, and metals to justify why these are useful in the functioning of designed materials.

While the standards were partially met by Fog-Net Biomimicry Curriculum, I felt that these standards were not being met as comprehensively as they should be. The PBL Fog Net Biomimicry Curriculum includes planning of a prototype but was not designed with the production of orthographic projections or isometric drawings in mind. Incorporation of these tasks into the curriculum is feasible but will be left up to the teacher's discretion if they want to change it to accommodate this standard. In addition, while the curriculum talks about molecular structures of polymers, it does not discuss any of the other materials and compounds discussed in the standard in detail, meaning it is not within the scope needed to completely fulfill this standard.

I incorporated the rest of the feedback and edited my preliminary lesson plans to develop my final set of lesson plans for the PBL Fog Net-Biomimicry Curriculum, which can be found in the Finalized PBL Fog Net-Biomimicry Curriculum section below.

Finalized PBL Fog Net-Biomimicry Curriculum

The curriculum is broken down into 2 components, the unit outline, and the lesson plans. The unit outline consists of a general overview of the whole unit, including a short synopsis of the unit, the learning standards that will be met by the unit, desired results from students, the essential questions that will be posed to students, the knowledge and skills that they will gain from the unit, in addition to assessment evidence and learning activities.

The lesson plans are individual blocks of the unit that build upon each other to provide all the information the students need to meet all the desired results in the unit outline. The lesson plans consist of an introduction and then are methodically laid out in three stages: Desired Results, Assessment Evidence, and Learning Plan. The lessons are organized this way so that the standards and desired learning outcomes are kept front and center for the design of the lesson.

Desired Results consists of the necessary information for the educator, such as the standards that will be met in that lesson, the aim, and essential question, the understandings students should take away from the lesson, content objectives, and key vocabulary.

Assessment Evidence provides the educator with the performance task of the lesson. It includes the key evidence that shows students are meeting the desired results of the lesson and the criteria to measure or demonstrate it.

Lastly, the Learning Plan provides the learning activities that the educator will use in the lesson. They usually consist of an opener, learning activity, application of activities, and summary/closing. The Learning Plan also lists the multiple intelligences that will be addressed for the students, how the students will be grouped, instructional delivery method, accommodations, modifications, homework activities, and materials needed for any of the learning exercises.

Unit Outline

Subject: **Engineering**
Unit: Moroccan Fog Nets and Biomimicry In this unit, students will learn about the engineering design process by studying the Cloud Fisher fog collection nets located in the Anti-Atlas Mountains of Morocco as a solution to the water scarcity issues in the region. Students will learn about the cultural context of the problem and then go over a variety of topics such as contact angle and biomimicry to design a technically feasible solution. The purpose of the unit is to show that engineering takes a variety of inspiration from different sources and can be used to benefit humanity rather than just product development.
Standards
Science, Technology/Engineering Curriculum • HS-ESS3-1. Construct an explanation based on evidence for how the availability of key natural resources and changes due to variations in climate have influenced human activity. • HS-ETS1-1. Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society. • HS-ETS1-2. Break a complex real-world problem into smaller, more manageable problems that each can be solved using scientific and engineering principles.* • HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, aesthetics, and maintenance, as well as social, cultural, and environmental impacts.* • HS-ETS1-6(MA). Document and present solutions that include specifications, performance results, successes and remaining issues, and limitations.* • HS-ETS2-4(MA). Explain how manufacturing processes transform material properties to meet a specified purpose or function. Recognize that new materials can be synthesized through chemical and physical processes that are designed to manipulate material properties to meet a desired performance condition
Desired Results
Students will be able to: ● Discuss the effect that water access has on the Berber minority in Morocco ● Explain why climate change and desertification are making life for the Berber people worse ● Explain why fog water collection nets are a feasible solution for solving water scarcity in the region ● Demonstrate that fog is a source of water ● Explain how fog water harvesting works ● Explain the concept of wettability of a material ● Describe the selection process of choosing a material ● Explain the concept of biomimicry and its use in engineering ● Provide examples of biomimicry present in the modern world ● Identify what organisms are good at collecting and releasing water ● Properly research and identify peer-reviewed articles and respected sources ● Perform contact angle measurements on certain materials ● Use ImageJ to characterize the contact angle ● Demonstrate out-of-the-box thinking ● Develop a prototype net for the portable PBL fog machine ● Justify the design of their fog net prototype ● Evaluate the prototype and suggest improvements for the next iteration of their design ● Demonstrate teamwork and conversational skills

Essential Questions	Knowledge and Skills
-Why are fog nets necessary in Morocco? -Why choose fog nets as a solution for water scarcity vs other methods? -What do you think the effect will capture the fog in the future, for both people and the environment? -What inspiration can we take from organisms that thrive in water-scarce environments?	-Make students understand the Moroccan culture and how much the fog nets changed their society for the better -Make students understand that nature has solved a lot of problems humanity is currently facing through the process of evolution

