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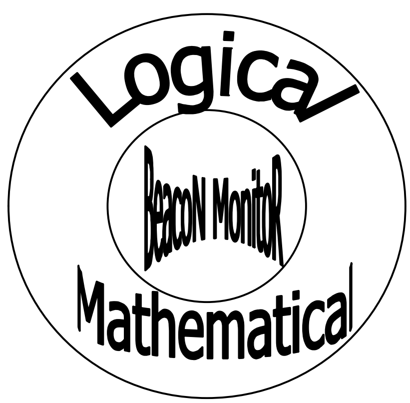
BEACON MONITOR EXPERIMENT ON DEEP SPACE 1

How do space scientists program a computer to be smart enough to make up its own mind?

Students often use computers for games, accessing the internet, word processing, and graphics design. But what makes it all work? This five-fold activity leads to an understanding of how to write algorithms to solve problems, make decisions, and take action.

The U.S. civilian space agency, the National Aeronautics and Space Administration (NASA), envisions a revolutionary space exploration program for the 21st century. To prepare for the future, NASA has created the New Millennium Program to conduct a series of flights into deep space and into orbit around Earth that will test new, high-risk technologies. The New Millennium Program will "field test" the spacecraft designs of the future. The first mission, launched in October 1998, is called ***Deep Space 1***. It carries twelve new feats of technology being used as never before in a spacecraft—including the *Beacon Monitor Experiment.*

Grade Level: *Elementary and middle school*
Small Group Activity: *3-5 in a group*
Objectives: *Learn the basics about writing algorithms, analyzing levels of decision space, and how a beacon monitor system works.*
Materials: *Paper and pencils*
Timetable: *Warm-up, About 15 minutes; main activity, about 40 minutes*
Vocabulary: ***algorithm, anomaly, autonomy, beacon monitor, decision space***



BEACON MONITOR EXPERIMENT ON DEEP SPACE 1

WARM-UP ACTIVITY: WE'VE GOT ALGO-RHYTHM!

ALGORITHM: A MATHEMATICAL OR LOGICAL SEQUENCE USED IN COMPUTER SCIENCE

An ***algorithm*** is a logical, step-by-step procedure to solve a problem. One kind of algorithm is an arrangement of questions that require yes or no answers that leads to a ***decision***. Sometimes we say that a mind works like a computer, or that a computer works like a mind. What do you think? Can a computer make up its mind? Yes or No? Well, make up your mind!

Actually, a computer can make a decision only if a computer programmer (someone like you) invents an ***algorithm***. A computer is restricted to responding to *on* or *off* signals because information travels in discrete electronic pathways that have gates that are either open or closed (letting a signal *stop* or *go*). Whether you think of it as *open/closed, on/off, 1/0, yes/no, stop/go, potato/tomato*—it basically comes down to answering the question: Is the gate open? Yes or No. Let the information flow! Why not draw your own version of this idea?

An ***algorithm*** defines the meaning of the answer. Each *Yes* or *No* leads to a new question that ultimately leads to a decision to take *action.* The idea of an algorithm is to ask a connected series of questions whose answers help make an important decision.

Example:

RESTAURANT ALGORITHM

A girl is at a restaurant with her family. She decides she is going to answer only yes or no. The waiter comes over to take her order.

Are you thirsty? *Yes.*
Would you like some water? *No.*
Coffee? *No.*
Tea?* *No.*
Milk? *Yes.*
Regular Milk? *No.*
Chocolate Milk? *Yes.*
Would you like it cold? *No.*
Would you like it hot? *Yes.*
Would you like a hot chocolate? *YES!*
Coming right up!

The challenge is to come up with the *fewest* questions that exchange the *most* information that leads to an *action.*

*Remember, if the answer to "Tea?," for example, had been "Yes," this "pre-programmed" algorithm would have branched to a different set of questions, such as:

Iced tea? No
With lemon? No
With milk? Yes
With sugar? Yes

Warm-up Activity Instructions

Now that we've got algo-rhythm,
Let's invent some algorithms!

Pick an interesting DECISION to make.

Brainstorm about possible alternatives.

Consider different angles to ponder.

Invent some algorithms that lead to decisions to make or actions to take.

Test your algorithm in your own group.

Follow the pathways created by the yes or no answers.

Does the logical sequence work out the way you think it should?

When you are ready, share your algorithm with the whole class.

MAIN ACTIVITY: ONE TWO, THINK IT THROUGH

DECISION SPACE, WHAT ON EARTH ARE WE GOING TO DO?

We make decisions every day. Solving a problem or responding to an emergency requires our total attention. We must gather as much information as quickly as possible. Then we focus on our range of choices about what to do. Computer scientists call that range of choices *decision space.* One way to understand this is to think through the decision space of a familiar situation.

For example, think of a backyard injury: While Mom is home, she *monitors* the well-being of her children. A child scrapes his knee and sends out a red alert *beacon signal*: *"Ouch! Oh, Mom!"* The shout alerts Mom that an *anomaly* has occurred: Something's gone wrong! Once Mom *receives the signal,* she rushes to the backyard, reads the vital signs, and makes a decision about what to do. Mom's realistic range of choices, or *decision space,* might include:

1. Kiss the scrape and let the child keep playing.
2. Clean the scrape and put on a gauze bandage.
3. Rush the child inside. Stop the bleeding.
4. Call 911 immediately and wait for the paramedics!

The nature of the *anomaly*, in this case, the seriousness of the scrape, determines which of these four actions Mom takes. Each possible action represents a different *level of decision space*.

