Landmark Lesson Plan:

Norbert Rillieux, Thermodynamics and Chemical Engineering

Grades: 9-12
Subject areas: Chemistry, Engineering, Thermodynamics and History
Based on "Norbert Rillieux and a Revolution in Sugar Processing," a National Historic Chemical Landmark
Principal author: Susan Cooper

The following inquiry-based student activities are designed for use in high school lesson planning. The handout and activities will help students understand the chemical engineering advances of Norbert Rillieux (1806-1894). Rillieux, an African American inventor and one of the earliest chemical engineers, had a major impact on how sugar was produced on Southern plantations during the time of slavery. The basic design of his multiple-effect evaporator is still being used today.

The activities are designed as a ready-to-go lesson, easily implemented by a teacher or his/her substitute to supplement a unit of study. In chemistry, the activities relate to engineering practices and thermodynamics. In history, the themes are the Industrial Revolution, the status of African Americans during slavery and the American Civil War.

All resources are available online at www.acs.org/landmarks/lessonplans.

While these activities are thematically linked, each is designed to stand alone as an accompaniment for the handout. Teachers may choose activities based on curricular needs and time considerations.

- Take a few minutes to introduce the lesson with a few conversation starters. Norbert Rillieux was born a *gens de couleur libre*—a free person of color—in New Orleans prior to the Civil War. Being a free African American, Rillieux navigated a fine line between enslaved persons of color and free whites. He was educated in France and returned to Louisiana to practice engineering. There he invented the multiple-effect evaporator, a safer and more efficient device that improved the consistency of sugar produced on plantations. Rillieux is celebrated today as one of the earliest chemical engineers in history, owing to his understanding of thermodynamics, engineering practices and chemistry.
- Distribute the **Activities** selected for the class.
- Have students read the handout on **Norbert Rillieux, Thermodynamics and Chemical Engineering**.
- After class use the **Answer Guide** for student feedback and discussion.

Student Activities with Objectives

Anticipation Guide "Norbert Rillieux, Thermodynamics and Chemical Engineering" (10-20 min.)
- Students read the handout and explore their own ideas about chemical engineering, thermodynamics and the role of African Americans during the Civil War period.

History Chronology, Concurrent Events and Reading Exercises (10-15 min.)
- Students chronologically order events in the reading and develop connections to the American Civil War and worldwide Industrial Revolution.
- Students answer questions about Rillieux's invention based on the reading.

Thermodynamics and Latent Heat (25-30 min.)
- Students chart thermodynamics principles present in the Jamaican Train and multiple-effect evaporator systems.

Exploring Engineering Practices (10-15 min.)
- Students explore steps in engineering practice and relate it to the reading.

3-2-1 Contact (10-15 min.)
- Students connect concepts from Rillieux's biography to concepts in history and chemistry.

Norbert Rillieux, Thermodynamics and Chemical Engineering

Norbert Rillieux, an African American inventor living in the pre-Civil War south, is considered to be one of the earliest chemical engineers. Rillieux's lasting scientific achievement was his recognition that latent heat could be harnessed to produce better quality sugar at lower cost and reduced labor. One of the great early innovations in chemical engineering, his invention of the multiple effect evaporator under vacuum is widely recognized the best and most efficient method for industrial evaporation.

Rillieux's Early Life

Norbert Rillieux's early life in New Orleans contributed to his later success as a chemical engineer, an occupation that was not even recognized when he was born in 1806. His father, Vincent Rillieux, was a white planter and inventor who worked with steam engines, so Rillieux had early exposure to the sugar cane plantations that were common in Louisiana as well as the opportunity to tinker with machines from a young age.

Rillieux's mother, Constance Vivant, was a "free woman of color," a term that referred to free people of African descent in areas of French influence such as Louisiana. Rillieux was born into a higher social status than both slaves and free African Americans in the former English colonies of the eastern U.S.

Even as a boy Rillieux showed interest in engineering, so his father sent him to France for his education. The Industrial Revolution was taking place during the early 19th century—it was a time when manufacturing technology was emerging, providing numerous opportunities for inventors. He was appointed as an instructor of applied mechanics at a university in Paris by the time he was 24 years old. Around 1830 Rillieux began work on the multiple effect evaporator under vacuum, which became the basis for all modern industrial evaporation. The insight Rillieux had was to harness the latent heat of vaporization of water and distribute this heat to successive containers.