Assessment Evidence

- Are the students contributing to the conversation/ are they able to answer the questions?
- Are they understanding the cultural context of Morocco and how that impacts the creation of a feasible solution?
- Are they able to research and find trustworthy sources?
- Are they able to measure contact angle and produce values being reasonably close to published data?
- Are they able to produce preliminary designs of water collection devices?
- Are they able to produce prototypes of their fog nets?
- Are they able to collect a reasonable amount of fog with their net?
- Are they able to identify things that worked and things that didn’t

Learning Activities

- Watching videos/performing readings on Moroccan fog nets, contact angle, biomimicry
- Small group exercises on producing designs for water collection
- Contact Angle Lab
- Conduct research on water collection mechanism in nature
- Perform tests on different materials to find which would be best for fog collection
- Fog Net Collection Lab

Lesson Plans

Lesson 1: The Moroccan Water Crisis- And Solution

The Moroccan Water Crisis

WPI PBL To-Go Fog Net – Biomimicry Curriculum

Subject/Course: Engineering

Unit: Moroccan Fog Nets

Grade Level: 11-12

Overview of and Motivation for Lesson:

The purpose of this lesson is to introduce the humanitarian problem of lack of access to clean water in areas that have low rainfall and drying up wells due to climate change and desertification, and the use of fog water collection nets as a solution. This is crucial background information, as creating their own fog water collection system will be student's project for this Unit. Students will be asked about where they think their water comes from. They will be provided with information about the Anti-Atlas mountains in the Berber region of Morocco.

Connection to Project:

This project follows a real-world humanitarian problem and the resulting engineering project to create a solution.

Stage 1- Desired Results
Standard(s): • HS-ESS3-1. Construct an explanation based on evidence for how the availability of key natural resources and changes due to variations in climate have influenced human activity. • HS-ETS1-1. Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society.
Aim/Essential Question: • How can we provide water to areas that lack traditional freshwater access? • How do societies deal with water scarcity? • What designs are effective and sustainable?
Understanding(s): *Students will understand that . . .* • Engineering is useful for providing solutions to many humanitarian problems • Engineering and Humanities are not mutually exclusive • Thinking outside of the box can lead to innovation
Content Objectives:

Students will be able to . . .

- Use the information presented via instruction to infer how culture in Morocco is related to the water problem.
- Use this information to empathize with members of the Berber region of Morocco.
- Use what they know about the Berber/Moroccan culture to create a feasible and sustainable engineering solution.
- Produce a preliminary solution to the water crisis problem

Key Vocabulary

- Humanitarian Engineering
- Berber
- Morocco
- Anti-Atlas Mountains
- Desertification
- Water Scarcity
- Fog

Stage 2-Assessment Evidence

Performance Task or Key Evidence

- Ranked Tier List of Water Collection Ideas
- Sketches of Ideas
- Reflections from Video and Discussion

Key Criteria to measure Performance Task or Key Evidence

- Students will be able to produce a preliminary design of a water collection system, and then evaluate it against a currently available technology.

Stage 3- Learning Plan

Learning Activities:

Opener:

Students will be asked if they have ever experienced water scarcity/lack of access to clean drinking water, or if they know of places that lack it (Flint, Michigan). Talk about freshwater access in the United States.

- Where does your water come from?
- What are different sources of freshwater? i.e. wells, aquifers, rivers, lakes, rainwater, desalinization
- What happens when there is a drought?

Learning Activity 1:

Students are provided with the following scenario:

"You and a group of friends are going on a multi-day hiking trip deep in the mountains, unfortunately, a couple of days in, one of your friends slips and falls down the mountain and breaks his leg. In his fall, your only map was carried away by the wind. Fortunately, you are able to call for help, but due to the remote location and heavy fog in the area, it will take several days for the rescue party to arrive. You are unable to travel from your location due to your friend's injury and are running low on water, as you used most of it to clean your friend's wounds. You need to collect freshwater, but there are no streams, ponds, or lakes, near you. How would you go about collecting water?"

In small groups, they will brainstorm a bulleted list and produce a sketch with an explanation. This will then be presented in front of the class. After presentations, relate this to being an everyday reality for many people enduring water scarcity around the world, specifically to the pre-CloudFisher establishment in Morocco. A short reading on living conditions in this region could be included here if deemed appropriate.

Learning Activity 2:

Students will be shown a video about the fog water harvesting nets set up in the Anti-Atlas Mountains of Morocco.

https://www.youtube.com/watch?v=0F7CQMd6mQ4

As a class, students will be asked to compare their ideas to the Cloud Fisher nets, in addition to evaluating the system as a whole.

- How are they similar? How are they different?
- Are there any changes you would make to your idea after watching this?
- How have people's lives changed as a result of the nets? List reasons

Application

Students will be asked to compare and contrast their water collections with currently available technology, seeing the similarities and differences.

Summary/Closing

After watching the video and participating in the class conversation, students will be asked to reflect on what was learned in class. Reflection should include questions such as:

- How have people's lives been improved with the fog nets?
- Why have women specifically benefited from the installation of fog nets?
- Are the fog nets sustainable? How are they maintained?

