Thermodynamic Engineering: An Irrigation Enigma

3D-Student Science Performance *Diedre Young, Soybean Science Challenge and Dr. Daniel Young, Assistant Professor of Physics, University of NC-Chapel Hill*	
Grade 10-12 Engineering based Physics **Lesson Topics:** • **Diffusion** • **Newton's Law of Cooling** • **Heat Transfer Equations** • **Thermal Conductivity** • **Kinetic Molecular Theory**	**Lesson Title** **Thermodynamic Engineering; The Irrigation Enigma** 

Performance Expectations (Standard) from State Standards or NGSS:

Topic Three: Heat and Thermodynamics:

P-PS3-1: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [AR clarification statement: Emphasis is on systems of two or three components, thermal energy, kinetic energy, and energies in gravitational, magnetic, and electric fields.]

P-PS3-1AR: Construct an explanation based on evidence of the relationship between heat, temperature, and the Kinetic Molecular Theory. [Clarification Statement: Emphasis on planning and conducting experiments to collect then analyze data. An example could include measuring temperature changes related to phase change and specific heat.]

P-PS3-4: Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [AR Clarification Statement: Emphasis is on mathematical thinking to describe energy changes. Examples of investigations could include mixing liquids at different initial temperatures and adding objects at different temperatures to water.]

PS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. [AR Clarification Statement: Examples could include use of wind and solar energy and total energy loss from homes.]

P3-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. [AR Clarification Statement: Examples could include designing and building a machine, using schematics to break down an engine into major functional blocks, and designing improvements to reduce total energy loss from a home.]

P3-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, and aesthetics, as well as possible social, cultural, and environmental impacts. [AR Clarification Statement: Examples could include evaluating the different parts of a machine, the entire machine, and reducing energy loss in homes.]

Connections to the Arkansas English Language Arts Standards:

SL.11-12.5: Make strategic use of digital media in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

Connections to the Arkansas Disciplinary Literacy Standards

RST.11-12.1: Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

RST.11-12.9: Synthesize information from a range of sources into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

WHST.9-12.7: Conducting short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

WHST.11-12.8: Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively.

Connections to the Arkansas Mathematics Standards:

MP.2: Reason abstractly and quantitatively.

MP.4: Model with mathematics

HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

HSN.Q.A.2: Define appropriate quantities for the purpose of descriptive modeling

HSN.Q.A.3: Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

HSS.IC.B.6: Read and explain, in context, the validity of data from outside reports by: identifying the variables as quantitative or categorical; describing how the data was collected; indicating any potential biases of flaws; identifying inferences the author of the report made from sample data.

Lesson Performance Expectations:

- **Students will use critical thinking to engineer an alternate solution to the large amount of water loss farmers encounter when irrigating their crops, focusing on energy flow and heat transfer.**
- **Students in groups will do a round robin of their engineering projects with physics calculations to augment their findings. Students will include overall rate of water retention/loss with subsequent cost.**
- **Students will understand their alternate irrigation idea could decrease global water loss through irrigation.**

Elicit:

Start the lesson by telling students that substances change their temperature because heat has been added or taken from them. What is heat?" Heat is thermodynamic energy. So, ask students, "What is the molecular nature of temperature? How

Student Science Performance

Phenomenon: **Water exposed to the atmosphere will evaporate. In farming, evaporation means less liquid water to crops with more irrigation needed. This leads to erosion, salt/mineral build up (irrigation water contains dissolved minerals and salts so as it evaporates, those excess salts and minerals are left in the soil) and run-off. Can we water crops with less water loss due to evaporation?**

Gather *(In this section students will generally be asking questions, obtaining information, planning, and carrying out an investigation, using mathematical and computational thinking, or using models to gather and organize data and/or information.)*

