Deep Space Atomic Clock

For the Teacher

Challenge

Design a water clock to mark the precise measurement of the passing of time.

Materials

Items required for activity:

- Plastic bottles or large containers that will hold water. Various sizes up to 2 liter, or gallon size. It is best if the containers have a flat bottom. Each team will need at least two bottles of the same size.
- Variety of sturdy materials (wood, PVC, blocks, ring stand, etc.) to make a stand to elevate the upper container that will hold the water above the lower container.
- Pin/thumb tack to pierce hole in container
- Source of water
- Ruler/measuring tape
- Stopwatch
- Paper to use for increment markings (may need tape to attach to lower container)
- Plumber's putty or waterproof tape (optional)

Safety Concerns

Be sure the stands the students build are sturdy

Pre-Activity Set-up

Students will be designing and building a water clock to keep accurate time for a specified amount of time. The materials for this activity can be predetermined or can be more open-ended.

Find an area where the students can elevate their water clocks above the container that will collect the water. A wire shelf will work, or students can construct something that will allow the water to drip down into a container below.

Students will need to observe the water dripping over several hours. They don't need to watch every drop fall, but should take readings every 15–30 minutes for a couple of hours to ensure accuracy of their measurements. The *Experiment and Record* sheet assumes you will track time for 3 hours. If you do not have time to do this, adjust the worksheets and have students make estimates. If you shorten the recording times, remove all but the last bit of water so students can observe and track what happens when the upper container is almost empty.

The students will need to count the number of drops that occur in 60-second increments and mark on the lower container. The amount of drops that occur in one minute is called the flow rate. For example, there could be 65 drips (depending on hole size) in 60-seconds. Student will mark on the paper or container at the 60-second increments. Take a photo of the increments marked on the container. The goal is to have the side of the lower container with reliable markings to see how much time has passed. Students might find it helpful to use a piece of paper marked with the increments alongside the lower container. This way they can make adjustments without messing up the container.

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Motivate

- Ask students to come up with ways they can mark the passing of time. More information about time can be found here: *http://www.nist.gov/pml/general/time/early.cfm*
- Show the students the "Deep Space Atomic Clock" video: *http://www.nasa.gov/mission_pages/tdm/clock/sammy-the-second.html*
- Connect the challenge to NASA by discussing the development of the Deep Space Atomic Clock to provide precise time and therefore precise navigation in deep space. See *Student Page* and this website for more information: *http://www.nasa.gov/mission_pages/tdm/clock/*
- Challenge the students to design a water clock.

Ask

- Students will write out any questions they may have about clocks, keeping time, or the challenge.
- A common question for students will be, "How do we mark the time increments on our clocks?" There are several ways the students can do this, and they may figure it out on their own. See the *Pre-Activity Step-up* section for more information.

Imagine

- Students should consider the various elements of a water clock.
- The upper container drips at a constant rate to the lower container. Students will need to determine the hole size for the water to drip through. The hole needs to be big enough to have water flow through but not so big it streams out. The hole can be in the center or on the sides of the container. If a hole is too large, they can use plumbers putty to plug it up and then make a new hole somewhere else on the container.
- They will also need to determine how to mark the increments of time on the outside of the lower container on the paper.

Plan

- Students will need to make a plan for recording the increments of time. This is called calibrating, and they will need to mark how much time passes based on how much water has dripped through. The flow rate is the number of drops per minute. One student will need to use the stopwatch, and the others will count the drips or flow rate. Remind students that an accurate clock is very important and to record the flow rate and time correctly.
- Water tension will cause the water line to curve; students will need to determine if measurements will be at the top or the bottom of the curve. Consistency in measurement will be key to an accurate clock.

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Create

- Students work to build their water clock. They will begin experimenting with flow rate and improving their design to get a consistent and constant flow of water.

Experiment

- After determining the water clock has a consistent and constant flow of water, students will fill the upper container with water and determine the actual flow rate (drops of water per minute). After completing the *Experiment and Record* sheet, another team will test the accuracy of their clock. Discussion questions are on the *Experiment and Record* and the *Quality Assurance Student* pages.

Improve

- Students will spend more of the improvement time trying to get a constant and consistent flow of water. After they have completed the *Experiment and Record* sheet, and if time allows, they could make further adjustments to their water clock. If time does not allow for a complete retesting, have students write out what changes they would make and what they predict will be the new outcome.