Multiple Intelligences Addressed:

☐ Linguistic	☒ Logical-Mathematical	☐ Musical	☐Bodily-kinesthetic

☒ Spatial ☒ Interpersonal ☒ Intrapersonal ☒ Naturalistic

Student Grouping

☒ Whole Class ☒ Small Group ☐Pairs ☒ Individual

Instructional Delivery Methods

☐ Teacher Modeling/Demonstration ☒ Lecture ☒ Discussion

☒ Cooperative Learning ☐ Centers ☒Problem Solving

☐ Independent Projects

Accommodations	**Modifications**
	If the course is remote/online, create groups for breakout rooms and have them submit their documents/screenshare

Homework/Extension Activities:

- Students will be asked to provide another example of humanitarian engineering and write a half-page summary and/or drawing of the system of it. These can be shared with peers at the beginning of the next class or via Canvas/Google Classroom/etc.
- Students will be asked to research if any other areas of the world can benefit from technology

Materials and Equipment Needed:

- Pencil and Notebook
- Whiteboard/online document
- Projector

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

Lesson 2: Wettability and Contact Angle

Wettability and Contact Angle

WPI PBL To-Go Fog Net – Biomimicry Curriculum

Subject/Course: Engineering

Unit: Moroccan Fog Nets

Grade Level: 11-12

Overview of and Motivation for Lesson:

The purpose of this lesson is to introduce the concept of wettability and the contact angle of a surface. This is necessary for the student, as creating their fog nets will require analysis of the wettability of their surface. Students will be asked to provide some examples of hydrophobic and hydrophilic surfaces/materials and if they think a hydrophobic or hydrophilic material will be ideal for the creation of the fog net.

Connection to Project:

This project involves the production of a fog water collection net and thus will interface with water, so contact angle will be a factor when choosing a material for their net, as different wettability and contact angle will affect how efficiently water is gathered from the fog.

Stage 1- Desired Results
Standard(s): • HS-ETS2-4(MA). Explain how manufacturing processes transform material properties to meet a specified purpose or function. Recognize that new materials can be synthesized through chemical and physical processes that are designed to manipulate material properties to meet a desired performance condition
Aim/Essential Question: • What is wettability? What is contact angle? • What properties affect contact angle and wettability? • What is a hydrophobic material useful for? What about a hydrophilic one?
Understanding(s): *Students will understand that . . .* • Material properties such as contact angle are important factors when designing a product in engineering • Using materials with different wettability are good for different applications • A surface with both hydrophobic and hydrophilic properties will be more ideal for the creation of the fog water collection nets
Content Objectives: *Students will be able to . . .*

- Describe the behavior of water on hydrophobic and hydrophilic surfaces and explain in general terms what causes the differences in behavior.
- Discuss situations in which applying a hydrophilic or hydrophobic surface would be advantageous.

Key Vocabulary

- Contact Angle
- Wettability
- Surface Tension
- Hydrophobic
- Hydrophilic
- Superhydrophobic
- Adhesion
- Cohesion

Stage 2-Assessment Evidence

Performance Task or Key Evidence

- Qualitative ranked order list of materials from highest wettability to lowest wettability
- Examples of hydrophobic and hydrophilic materials

Key Criteria to measure Performance Task or Key Evidence

- Students will be able to produce a ranked order list of materials from most to least hydrophobic

Stage 3- Learning Plan

Learning Activities:

Opener:

In small groups, students will be asked to recall what hydrophobicity and hydrophilicity are and provide examples of materials that are each. Would a car windshield be hydrophobic or hydrophilic? Why? Provide correct answer after.

Learning Activity 1:

Students will be shown 2 lecture style videos on contact angle and wettability

https://www.youtube.com/watch?v=m3cU_kVVnGM

https://www.youtube.com/watch?v=7ObOQLbRP48

Teachers are also welcome to present this information in lecture format if desired

Learning Activity 2:

Students will be provided with a worksheet with various pictures of droplets, and they will make a ranked order list of highest wettability to lowest wettability based qualitatively on the droplet shape. Answers will be gone over as a class.

Application

Students will be asked to reevaluate their materials from the opener and see if they are correct.

- Have any of the materials that you thought were hydrophobic/hydrophilic changed?
- What likely makes these materials how hydrophobic/hydrophilic?
- How can you increase/reduce the hydrophobicity/hydrophilicity of material?

Summary/Closing

After watching the video and participating in the class conversation, students will be asked to relate what they learned about wettability properties for the creation of a fog water collection net. Why might it be ideal to use a material that's both hydrophobic and hydrophilic rather than one of the extremes?