1. Students will ask the question "Can a better irrigation method than poly-pipe be developed to limit water loss through evaporation?
2. Students will do a literary search on various irrigation types and their ability to retard water loss during irrigation.
3. Students will come up with a research question, hypothesis, and engineering plan with physics equations to address the problem of how to irrigate crops with less

does something change temperature or phase?" and then "How does the changing of temperature tie into the water cycle? What elements of the water cycle involve a change in phase?" Get students thinking about how the water cycle works (introduce Kinetic Molecular Theory, heat transfer equations and Newton's Law of Cooling) and its importance to plants by inquiring "How would these equations impact plants?" Students should mention water, its high specific heat, and the water cycle as an essential for plant growth. Ask the question "How do plants receive	water loss using an alternative to poly-pipe irrigation. 4. Students will build an irrigation prototype, test it on soybean plants and compare their data (complete with physics data for support) to a poly-pipe control group. ***Teaching Suggestions:*** ***Teacher Note****: Ideas for designs could be different types of materials rather than plastic straws. Other ideas include insulating the straws, use thicker straws or make the holes smaller (reduce heat transfer). Another thought is to cool the water (increase the temperature difference). Students could also cover the straws and soil to increase condensation back to the soil.* Show the video *Irrigation for Agriculture* https://www.youtube.com/watch?v=24LJSJqpYuY to get students engaged in the project. Break the students into groups and, based on what was seen on the video and what was just covered, have the students do literary research on different irrigation techniques. Students should include research on how to manually decrease evaporation through engineering a way to block water loss. Students should come up with a research question, hypothesis, and engineering plan with physics calculations. If the engineering plan is doable and measurable, then a student group can try it. Students will need to present how they built their prototype and its success or failure at reducing water loss from evaporation compared to the poly-pipe irrigation at the end of the lesson, complete with calculations to mathematically show this conclusion. ***Reason*** *(In this section students are generally: evaluating information, analyzing data, using mathematical/computational thinking, constructing explanations, developing arguments, and/or using models to reason, predict, and develop evidence.)* 1. Students will compare their prototype data to their poly-pipe control data in a table and graph, constructing an explanation, using physics, as to why their irrigation alternative works better than poly-pipe irrigation. 2. Students develop an argument using evidence that supports the explanation (claim) that their irrigation prototype is the best alternative to poly-pipe irrigation.

water?" Comments such as rain, underground springs etc. will come up. Query the students, "If they are growing a garden, what will they need to do to ensure water is available for plants?" Irrigation should be the obvious response. Do a KWL chart about what students know about irrigation. Questions such as types of irrigation techniques and amount of water used should be addressed in the chart and stress how the Kinetic Molecular Theory (understanding the nature of temperature), Specific Heat of water (high compared to other solvents so a lot of	***Class Discussion:*** *Questions to initiate Discussion:* *Q: What is the molecular nature of temperature?* *Q: How does something change temperature or phase?* *Q: How do these principles tie into the water cycle?* *Q: What elements of the water cycle involve a change in phase?* ***Teaching Suggestions:*** Get students thinking about how the water cycle works (introduce Kinetic Molecular Theory, heat transfer equations and Newton's Law of Cooling) and its importance to plants by inquiring "How would these equations impact plants?" Students should mention water, its high specific heat, and the water cycle as an essential for plant growth. Ask the question "How do plants receive water?" Comments such as rain, underground springs etc. will come up. Query the students, "If they are growing a garden, what will they need to do to ensure water is available for plants?" Irrigation should be the obvious response. Do a KWL chart about what students know about irrigation. Questions such as types of irrigation techniques and amount of water used should be addressed in the chart and stress how the Kinetic Molecular Theory (understanding the nature of temperature), Specific Heat of water (high compared to other solvents so a lot of heat is absorbed), conduction (irrigation water exposed to the atmosphere) and Newton's Law of Cooling (transfer of heat between the irrigation pipes and the water) all play a very important role in how effective irrigation is to a farmer's crops. Farmers are constantly aware of the amount of water they use to irrigate their crops. Water costs money and irrigation is a huge business when it comes to crop production. Farmers are always looking for ways to conserve water; lower water usage means less cost, better sustainability, and less erosion. It is the students' job to design and implement an alternative to current irrigation techniques. This will require groups to brainstorm a project, acquire the necessary materials, build the prototype, and experimentally implement the prototype with soybean plants. Student groups will be looking for an overall decrease of evaporation from the control group. Have students brainstorm measurement ideas. Some ideas for measurement can be using a humidity tester or drying the soil of both the control and experimental plants and calculating the