Slavery and Sugar Cane

Rillieux visited sugar cane plantations around New Orleans and saw the primitive equipment and harsh conditions used to produce sugar crystals from cane juice. The common technique for producing sugar at this time was the "Jamaican train" method, in which the cane juice was boiled in successive stages until sugar crystals were produced. Beginning with a large kettle (up to 500 gallons) boiling over an open flame, teams of slaves ladled the concentrated syrup into the next kettle, and the process was repeated until the syrup reached the proper consistency to produce sugar crystals.

The process was primitive. It required the constant attention of teams of slaves performing tedious and dangerous labor. It was wasteful because much sugar was lost in the process, and inefficient because each kettle required its own source of heat—usually wood—which could not be regulated easily. Maintaining the fires was another laborious chore given to slaves. Finally, it took great skill to recognize when the syrup reached the right consistency to produce sugar crystals. If the sugar maker chose the wrong time to "strike" the sugar, the syrup would form molasses instead of valuable sugar crystals.

Portrait of Norbert Rillieux.

Multiple Effect Evaporator

Rillieux's understanding of basic thermodynamics principles was key to his development of the multiple effect evaporator. The system depends on transferring heat from one container to the next at reduced pressure. The process begins with heat from burning fuel, but the remaining heat in the system comes from the latent heat of the steam produced in each step.

Latent heat of vaporization is the heat required to separate the molecules of a substance (i.e. to produce water vapor, also called steam), which is the same as the heat released when the molecules condense (i.e. to produce water). The latent heat of vaporization of water is higher than any other common material due to the polarity of water.

Although others had recognized the value of the latent heat energy in the steam rising from the boiling cane juice, their attempts to harness it were unsuccessful.

Scientists were making use of thermodynamics principles in the early part of the 1800s, although they would not be understood until the second half of the century. The first law of thermodynamics explains that energy cannot be created or destroyed, but no one had figured out how to use the energy wasted in the Jamaican train process. Rillieux also knew that heat can only flow from a hot body to a cooler one, which we know as the second law of thermodynamics. Furthermore, he learned that reducing the atmospheric pressure above a liquid lowers its boiling point.

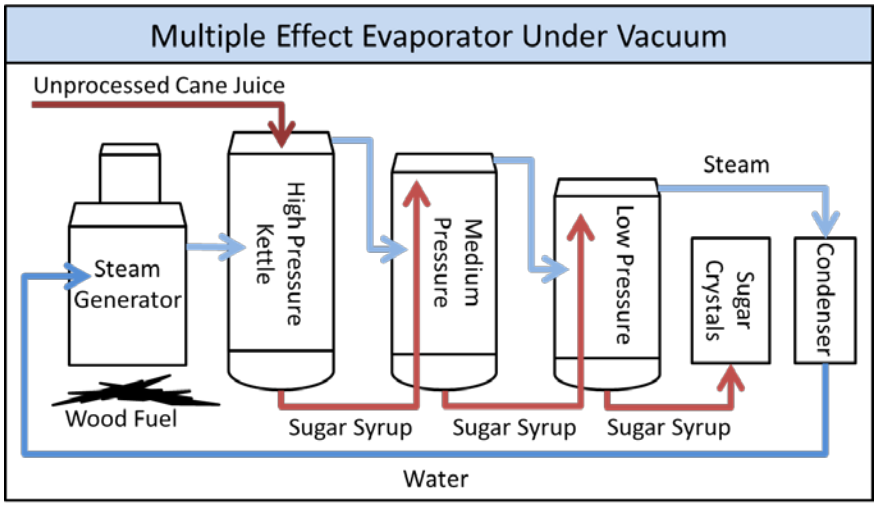
Using his understanding of thermodynamics principles, Rillieux's insight was to reduce the pressure of the system, thereby lowering the boiling point of the sugar cane juice. He did this by creating a partial vacuum above the cane juice through the use of pumps. As in the Jamaican train, three or four kettles were used, but they were closed so that the pressure could be reduced. Only the first pan needed to be heated by burning wood. The steam was pumped out of each kettle in succession to heat the next before passing through a condenser (a device to cool the steam and produce water) and returned to the steam generator to repeat the process. In 1846, Rillieux received a patent for this invention.

The multiple effect evaporator significantly lowered the cost of producing sugar because of the reduced need for fuel and slave labor. The sugar quality was improved because the cane juice boiled at a lower temperature, preventing scorching and making it much more likely to be able to correctly identify when the sugar syrup was ready to crystallize. It was a safer and more efficient way of evaporating sugar cane juice than previous methods, and the system began to be installed on plantations across the South.