Multiple Intelligences Addressed:

☐ Linguistic	☒ Logical-Mathematical	☐ Musical	☐Bodily-kinesthetic
☒ Spatial	☒ Interpersonal	☒ Intrapersonal	☐ Naturalistic

Student Grouping

☒ Whole Class ☒ Small Group ☐Pairs ☒ Individual

Instructional Delivery Methods

☐ Teacher Modeling/Demonstration ☒ Lecture ☒ Discussion

☒ Cooperative Learning ☐ Centers ☒Problem Solving

☐ Independent Projects

Accommodations	Modifications

	If the course is remote/online, create groups for breakout rooms and have them submit their documents/screenshare
Homework/Extension Activities: • Students will be asked to gather materials to bring for the contact angle lab, household items such as cardboard, plastic wrap, aluminum foil, wax paper will suffice.	
Materials and Equipment Needed: ● Pencil and Notebook ● Whiteboard/online document ● Projector	

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

Lesson 3: Contact Angle Lab

Contact Angle Lab

WPI PBL To-Go Fog Net – Biomimicry Curriculum

Subject/Course: Engineering

Unit: Moroccan Fog Nets

Grade Level: 11-12

Overview of and Motivation for Lesson:

The purpose of this lesson is to reinforce the concept of wettability and the contact angle of a surface. Students will be provided the opportunity to experimentally determine the contact angle of a material, rather than obtaining it from another source. This is necessary for the student, as creating their fog nets will require analysis of the wettability of their surface, and they will need to determine what possible household materials would be the most suitable for a fog net. After completion, students will compile their data onto a class document to compare.

Connection to Project:

This project involves the production of a fog water collection net and thus will interface with water, so contact angle will be a factor when choosing a material for their net, as different wettability and contact angle will affect how efficiently water is gathered from the fog.

Stage 1- Desired Results
Standard(s): • HS-ETS2-4(MA). Explain how manufacturing processes transform material properties to meet a specified purpose or function. Recognize that new materials can be synthesized through chemical and physical processes that are designed to manipulate material properties to meet a desired performance condition
Aim/Essential Question: • How do you measure contact angle? What tools are used? • How does surface treatment affect contact angle?
Understanding(s): *Students will understand that . . .* • Material properties such as contact angle are important factors when designing a product in engineering • A material's wettability can be determined experimentally • Materials with different wettability are good for different applications • A surface with both hydrophobic and hydrophilic properties will be more ideal for the creation of the fog water collection nets
Content Objectives:

Students will be able to . . . • Determine the contact angle of materials without relying on published data • Determine whether a surface is hydrophobic/hydrophilic based on experimentally determined contact angle
Key Vocabulary • Contact Angle • Wettability • Surface Tension • Hydrophobic • Hydrophilic • Superhydrophobic • Adhesion • Cohesion
Stage 2-Assessment Evidence
Performance Task or Key Evidence • Produce contact angle measurements from ImageJ • Compare with classmates' measurements and published data to evaluate if the proper methodology was used
Key Criteria to measure Performance Task or Key Evidence • Students will be able to produce contact angle measurements that are in line with their peers and published data
Stage 3- Learning Plan
Learning Activities: Opener: In small groups/lab groups, students will prepare their stations for the lab, cutting up their materials to make samples so that 3 drops can be placed on the material surface. Students will make predictions about which materials they think will have the highest/lowest contact angle. Learning Activity 1: Students will install ImageJ on their computer in addition to the drop analysis script, students will then follow a tutorial on how to measure contact angle and go through a couple of test runs on some already prepared images. https://www.youtube.com/watch?v=AAROcG0miC8 https://imagej.nih.gov/ij/download.html

http://bigwww.epfl.ch/demo/dropanalysis/

To save time, teachers/staff are also welcome to prepare computers with these programs already installed and set up.

Learning Activity 2:

Students will be given a lab procedure and will prepare their area for proper imaging of their samples. Students will use an eyedropper/syringe to drop water on the surface of their material sample and image them perpendicular to the material surface at surface level to the best of their ability. Students will place 3 drops per material and record the contact angle of each drop, repeat for a broad range of material samples.

Learning Activity 3:

Students will be given 2-3 samples of the same material with different surface treatment(s); students will be asked to measure the contact angle of all samples and compare them. Did the surface treatments affect the contact angle? Why?

Application

Students will be asked to reevaluate their predictions from the opener and see if they are correct in addition to analyzing class-wide data.

- Have any of the materials that you thought were hydrophobic/hydrophilic changed?
- What materials were the most/least hydrophobic?
- What did the surface treatment do to the contact angle of the materials?
- Why might surface treatments be better than finding a material with a specific contact angle?

Summary/Closing

After the collection of data, what material(s) do you would work best as a fog net? Why?

Multiple Intelligences Addressed:

☐ Linguistic	☒ Logical-Mathematical	☐ Musical	☐Bodily-kinesthetic
☒ Spatial	☒ Interpersonal	☒ Intrapersonal	☐ Naturalistic

Student Grouping

☒ Whole Class ☒ Small Group ☐Pairs ☒ Individual

Instructional Delivery Methods

☐ Teacher Modeling/Demonstration ☒ Lecture ☒ Discussion

☒ Cooperative Learning ☐ Centers ☒Problem Solving

☐ Independent Projects

Accommodations	**Modifications**

Homework/Extension Activities:

- Students will be asked to report their findings on a data-sheet in order from least hydrophobic to most hydrophobic with their experiential findings.