heat is absorbed), conduction (irrigation water exposed to the atmosphere) and Newton's Law of Cooling (transfer of heat between the irrigation pipes and the water) all play a very important role in how effective irrigation is to a farmer's crops. **Engage:** Show the video *Irrigation for Agriculture* https://www.youtube.com/watch?v=24LJSJqpYuY to get students engaged in the project **Explore:** Farmers are constantly aware of the amount of water they use to irrigate their crops. Water costs money and irrigation is a	difference. Once measurements are complete, student groups will present their findings in a round robin setting. ***Communicate*** *(In this section students will be communicating information, communicating arguments (written and oral for how their evidence supports or refutes an explanation, and using models to communicate their reasoning and make their thinking visible.)* 1. **Students in groups, in a round robin setting, will use their data model (with physics calculations to augment their findings) and prototype to present an argument for their choice of irrigation alternative.** Students will do a round robin about their findings, presenting their engineered prototype and their data collected (augmented with physics calculations) from the engineering experiment compared to the poly-pipe control. A research paper on the prototype and a reflection paper on what they learned will be handed in by each student.

huge business when it comes to crop production. Farmers are always looking for ways to conserve water; lower water usage means less cost, better sustainability, and less erosion. It is the students' job to design and implement an alternative to current irrigation techniques. This will require groups to brainstorm a project, acquire the necessary materials, build the prototype, and experimentally implement the prototype with soybean plants. *Student groups will be looking for an overall decrease of evaporation from the control group.* Have students	

brainstorm measurement ideas however, some ideas for measurement can include using a humidity tester or drying the soil of both the control and experimental plants and calculating the difference. Students are to use Newton's Law of Cooling, Heat Transfer Equations and Thermal Conductivity equations if possible, to support their findings. For instance, the use of a different type of irrigating pipe would change the thermal conductivity of the material and allow heat to be transferred faster or slower as a result. Once measurements and	

calculations are complete, student groups will present their findings in a round robin setting. **Explain:** Irrigation literally feeds the world. It has opened the doors for large crop production and multiple season growths. The downside to irrigation is it comes with a lot of water loss though evaporation. Evaporated water, while great for the water cycle, doesn't get to plants and this means more water is needed to add to crops. Increased water means more erosion, more runoff, an escalation of salts in the soil and an increased cost to	

the farmer. *This would be a good time to cover the properties of water; its uniqueness (excellent solvation, dipole characteristics, different phases within a narrow temperature range, cohesion, and surface tension, etc.) and its crucial role in life. Review the Kinetic Molecular Theory, Thermal Conductivity, Newton's Law of Cooling, and Heat Transfer Equations. Sample calculations for students to master are highly recommended.* $Q=mc\Delta T$ $Q=L\Delta m$ $Q/\Delta t=-kA\ (\Delta T/\Delta x)$ $dQ/dt=-hA\Delta T$	

(optional) There are several types of irrigation. The most common are surface irrigation (such as water running in ditches between rows), sprinkler systems and poly-pipe irrigation (pipes with holes in them run down rows to reduce evaporation and get water to the plants at the spot). Of the three, poly-pipe is the best for water conservation, but can we do better? Can an alternative irrigation method be found that decreases evaporation to a lower level than poly-pipe? **Elaborate:** Break the students into groups and, based on what was	

seen on the video and what was just covered, have the students do literary research on different irrigation techniques. Students should include research on how to manually decrease evaporation through engineering a way to block water loss. Students should come up with a research question, hypothesis, and engineering plan. If the engineering plan is doable and measurable, then a student group can try it. Students will need to present how they built their prototype and its success or failure at reducing water loss from evaporation compared to the poly-pipe irrigation at the end of the	

lesson with physics calculations, if possible, to support their findings. **Research website suggestions:** https://www.uaex.uada.edu/publications/pdf/mp197/chapter8.pdf https://www.uaex.uada.edu/media-resources/news/june2017/06-21-2017-Ark-surge-irrigation-fact-sheet.aspx https://www.uaex.uada.edu/counties/greene/docs/AG-files/22-29-irrigation-tools-beds-project.pdf https://www.uaex.uada.edu/media-resources/news/november2015/11-06-2015-Ark-Poly-pipe-cost-share.aspx	

http://www.fao.org/docrep/T7202E/t7202e08.htm https://www.uaex.uada.edu/media-resources/news/november2015/11-06-2015-Ark-Poly-pipe-cost-share.aspx https://owlcation.com/stem/5-Properties-of-Water https://www.uaex.uada.edu/publications/PDF/FSA-9512.pdf **Evaluate:** Students will do a round robin about their findings, presenting their engineered prototype and their data collected with supporting calculations from the engineering experiment. A research paper on	