Although his invention made Rillieux a rich man, he was not celebrated for his achievements. He was not allowed to sleep in the plantation houses where he installed his evaporators due to his skin color. As the Civil War approached, the status of free blacks deteriorated with the imposition of new restrictions. For these reasons, Rillieux returned to France a few years before the Civil War began, never again to live in the United States. He turned his attention to archaeology and translating Egyptian hieroglyphics. Rillieux died in France at the age of 92.

Rilliuex's Legacy

What Rillieux did, and what became the basis for all modern industrial evaporation, was to harness the energy of steam rising from the boiling sugar cane syrup in several connected chambers, leaving sugar crystals. His invention is considered to be one of the earliest examples of chemical engineering, and it remains the basis for all modern forms of industrial evaporation. The basic idea of Rillieux's evaporator is still used today to produce sugar, as well as other products such as condensed milk and freeze-dried foods.



Student Name: _____ Date: _____ Period: _____

Anticipation Guide for Handout on "Norbert Rillieux, Thermodynamics and Chemical Engineering"

Before reading the handout, consider the statements below. In the first column, write "A" or "D" to indicate your agreement or disagreement with each statement.

As you read the handout, compare your thoughts with information from the article, writing "T" or "F" to indicate whether the statement is true or false. Write notes from the reading that support or refute the statement in the spaces below each statement.

Me	Text	Statement
		1. In pre-Civil War Louisiana, some African Americans were slaves and some were free.
		2. Chemical engineering as a profession existed prior to the Industrial Revolution.
		3. Producing sugar from sugar cane requires boiling sugar cane juice.
		4. Molasses is a byproduct of sugar production.
		5. The Jamaican train brought people from the island of Jamaica in the Caribbean to be sold as slaves in New Orleans.
		6. When water vapor condenses, it releases more heat per gram than any other common substance.
		7. The heat required to evaporate one gram of water is the same as the heat given up when one gram of water vapor condenses.
		8. Heat energy can flow both from hot objects to cold objects and from cold objects to hot objects.
		9. The boiling point of a solution is increased when the pressure above the solution is decreased.
		10. Because of Rillieux's achievements in chemical engineering, he was celebrated and lived a comfortable life in the United States.

Student Name: _____ Date: _____ Period: _____

History Chronology, Concurrent Events and Reading Exercises

1. Using the handout provided, put the following historical events in chronological order, labeling the earliest event with "1" and the last event as "7."

	Order	Event
a.	_____	Rillieux travels to France to study engineering.
b.	_____	The American Civil War takes place.
c.	_____	Rillieux moves to France to study archaeology.
d.	_____	Rillieux dies in Paris, France.
e.	_____	The Industrial Revolution begins.
f.	_____	Rillieux invents the multiple effect evaporator.
g.	_____	Rillieux is born in New Orleans, Louisiana.

2. Using the handout provided and other resources, answer the following questions.
   a. What major movement in world history was taking place at the time of Norbert Rillieux's discovery?

   b. What major movement in U.S. history was taking place during Rillieux's discovery?

3. Fill in the blanks below using the reading material provided.
   a. By using the latent heat of _____ to produce energy to power later stages in the evaporation process, Rillieux replaced _____, which was the main fuel source in the Jamaica train process.
   b. In the first stage of the Jamaica train process, _____ is boiled and water is evaporated to produce _____. Later stages produce progressively thicker _____ until the final desired product, _____, are formed.
   c. When the pressure above a liquid is reduced, the boiling point of the liquid (increases, decreases, or remains constant) _____.
   d. At the boiling point, the temperature of a liquid (increases, decreases, or remains constant) _____, so any added energy goes into separating the particles to produce a gas. That energy is released when the gas particles condense.

Student Name: _____ Date: _____ Period: _____

Thermodynamics and Latent Heat

1. Using the handout provided, fill in the shaded cells below.

		Jamaican Train			Multiple Effect Evaporator		
	Container Size *(write "smallest," "medium," or "largest")*	Heat Source	Boiling Point Trend *(draw an arrow from highest to lowest, or an equals sign if no change)*	Pressure Trend *(draw an arrow from highest to lowest, or an equals sign if no change)*	Heat Source	Boiling Point Trend *(draw an arrow from highest to lowest, or an equals sign if no change)*	Pressure Trend *(draw an arrow from highest to lowest, or an equals sign if no change)*
Sugar cane juice ↓ Sugar crystals							

2. State **three advantages** of using the multiple effect evaporator over the Jamaican train to produce sugar.

   a. _____

   _____

   b. _____

   _____

   c. _____

   _____

Student Name: _____ Date: _____ Period: _____

Exploring Engineering Practices

Engineering is the systematic practice of solving problems and developing technology as a result of that practice. The engineering process involves defining problems, developing solutions, and optimizing and improving solutions.