Materials and Equipment Needed:

- Pencil and Notebook
- Whiteboard/online document
- Projector
- Computer
- ImageJ Program and Drop Analysis Script
- Eyedropper/syringe
- Collected Materials

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

Introduction to Biomimicry

WPI PBL To-Go Fog Net – Biomimicry Curriculum

Subject/Course: Engineering

Unit: Moroccan Fog Nets

Grade Level: 11-12

Overview of and Motivation for Lesson:

The purpose of this lesson is to introduce the topic of biomimicry and its relationship to engineering design. The concept of fog water collection nets came from studying local flora and fauna in regions where water scarcity is present, and as result stills serve as a source of inspiration for engineers and scientists. Furthermore, biomimicry has become increasingly important in designing sustainable systems, as sustainability has become much of the focus of recent engineering practices. Using the information from this lesson and the previous lessons, students will begin designing their fog collection devices.

Connection to Project:

Many water collection designs are based on or inspired by mechanisms found in organisms that live regions marked by water scarcity. This includes the fog water collection nets that are being set up around the world.

Stage 1- Desired Results
Standard(s): • HS-ETS1-1. Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society. • HS-ETS1-2. Break a complex real-world problem into smaller, more manageable problems that each can be solved using scientific and engineering principles.
Aim/Essential Question: • What is biomimicry? • How is biomimicry important to engineering? Why would an engineer use biomimicry? • What are some examples of biomimicry?
Understanding(s): *Students will understand that . . .* • Biology is a useful source of inspiration for many engineering designs • Nature is often a better engineer than we are, as it already has solved many problems that certain populations face today • The incorporation of biomimicry leads to better design

Content Objectives:

Students will be able to . . .

- Research flora and fauna that have inspired innovation
- Properly find and identify academic articles
- Provide examples of biomimicry

Key Vocabulary

- Biomimicry
- Sustainability
- Innovation

Stage 2-Assessment Evidence

Performance Task or Key Evidence

- Provide examples of biomimicry
- Provide reasons why biomimicry is useful for engineering

Key Criteria to measure Performance Task or Key Evidence

- Correctly identify examples of biomimicry that are present in the design of technology

Stage 3- Learning Plan

Learning Activities:

Opener:

Students will be asked if they know what biomimicry is and to write down a definition and provide an example.

Learning Activity 1:

Students will be shown 2 videos on biomimicry as an introduction.

https://www.youtube.com/watch?v=neUKzwYDB_c

https://www.youtube.com/watch?v=iMtXqTmfta0

Learning Activity 2:

Students are provided with the problem statement "My family lives in a region with very variable rainfall - near-drought for half the year, and torrential rains for the other half. How can we capture and store rainwater from the rainy season to use during the drought? How can we minimize or prevent the saturation and erosion that happens during the rainy season? How can we capture and manage our use of water? How can we distribute water during rainy or dry seasons?"

Instead of solving this conventionally, ask students to look up examples of water/food storage for future use in nature. Students will work individually and then discuss their research in small groups. Each group will then summarize their findings to the class.

Application

Students will be asked to reevaluate their materials from the opener and see if they are correct.

- Define biomimicry again, compare it to your original definition, what has changed?
- Why is biomimicry useful compared to conventional design?

Summary/Closing

After watching the videos and working through the water storage problem, students should have a good of where to initially look to find inspiration, what are some organisms or ecosystems that should be looked into.

Multiple Intelligences Addressed:

☐ Linguistic ☒ Logical-Mathematical ☐ Musical ☐Bodily-kinesthetic

☒ Spatial ☒ Interpersonal ☒ Intrapersonal ☐ Naturalistic

Student Grouping

☒ Whole Class ☒ Small Group ☐Pairs ☒ Individual

Instructional Delivery Methods

☐ Teacher Modeling/Demonstration ☒ Lecture ☒ Discussion

☒ Cooperative Learning ☐ Centers ☒Problem Solving

☐ Independent Projects

Accommodations	**Modifications**
	If the course is remote/online, create groups for breakout rooms and have them submit their documents/screenshare

Homework/Extension Activities: • Students will do some preliminary research into water collecting animals for their fog nets
Materials and Equipment Needed: ● Pencil and Notebook ● Whiteboard/online document ● Projector

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

Lesson 5: Biomimetic Water Collection

Biomimetic Water Collection

WPI PBL To-Go Fog Net – Biomimicry Curriculum

Subject/Course: Engineering

Unit: Moroccan Fog Nets

Grade Level: 11-12

Overview of and Motivation for Lesson:

The purpose of this lesson is to reinforce the topic of biomimicry and its relevance to the final project. As previously mentioned, the idea of fog water collection nets came from studying local flora and fauna in regions where water scarcity is present, students will be researching organisms present in these areas or organisms with desirable traits for water collection to influence the design of their own fog water collection nets. Using the information from this lesson and the previous lessons, students will begin compiling potential design ideas for their final project.

Connection to Project:

Many water collection designs are based on or inspired by mechanisms found in organisms that live in regions marked by water scarcity. Implementing biomimicry into the design of their net provides an outlet for innovation and increased efficiency.