Challenge Closure

Engage the students in a discussion by reviewing and posing the following questions:

- Which design characteristics provided the most reliable results?
- Discuss possible explanations for why the designs with the best results worked better.
- What happened to the flow rate when your upper container was first filled with water?
- What happened to the flow rate when the water in the upper container was almost gone?
- After the one-hour, two-hour and three-hour tests were complete, did you see variations in the flow rate?
- What do you think caused the variations?
- Looking at the distance of the incremenets of time (in the second table), are they evenly dispersed? Why or why not?
- Was your water clock a precise measurement of time? Why or why not?
- Predict what the variation of time on your water clock would be after 24 hours.
- What, if anything, did you learn about your team's design while testing another group's design?
- Complete the *More Fun with Engineering* activity and discuss the variations between different clocks. Include the knowledge learned from your water clock.

Background

Deep Space Atomic Clock

Earth-based atomic clocks keep very precise time. The best will only be off by one second in 300,000 years. They work not by counting grains of sand or drops of water, but by counting the movement of electrons. They are extremely complicated and are very important to governments, astronomers, military, and even people trying to locate the nearest gas station! See the *More Fun with Engineering* activity to learn more about Earth-based atomic clocks.

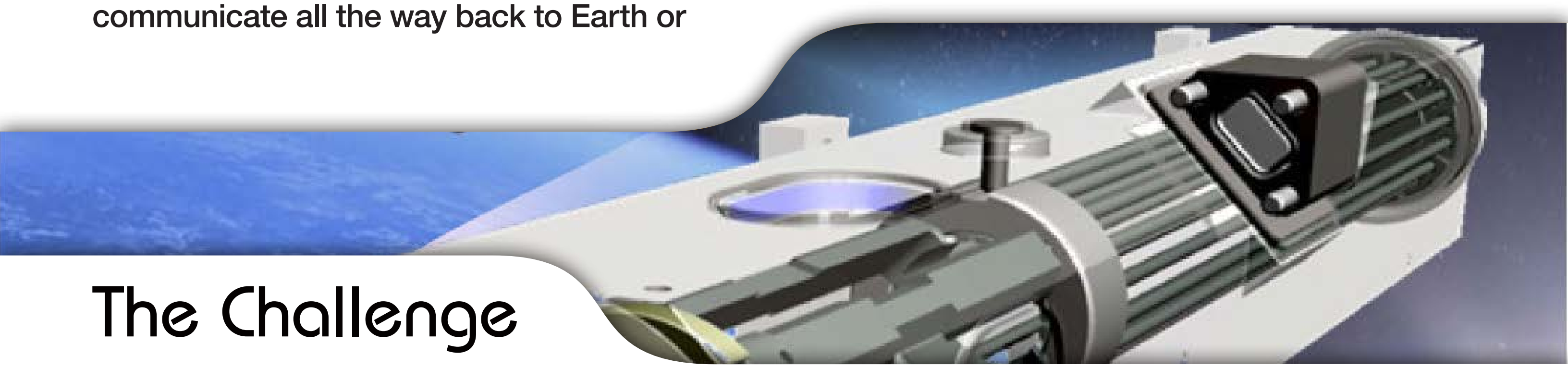
As shown in the video (*http://www.nasa.gov/mission_pages/tdm/clock/sammy-the-second.html*), keeping precise time ensures precise navigation. If the time is incorrect by just a few seconds, it can put someone off-course by many miles. For NASA, if the clock gets off by a few seconds, the spacecraft could miss the planet it was trying to observe, or worse, could hit something that would damage the spacecraft!

The Deep Space Atomic Clock mission will change the way we conduct deep space navigation. By no longer needing to communicate all the way back to Earth or a satellite to process data, the Deep Space Atomic Clock will handle everything on its own and will allow for time sensitive events to occur exactly when they need to. There will no longer be a need to upload the navigation directions hours ahead of time since it can instead be uploaded just minutes ahead of time, which will make it more accurate.

Just like Earth-based atomic clocks, the Deep Space Atomic Clock is a very complicated machine that will also have to be able to survive the harsh environment of space travel. Spacecrafts travel through space at about 17,000–36,000 miles per hour. The spacecraft needs to be able to make quick decisions in deep space in order to make landings and critical changes to orbits possible.

More information can be found at

http://www.nasa.gov/mission_pages/tdm/clock/clock_overview.html



The Challenge

Design a water clock to record precise measurement of the passing of time.