How did Norbert Rillieux exhibit the following engineering practices in his development of the multiple-effect evaporator under pressure? How would you work to improve sugar production if you were Rillieux?

1. Defining problems: What problem or problems were present in sugar production during Rillieux's time?

2. Planning and carrying out investigations: What ways did Rillieux think of to solve the problem?

3. Analyzing and interpreting data: How could Rillieux demonstrate that his multiple effect evaporator method improved sugar production?

4. Using mathematics and computational thinking: One possible measurement recorded by Rillieux to show the effectiveness of his multiple effect evaporator is listed below. List two other possible measurements or calculations.

    a. He might have made a comparison of the mass of sugar cane juice processed to the mass of sugar crystals produced.

    b.

    c.

5. Obtaining, evaluating and communicating information:

    a. How did Rillieux's work come to be accepted by the scientific community?

    b. What is the impact of Rillieux's work today?

6. Your Reflection:

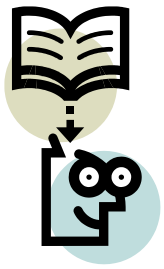
    a. Why was Rillieux's invention important?

    b. Name a product or a process that you are familiar with that relies on the first or second law of thermodynamics. Explain.

Student Name: _____ Date: _____ Period: _____

3-2-1 Contact

After reading the article, respond briefly to the prompts listed below in the space provided.

3	What three events from his life made it possible for Rillieux to succeed in developing the multiple effect evaporator? 1 2. 3.
2	Explain how the Rillieux's multiple effect evaporator relied on what came to be known as the First and Second Laws of Thermodynamics. First law: Second law:
1	Based on what you learned from reading this article, what one thing did you learn about how historical events help shape technological advances?
Contact 	Describe a personal experience (not mentioned above) that connects to something you read in the article—something that your personal experience validates.

Norbert Rillieux, Thermodynamics and Chemical Engineering Answer Guide
Anticipation Guide

Me	Text	Statement
(Student answers will vary)	**True**	1. In pre-Civil War Louisiana, some African Americans were slaves and some were free.
	False	2. Chemical engineering as a profession existed prior to the Industrial Revolution.
	True	3. Producing sugar from sugar cane requires boiling sugar cane juice.
	True	4. Molasses is a byproduct of sugar production.
	False	5. The Jamaican train brought people from the island of Jamaica in the Caribbean to be sold as slaves in New Orleans.
	True	6. When water vapor condenses, it releases more heat per gram than any other common substance.
	True	7. The heat required to evaporate one gram of water is the same as the heat given up when one gram of water vapor condenses.
	False	8. Heat energy can flow both from hot objects to cold objects and from cold objects to hot objects.
	False	9. The boiling point of a solution is increased when the pressure above the solution is decreased.
	False	10. Because of Rillieux's achievements in chemical engineering, he was celebrated and lived a comfortable life in the United States.

Norbert Rillieux, Thermodynamics and Chemical Engineering Answer Guide
History Chronology, Concurrent Events and Reading Exercises

1. Using the handout provided, put the following historical events in chronological order, labeling the earliest event with "1" and the last event as "7."

	Order	Event
c.	**3**	Rillieux travels to France to study engineering.
d.	**6**	The American Civil War takes place.
e.	**5**	Rillieux moves to France to study archaeology.
f.	**7**	Rillieux dies in Paris, France.
g.	**1**	The Industrial Revolution begins.
h.	**4**	Rillieux invents the multiple effect evaporator.
i.	**2**	Rillieux is born in New Orleans, Louisiana.

3. Using the handout provided and other resources, answer the following questions.

   a. What major movement in world history was taking place at the time of Norbert Rillieux's discovery?

   The Industrial Revolution.

   b. What major movement in U.S. history was taking place during Rillieux's discovery?

   Disagreement over slavery, which lead to the Civil War.

3. Fill in the blanks below using the reading material provided.

   a. By using the latent heat of **vaporization (evaporation)** to produce energy to power later stages in the evaporation process, Rillieux replaced **wood**, which was the main fuel source in the Jamaica train process.

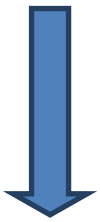
   b. In the first stage of the Jamaica train process, **sugar cane juice** is boiled and water is evaporated to produce **sugar syrup**. Later stages produce progressively thicker **sugar syrup** until the final desired product, **sugar crystals**, are formed.

   c. When the pressure above a liquid is reduced, the boiling point of the liquid **decreases**.

   d. At the boiling point, the temperature of a liquid **remains constant**, so any added energy goes into separating the particles to produce a gas. That energy is released when the gas particles condense.