Stage 1- Desired Results
Standard(s): • HS-ETS1-1. Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society. • HS-ETS1-2. Break a complex real-world problem into smaller, more manageable problems that each can be solved using scientific and engineering principles.
Aim/Essential Question: • How can we use biomimicry to improve water collection technology? • What organisms/ecosystems should be looked at for inspiration?
Understanding(s): *Students will understand that . . .* • Water scarcity is a millennia-old problem in biology, many organisms have evolved special features/mechanisms to improve water their water intake and efficiency • Nature is often a better engineer than we are, as it already has solved many problems that certain populations face today • The incorporation of biomimicry leads to better design

Content Objectives:

Students will be able to . . .

- Research flora and fauna that have intrinsic water collection abilities
- Properly find and identify academic articles
- Derive how the feature of the organism might be incorporated into the design

Key Vocabulary

- Biomimetic
- Ecosystem
- Biome
- Water Collection
- Desert
- Chapparal
- Water Scarcity

Stage 2-Assessment Evidence

Performance Task or Key Evidence

- Provide examples of biomimicry for water collection
- Identify potential biomimetic traits that can be incorporated into the design of the fog water collection nets

Key Criteria to measure Performance Task or Key Evidence

- Identification of organism with useful feature/trait
- Incorporation of feature/trait into net design

Stage 3- Learning Plan

Learning Activities:

Opener:

Students will create a ranked order list of ecosystems/biomes to investigate that might have organisms with useful properties (desert, chaparral, tundra, etc.), students also can create a list of organisms to look into based on previous knowledge from other classes and earlier in the unit.

Learning Activity 1:

Students will be asked to look up information on biomimetic water collection. Students should be able to find both primary and secondary sources to compile enough information for their project. Search parameters to help students find sources include biomimetic, water collection, water collecting organisms, water storage biomimicry, fog water collection, etc.)

In addition, the following list of organisms can be used if students are struggling:

- Namib desert beetle
- Stenocara beetle
- Cactus
- Welwitschia plant
- Namib dune bushman grass
- Coast Redwood
- Epiphytes
- Moss
- Bishop pine (Santa Cruz Island)
- Douglas fir (Bull Run River, Oregon)
- Spruce-Fir zone (Camel's hump Vermont)
- Nolana (Chile)
- Alstromeria (Chile)

Application

Students will be asked to identify features/traits that help their specific organism catch/manage water

Summary/Closing

While it might be difficult to implement biomimicry into your net design, especially with limited access to materials available in a high school classroom, what have you learned of water collection in nature? What features help? Is there anything you can apply to your net design?

Multiple Intelligences Addressed:

☐ Linguistic	☒ Logical-Mathematical	☐ Musical	☐Bodily-kinesthetic
☒ Spatial	☒ Interpersonal	☒ Intrapersonal	☒ Naturalistic

Student Grouping

☒ Whole Class ☒ Small Group ☐Pairs ☒ Individual

Instructional Delivery Methods

☐ Teacher Modeling/Demonstration ☒ Lecture ☒ Discussion

☒ Cooperative Learning ☐ Centers ☒Problem Solving

☐ Independent Projects

Accommodations	Modifications
	If the course is remote/online, create groups for breakout rooms and have them submit their documents/screenshare

Homework/Extension Activities:

- Students will create a bulleted list of what they want to include in their design and produce a rough sketch based on all the information they have learned in this unit.

Materials and Equipment Needed:

- Pencil and Notebook
- Whiteboard/online document
- Projector
- Computer/Databases

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

Lesson 6: Fog Net Collection

Fog Net Collection Lab

WPI PBL To-Go Fog Net – Biomimicry Curriculum

Subject/Course: Engineering

Unit: Moroccan Fog Nets

Grade Level: 11-12

Overview of and Motivation for Lesson:

The purpose of this lesson is to introduce students to the process of engineering design and prototyping. Students will use all the knowledge gathered from the previous lesson (i.e. Cultural Context, Contact Angle, Biomimicry) to design fog collection systems with materials given during class and justify their design choices. They will then test their devices and make observations on how their design works and how it can be improved. This process will mimic the research and development process that engineers go through when producing a product, specifically the process used when designating the fog water collection nets to be used in Morocco.

Connection to Project:

Students will use everything they learned plus other skills such as critical thinking and creativity to create a design and a prototype. Designing a successful fog net or learning what makes a successful fog net is the ultimate goal of this project.

Stage 1- Desired Results
Standard(s): • HS-ETS1-1. Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society.* • HS-ETS1-2. Break a complex real-world problem into smaller, more manageable problems that each can be solved using scientific and engineering principles.* • HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, aesthetics, and maintenance, as well as social, cultural, and environmental impacts.* • HS-ETS1-6(MA). Document and present solutions that include specifications, performance results, successes and remaining issues, and limitations.*
Aim/Essential Question: • What factors need to be considered when designing a fog water collection net • What material/contact angle(s) work the best? • What physical structure/geometries work the best? • How can we use biomimicry to influence/improve designs?
Understanding(s):

Students will understand that . . .