the prototype and a reflection paper on what they learned will be handed in by each student. **Extend:** End the lesson with how evaporation and the thermal properties of water have huge impacts on our food supply. After the round robin, have students debate their project's success in comparison to other projects in the classroom. Have the students do an economic impact paper on water savings using their engineering project. Have a local farmer do a presentation in the classroom of the impact irrigation has on crops and the costs	

involved with irrigation. Have the class do a presentation of their findings at the local County Extension Office. *Teacher Note: Need help with the physics in this lesson?* *Dr. Daniel Young, assistant professor of physics at the University of North Carolina-Chapel Hill was the academic support behind the physics in this lesson and is willing to answer any questions. You can email him at dyoung4@email.unc.edu .*	

Formative Assessment for Student Learning		
Elicit Evidence of Learning: *This box is the individual communication performance from the student prompts in Appendix A*		
Evidence of Student Proficiency *The student will use critical thinking to engineer an alternate solution to the large amount of water loss farmers deal with when irrigating their crops. The student will come up with a valid hypothesis and will find valid research for this project.* *The student will perform experimentation that will validate their hypothesis and the concepts learned will be used for critical thinking on determining alternatives to poly-pipe irrigation.*	**Range of Typical Student Responses** *This section provides a range of typical student responses, often using a three- point scale.* *Descriptors of grade-level appropriate student responses:* • *Full understanding: the student will engineer an irrigation alternative, do comparison experiments between the alternative and poly-pipe, and successfully present the findings in a round robin setting.* • *Partial understanding: the student will engineer an alternative and set up the poly-pipe control, but data collected is not correct and is unable to present accurately in a round robin setting.* • *Limited understanding: The student understands an irrigation alternative is necessary but does not develop an alternative; or produces a sub-par alternative. Student does not correctly collect data and cannot present accurately in a round robin setting.*	**Acting on Evidence of Learning** *This is a brief description of the instructional actions to take based on the students' performance. When the action includes extensive descriptors and/or materials you may wish use* ***Appendix C.*** *Description of instruction action and response to support student learning.* • *Action for student who displays partial or limited understanding: Student will be partnered with an academically strong student and multiple verbal assessments will take place throughout the lesson.* • *Extensions of learning for student who displays full understanding: After the round robin, have students debate their project's success in comparison to other projects in the classroom.* *Have students do an economic impact paper on the water savings based on the project.* *Have a local farmer do a classroom presentation on the impact irrigation has on crops and the costs involved with irrigation.* *Have the students do a presentation of their findings at the local county extension office.*

SEP, CCC, DCI Featured in Lesson	**Science Essentials** *(Student Performance Expectations from Appendix C, D, E)*
Science Practices Developing and Using Models. Constructing Explanations and Designing Solutions. Planning and carrying out investigations. Asking questions and defining	• Develop a model based on evidence to illustrate the relationships between systems or between components of a system. • Design and evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations. • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design" decide on types, how much, and

problems.	accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design. • Analyze complex real-world problems by specifying criteria and constraints for successful solutions.
Crosscutting Concepts Cause and Effect Scientific Knowledge Assumes an Order and Consistency in Natural Systems. Energy and Matter. Interdependence of Science, Engineering, and Technology. Influence of Engineering, Technology, and Science on Society and the Natural World.	• Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. • Systems can be designed to cause a desired effect. • Science assumes the universe is a vast single system in which basic laws are consistent. • Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. • Science and engineering complement each other in the cycle know as research and development (R&D). May R&D projects may involve scientists, engineers, and others with a wide range of expertise. • Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. • New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.
Disciplinary Core Ideas PS3.A Definitions of Energy (P-PS3-1). PS2.C: Stability and Instability in Physical Systems (P-PS3-4). PS3.B: Conservation of Energy and Energy Transfer (P-PS3-1AR). PS3.D: Energy in Chemical Processes (P3-ETS1-1). ETS1.A: Defining and Delimiting	• Systems often change in predictable ways; understanding the forces that drive the transformation and cycles within a system, as well as the forces imposed on the system from the outside, helps predict its behavior under a variety of conditions. • When a system has a great number of component pieces, one may not be able to predict much about its precise future. For such systems, one can often predict average but not detailed properties and behaviors. • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even