Norbert Rillieux, Thermodynamics and Chemical Engineering Answer Guide
Thermodynamics and Latent Heat

1. Using the handout provided, fill in the shaded cells below.

		Jamaican Train			Multiple Effect Evaporator		
Sugar cane juice	Container Size	Heat Source	Boiling Point Trend	Pressure Trend	Heat Source	Boiling Point Trend	Pressure Trend
	**Largest**	**Burning wood (or direct heat)**	**=**	**=**	**Wood (or steam from generator)**		
	Medium	**Burning wood (or direct heat)**	**(boiling point remains constant)**	**(boiling point remains constant)**	**Steam (or latent heat)**		
Sugar crystals	**Smallest**	**Burning wood (or direct heat)**			**Steam (or latent heat)**		

2. State three advantages of using the multiple effect evaporator over the Jamaican train to produce sugar.

   a. **Saves energy because steam is used instead of fuel.**

   b. **Safer method because people do not ladle syrup into successive containers.**

   c. **Better quality sugar is produced because the syrup is boiled at a lower temperature.**

   Other possible answers: Not as much sugar was wasted using the multiple-effect evaporator due to ladling; Rillieux's invention was cheaper to operate because not as much fuel was needed.

Norbert Rillieux, Thermodynamics and Chemical Engineering Answer Guide
Exploring Engineering Practices

1. Defining problems: What problem or problems were present in sugar production during Rillieux's time?

   Refining sugar required a lot of energy in the form of burning fuel (wood), as well as a lot of manpower (slaves) to do dangerous work. Sugar crystals were dirty.

2. Planning and carrying out investigations: What ways did Rillieux think of to solve the problem?

   Rillieux developed a multiple-effect evaporator, based on thermodynamic principles to take advantage of the latent heat of vaporization of water.

3. Analyzing and interpreting data: How could Rillieux demonstrate that his multiple effect evaporator method improved sugar production?

   Rillieux installed his invention at some sugar plantations in Louisiana to demonstrate its effectiveness. The planters saw the improved quality of the sugar crystals.

4. Using mathematics and computational thinking: One possible measurement recorded by Rillieux to show the effectiveness of his multiple effect evaporator is listed below. List two other possible measurements or calculations.

   a. He might have made a comparison of the mass of sugar cane juice processed to the mass of sugar crystals produced.

   b.& c.: **Possible answers: Temperature measurements of syrup in kettles; equations for latent heat of vaporization; comparison of mass of sugar cane juice processed to mass of sugar crystals produced; Comparison of amount of fuel needed for Jamaican train method compared to multiple-effect evaporator method**

5. Obtaining, evaluating and communicating information:

   a. How did Rillieux's work come to be accepted by the scientific community?

      By installing his invention at sugar plantations, Rillieux was able to demonstrate that it worked. Late in life, Rillieux developed a similar method to refine sugar beets.

   b. What is the impact of Rillieux's work today?

      The multiple-effect evaporator is still in use in many industries today (making glue, soap, freeze-dried foods, etc.).

      Rillieux's contribution to the practical issues associated with thermodynamics principles helped advance chemical engineering.

6. Your Reflection:

   a. Why was Rillieux's invention important?

   b. Name a product or a process that you are familiar with that relies on the first or second law of thermodynamics. Explain.

      Individual students' answers will vary.

Norbert Rillieux, Thermodynamics and Chemical Engineering Answer Guide
3-2-1 Contact

After reading the article, respond briefly to the prompts listed below in the space provided.

3	List three events from his life made it possible for Rillieux to succeed in developing the multiple effect evaporator? 1. **He was born a free man of color, not a slave.** 2. **His father sent him to France for an education.** 3. **He grew up in an area where sugar plantations are common,** or **he visited sugar plantations as a young person.** **Other possible answers: He enjoyed solving problems even as a child. His father was interested in engineering.**
2	Explain how the Rillieux's multiple effect evaporator relied on what came to be known as the First and Second Laws of Thermodynamics. First law: **Instead of wasting the energy from burning wood (fuel), Rillieux's invention made use of the energy absorbed by the water as it turned to steam.** Second law: **Heat flows toward the cooler container, taking advantage of the latent heat of vaporization to heat each successive container. Rillieux's invention reduced the pressure above the containers, thereby reducing the boiling point of the sugar solutions.**
1	Based on what you learned from reading this article, what one thing did you learn about how historical events help shape technological advances? **Student answers will vary.**
Contact 	Describe a personal experience (not mentioned above) that connects to something you read in the article—something that your personal experience validates. **Student answers will vary.**