The design constraints are:

- Use only materials provided to you to create the water clock.
- Water clock must keep time for 3 hours.

Reminder For All Challenges

- Be sure to document all testing results.
- Make any necessary design changes to improve your results and retest.
- Complete all conclusion questions.

Our Team's Plan

Deep Space Atomic Clock

ASK

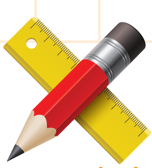
What questions do you have about today's challenge?

IMAGINE

How will your clock work?

PLAN

Draw and label your water clock.



Be sure to include measurements!

Write instructions on how to use your water clock.

Experiment & Record

Team Name ____________________

After determining that you have a constant and consistent flow of water, begin the testing.

Reminder
- If you make any design changes during testing, add more water to upper container and begin all testing again.

1. What is your initial flow rate (drops per minute)?:

2. Complete several tests within the hour increment to determine the average for that hour.

Flow Rate	1-hour Measure (drops/minute)	2-hour Measure (drops/minute)	3-hour Measure (drops/minute)
Test #1			
Test #2			
Test #3			
Average			

3. At the same time you are measuring flow rate mark in increments the distance the water level dropped in that same minute.

Distance	1-hour Measure (cm)	2-hour Measure (cm)	3-hour Measure (cm)
Test #1			
Test #2			
Test #3			
Average			

4. Why are we measuring the distance the water level moved?

5. After completing both tables and looking at the increments of time, are they evenly dispersed? Why or why not?

Experiment & Record

Deep Space Atomic Clock

6. Test another team's water clock. Fill out the *Quality Assurance Worksheet*. Return the *Quality Assurance Worksheet* back to the team.

7. After reviewing your team's *Quality Assurance Worksheet*, how would you improve the design of your water clock if there was more time?

Challenge Closure

1. Which design characteristics provided the most reliable results?

2. Discuss possible explanations for why the designs with the best results worked better.

3. What happened to the flow rate when your upper container was first filled?

4. What happened to the flow rate when the water in the upper container was almost gone?

5. After the one-hour, two-hour, and three-hour tests were complete, did you see variations in the flow rate?

6. What do you think caused the variations?

7. After completing both tables and looking at the increments of time, are they evenly dispersed? Why or why not?

8. Was your water clock a precise measurement of time? Why or why not?

9. Predict what the variation of time on your water clock would be after 24 hours.

10. What, if anything, did you learn about your team's design while testing another group's design?

11. Complete the *More Fun With Engineering* activity and discuss the variations between different clocks. Include the knowledge learned from your water clock.

Quality Assurance

Deep Space Atomic Clock

Each team is to review another team's design and model, then answer the following questions.

Team Name	Yes	No	Notes
What was the team's flow rate? Drops per minute: ___________			
Did the team accurately record their flow rate?			
Do the markings accurately reflect the passing of time?			

List the specific strengths of the design.

List the specific weaknesses of the design.

How would you improve the design?

Inspected by: ____________________________________

Signature: ____________________________________

More Fun With Engineering

Deep Space Atomic Clock

Activity One:

Make a phone call to the U.S. Naval Observatory or the WWV Broadcast to listen to the official time. Compare the official time to a wall or computer clock in the classroom. After a week or so, call in again and see what the difference is. The class could do this for several weeks and see if they can predict the difference for upcoming weeks. While the service is free via short-wave, there are standard long distance charges for the telephone calls. Either way, it's fun to listen in!

In North America, radio time signals based on UTC are available from:

U.S. Naval Observatory in Washington, D.C. (202) 762–1401
http://www.usno.navy.mil/USNO/time

WWV at Fort Collins, Colorado
(303) 499–7111

http://www.nist.gov/pml/div688/grp40/wwv.cfm

This activity comes from the Smithsonian Astrophyical Observatory (SAO), Eyes on the Sky Feet on the Ground Chapter Three, Time and the Calendar, Activity 3–4 The Atomic Clock. *http://hea-www.harvard.edu/ECT/the_book/index.html*

Activity Two:

Global Positioning System (GPS), are a series of satellites around Earth that are able to track your location based on how far you are from several satellites and how long it has taken you to move between them. Without the accuracy of the time element, your location would not be accurate. Here is an activity about GPS and some resources if you would like to learn more:

http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/How_Do_Global_Positioning_Systems.html or *http://sideshow.jpl.nasa.gov/post/series.html.*