Engineering Problems (P3-ETS1-1, P3-ETS1-3). ETS1.B: Developing Possible Solutions (P3-ETS1-2).	as, within the system, energy is continually transferred from one object to another and between its various possible forms. • Although energy cannot be destroyed, it can be converted to less useful forms-for example, to thermal energy in the surrounding environment. Machines are judged as efficient or inefficient based on the amount of energy output needed to perform a particular useful task. Inefficient machines are those that produce more waste heat while performing a task and thus require more energy input. It is therefore important to design for high efficiency so as to reduce costs, waste materials, and many environmental impacts. • Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigations into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a give design meets them. • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

Appendix A - Student Prompts

Student Prompts for the Lesson

Phenomenon: **Water exposed to the atmosphere will evaporate. In farming, evaporation means less liquid water to crops with more irrigation needed. This leads to erosion, salt/mineral build up (irrigation water contains dissolved minerals and salts so as it evaporates, those excess salts and minerals are left in the soil) and run-off. Can we water crops with less water loss due to evaporation?**

Group Performances:

1. Ask questions to plan an investigation for the usage of alternative means of irrigation to decrease water loss.
2. Plan an investigation to gather evidence for the usage of a particular chosen alternative.
3. Construct an explanation for whether the researched, built, and experimented irrigation alternative is or is not a viable substitute to poly-pipe irrigation (including constraints and physics calculation support).
4. Use a model to show that the chosen researched, built, and experimented irrigation alternative is or is not a viable alternative to poly-pipe irrigation.

Class Discussion

Individual Performances:

1. Develop an argument for how the evidence you collected supports or refutes your explanation for the usage of a chosen alternative to poly-pipe irrigation.

Appendix B – *preparation, time duration and materials for lesson.*

Materials:

- Soybean Seeds
- Plastic containers (can be margarine tubs, yogurt tubs, cut 2L soda bottles etc.), at least four per group of four students (six plants in two for experimental and six plants in another two for control group).
- Potting soil (for optimum growth)

- Plastic straws glued together with consistent sized holes in them (to simulate a poly-pipe).
- Notebook for data collection
- Various materials for engineering design. Depends on student group.
- Humidity (or water) measurement devices.

Preparation:

Soybean plants work well for this lesson. They are easy to grow and sprout in about eight to ten days. Seeds can be obtained through the SSC on-line seed store (www.uaex.uada.edu/soywhatsup). Seeds are shipped out within a week of ordering. Students will need about a week to obtain materials for their engineering project. Another option is to have a set number of materials on hand for the whole class to use. Straws need to be glued and holes punched in them for use by students. Two straws per experimental and two for the control group should do it.

Time Duration:

Soybean plants take about a week to sprout so assume a week for the plants, a week for student brainstorming, planning and material acquisition (which can be done while waiting for plants to grow) and a week for building and experimenting. *Suggestion: to get the students invested in the lesson, have them plant the seeds in anticipation of the project.*

Teacher Note: *Ideas for designs could be different types of materials rather than plastic straws. Other ideas include insulating the straws, use thicker straws or make the holes smaller (reduce heat transfer). Another thought is to cool the water (increase the temperature difference). Students could also cover the straws and soil to increase condensation back to the soil.*

Teacher Note: Need help with the physics in this lesson?

Dr. Daniel Young, assistant professor of physics at the University of North Carolina-Chapel Hill was the academic support behind the physics in this lesson and is willing to answer any questions. You can email him at dyoung4@email.unc.edu

Appendix C –

Research website suggestions:

https://www.uaex.uada.edu/publications/pdf/mp197/chapter8.pdf

https://www.uaex.uada.edu/media-resources/news/june2017/06-21-2017-Ark-surge-irrigation-fact-sheet.aspx

https://www.uaex.uada.edu/counties/greene/docs/AG-files/22-29-irrigation-tools-beds-project.pdf

https://www.uaex.uada.edu/media-resources/news/november2015/11-06-2015-Ark-Poly-pipe-cost-share.aspx

http://www.fao.org/docrep/T7202E/t7202e08.htm

https://www.uaex.uada.edu/media-resources/news/november2015/11-06-2015-Ark-Poly-pipe-cost-share.aspx

https://owlcation.com/stem/5-Properties-of-Water