- Material properties such as contact angle are important factors when designing a product in engineering
- A designs geometry is just as important as the materials used
- A prototype is only the first step, design usually requires multiple iterations

Content Objectives:

Students will be able to . . .

- Determine the contact angle of materials without relying on published data
- Determine whether is hydrophobic/hydrophilic based on experimentally determined contact angle

Key Vocabulary

- Prototype
- Engineering Design

Stage 2-Assessment Evidence

Performance Task or Key Evidence

- Students will design and construct a fog water collection device.
- Students will test their devices and collect data and observations.
- Students will produce a project report with their findings and suggested improvement for the next round of design

Key Criteria to measure Performance Task or Key Evidence

- Students will be able to observe how their net collects water and propose solutions to increase the efficiency of water collection/other improvements.

Stage 3- Learning Plan

Learning Activities:

Part 1:

Opener:

In small groups/lab groups, students will prepare their stations for the lab, cutting up their materials to make samples so that 3 drops can be placed on the material surface. Students will make predictions about which materials they think will have the highest/lowest contact angle.

Learning Activity 1:

Students will be put in pairs/groups of the teacher's discretion; students will select their materials and begin assembling their fog collection net.

Learning Activity 2:

Students will attach their net to the Fog Device, leaving it attached for 15 minutes, and will measure how much water was collected then add it and compare it to a class-wide data sheet for each group's collection amount. Students should be encouraged to take pictures of their net and record justifications for their material choices. They will then be provided questions to think about for their lab report.

Part 2:

Learning Activity 3:

Students will have a chance to change/improve their design based on the results from their initial run. Once students have completed their redesign, they will test it on the fog unit gain, repeating steps followed in Learning Activity 2. Students will document the changes they made and compare the data from their new design to their initial design.

Application

Students will be asked to reevaluate their design after collecting their data, stating their hypothesis, materials used, justification, and suggested improvements.

Summary/Closing

What designs and materials worked as expected? What ones didn't? Why do you think this is? What improvements would you make for the next round of design if you had a chance?

Multiple Intelligences Addressed:

☐ Linguistic	☒ Logical-Mathematical	☐ Musical	☐Bodily-kinesthetic
☒ Spatial	☒ Interpersonal	☒ Intrapersonal	☐ Naturalistic

Student Grouping

☒ Whole Class ☒ Small Group ☒ Pairs ☐ Individual

Instructional Delivery Methods

☐ Teacher Modeling/Demonstration ☒ Lecture ☒ Discussion

☒ Cooperative Learning ☐ Centers ☒Problem Solving

☐ Independent Projects

Accommodations	Modifications

Homework/Extension Activities:

- Students will write a report on their design process, design iterations, findings, and any improvements/changes made to their net
- Students will work with their groups to make a presentation to show in front of the class. The presentation will talk about their approach to the fog net design, any biomimicry that was incorporated into their design, and how their design performed on both runs.

Materials and Equipment Needed:

- Pencil and Notebook
- Whiteboard/online document
- PBL-to-go Fog Device
- Computer
- Collected Materials from students
- Popsicle sticks/wooden skewers
- Hot glue
- Clay or similar
- Tape
- Scissors

Adapted from Grant Wiggins and Jay McTighe-*Understanding by Design*

PBL Fog Unit Development

To produce the first iteration of the PBL fog unit prototype (Figure 7), I modeled it after the current unit present in WPI's Goddard Hall Chemical Engineering Laboratory (Figure 4). The unit itself is comprised of a single room humidifier (PureGuardian H940AR 0.5-Gallon Cool Mist Humidifier 350 sq. ft., $35) and an enclosure to direct the fog.

To build the unit, I used a cardboard box to assemble a semi-enclosed housing with a funnel to concentrate the fog produced in a smaller area at the front. I lined the whole interior of the box with plastic wrap so that minimal water would wet the cardboard. I also attached a fan at the back of the box to push any fog that was generated towards the funnel. Next, a hole was cut out of the bottom of the housing and placed over the nozzle of the humidifier to ensure minimal fog escaped out of the unit. A net sample from the CloudFisher nets was attached to the front of the enclosure using binder clips. Unfortunately, I overestimated the amount of fog that the humidifier would produce, thus no collection was observed. The fan was likely responsible for this, so I decided to remove it in the next prototype.

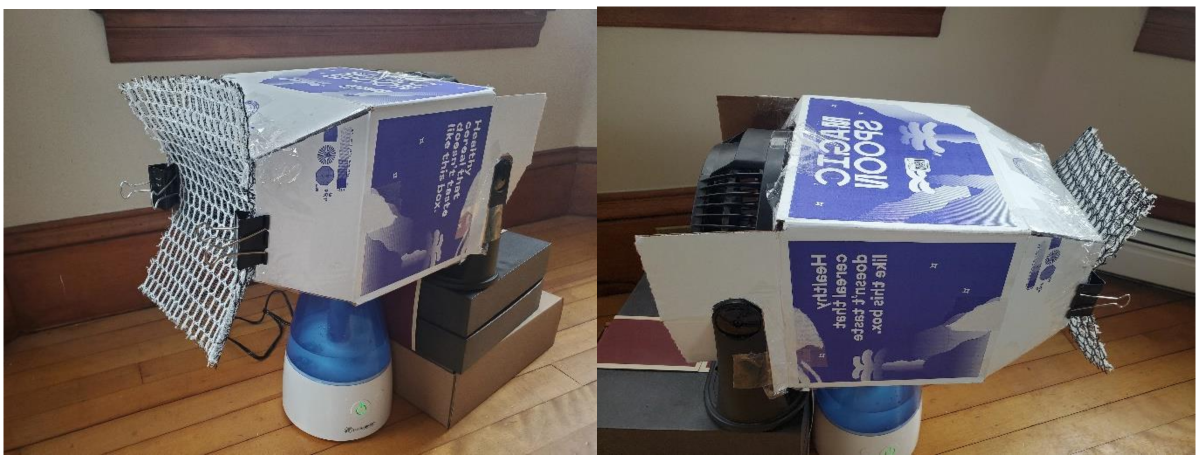

Figure 7. PBL Fog Unit Prototype 1.

In hopes to generate some collection from the design, the back was sealed, and fog could be seen flowing out from the front of the prototype in this trial (Figure 8). While this is an improvement from the previous iteration of the design, however not enough fog accumulated on the net to measure within the twenty minutes time window.

Figure 8. PBL Fog Unit Prototype 2

While fog flow was visible in the second iteration of the prototype, it also did not produce any measurable collection within the time frame. For the next prototype iteration, the plastic wrap-lined cardboard housing was completely discarded, as not enough fog was being produced to make use of its volume and shape.

To make the last iteration of the prototype, a corner section of PVC pipe was connected to the humidifier with tape. This allowed a horizontal concentrated stream of fog to be produced, making it more ideal for water deposition on the net than the previous two iterations. Due to the small circular size of the PVC pipe, using binder clips to attach the net to the fog unit prototype like the previous two iterations was not feasible; instead, a rubber band was used so that that net would stay in place. The use of the rubber band was also to preserve the net so that it could be used in its current form rather than cutting it to make a new sample for the smaller vent size.

Figure 9. PBL Fog Unit Prototype 3

Figure 10. PBL Fog Unit Prototype 3: close up of water deposition on net

Deposition of approximately 1 milliliter of water on the net was observed within the twenty-minute window for this design iteration of the prototype (Figure 10). This means it could feasibly be used in a classroom setting, especially for a pilot test of the curriculum.

However, this prototype is still far from ideal. The fog water deposition on the net was time-intensive and relatively small. Depending on the classroom, a twenty-minute time collection window is likely too long to dedicate to a single net for a single group. Another prototype will likely need to be developed to combat this issue, by producing a higher volume of fog and by allowing for multiple nets to be tested on the unit simultaneously. This can be done by using a larger humidifier or another device with a larger number of ultrasonic discs.

Ultrasonic discs are the mechanism by which the fog is produced. They work by producing high-frequency sound waves which get transposed into mechanical energy that is then transferred into the water. This causes the water to be broken into a fine mist when it leaves the discs' surface. The humidifier used in this prototype only possessed one ultrasonic disc, compared to the twelve discs on the atomizer on the unit located in Goddard Hall Chemical Engineering Lab (Figure 4), thus generating a significantly reduced amount of fog.

Implementation of the Curriculum

Unfortunately, due to COVID-19 restrictions and time restraints, the curriculum was unable to be tested in a classroom environment. Students were attending class online or attending class in a limited, socially distanced manner. This prevented conventional hands-on project-based learning curriculums from being used, thus the PBL Fog Net-Biomimicry Curriculum could not be tested in the way it was intended. While steps were taken to maximize the curriculum's potential based on relevant research, experience, and expertise, the true effectiveness of the PBL Fog Net-Biomimicry Curriculum on seeding STEM interest remains unknown.

Conclusions and Recommendations

The curriculum was developed and revised, and the final curriculum and lesson plans can be found in Findings.

The next logical step and recommendation is to test the curriculum on a group of students and collect feedback from both students and educators. Educators should be able to evaluate student engagement qualitatively via observations and student surveys and quantitatively via standardized testing. Educators should also be able to provide feedback on whether the curriculum covered enough content and met enough standards to be worth the investment.

While a relatively effective prototype fog unit was developed from a common household humidifier, it is recommended that another prototype be made. The final iteration prototype still took roughly 20 minutes to accumulate a measurable amount of fog on the net, and since only one net can be tested at a time, it might not be the most feasible for classroom usage, at least on a larger scale. A new prototype that incorporates a greater number of ultrasonic discs or produces more fog through some other water-based mechanism would be better, especially if it could accommodate more than one net. This would result in the collection of a larger and more easily measurable amount of water on the student prototype nets, faster rates of water deposition on the nets, and more efficient class time usage. Furthermore, it would also be more engaging to students, as a larger amount of fog generation would be more exciting to them.

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