DECISION SPACE IN DEEP SPACE

A spacecraft needs tender loving care to make sure everything is in working order. On Deep Space 1, the Mission Operations ground crew has the job of keeping track of the spacecraft to make sure that it's doing fine. "Mission Ops" *monitors* the well being of the spacecraft. If there is a problem, we call it an *anomaly.* An *anomaly* is an unplanned—basically, something that has gone wrong.

For example, there might be a temperature *anomaly*. Maybe the temperature is fluctuating wildly and must be brought under control by turning on a heater or maneuvering to put an overheated radiator in the shade. Someone must be alerted to the spacecraft's status at such critically important moments, ready to take action by sending up the proper set of commands.

While such moments can be tremendously exciting, a long mission cruise is, for the most part, *uneventful*. It is costly to design a mission that requires constant operator attention. And the "backyard" is deep space, a lot farther away than a shout to Mom. What on Earth are we to do?

Up until now Mission Ops has had to rely almost exclusively on the few large, expensive antennas of the Deep Space Network to do its job. But today, this is becoming impractical and costly, like calling an ambulance for a stubbed toe. It will become even more impractical in the future, because NASA is launching many more, smaller and cheaper spacecraft, but the number of antennas and the number of hours in the day when they can be scheduled to "listen" to a particular spacecraft will remain the same.

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A new, experimental way is to use a *beacon monitor*—to be tested out for the first time by Deep Space 1.

Success of the Deep Space 1 *Beacon Monitor Experiment* may lead to its use on other space exploration missions that will journey to many exciting places in the solar system—and perhaps beyond!

WHY A BEACON MONITOR?

With many spacecraft operating simultaneously, beacon monitor operations will greatly reduce the load on the Deep Space Network. Smaller antennas can be used routinely to monitor beacon tones, with the larger antennas reserved for mission-critical communications and data retrieval.

HOW DOES IT WORK?

This intelligent system selects one of four signals to transmit. Each signal is a code to indicate how urgently contact with controllers on Earth is needed. The signals have prearranged meanings and are simple enough to be detected on Earth by smaller (and, therefore, less expensive) antennas.

MESSAGE:	ACTION:
• GREEN: I'm OK.	None Required.
• YELLOW: I corrected an anomaly myself.	Check things out if you want to.
• ORANGE: I have data to transmit.	Schedule download on the DSN pretty soon.
• RED: Red Alert! I need help NOW!	Alert everyone! Solve the problem right away!

How does a beacon monitor decide when to send which message back to Earth? It's got *algo-rhythm*! By running advanced algorithms, the computer is smart enough to recognize conditions that correspond to the four levels of decision space, the four different signals.

The computer, however, is not smart enough to invent an algorithm on its own. But you are! You can invent algorithms for your own beacon monitor system!

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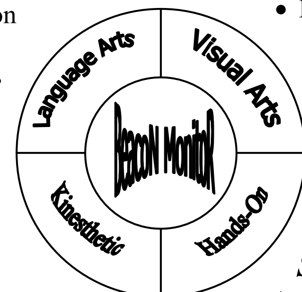
BEACON MONITOR EXPERIMENT ON DEEP SPACE 1

BEACON MONITOR GROUP SCIENCE AND TECHNOLOGY PROJECT ACTIVITIES

LANGUAGE ARTS EXPLORATION

DECISION SPACE

- In a small group, brainstorm about situations in everyday life where the *decision space* can be expressed as four possible actions.
- Select one situation. Devise a concise message corresponding to each of the four possible actions.
- Invent an algorithm that creates a yes/no pathway leading to each message. Write it out.
- Then read aloud and dramatize what you worked out to the whole group.
- Consider a variety of possible *decision spaces:* for example, making change with the fewest coins; making your way through a maze; what to do in an emergency injury situation; preparing for stormy weather; preparing for a volcanic eruption.
- Consider different ways to send the message: gestures, sounds, rhythms, colors, lights.
- Don't forget the beacon monitor experiment on Deep Space 1. Write some algorithms that would work on a space exploration mission that monitors the well-being of the systems on-board. The challenge is to introduce *autonomy* into the design.



KINESTHETIC EXPLORATION

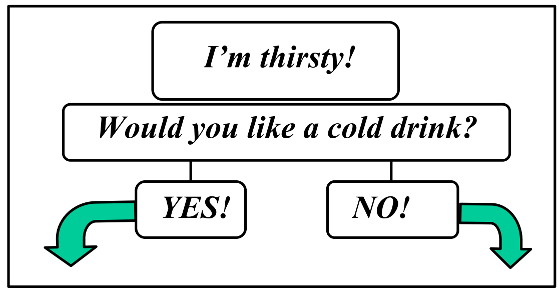
RED LIGHT, GREEN LIGHT!

- Collaborate in a small group to create a *live version* of a beacon monitor experiment!
- Construct your own Deep Space 1 spacecraft using each other as the component parts.
- Think of the parts as *characters* in a play.
  - Green Signal Beam: Everything's A-OK!
  - Yellow Signal Beam: I fixed a problem.
  - Orange Signal Beam: Download data soon.
  - Red Signal Beam: URGENT ATTENTION!
  - Antenna: To communicate with Earth
  - Computer: the "brains."
  - Heater: To provide heat when needed.
  - Louver: To radiate heat out into space.
  - Attitude Control Thrusters: to adjust the orientation of the spacecraft
  - Ion Propulsion Engine: Long-term thrust
  - Autonomous Navigation: Steering by the stars.
  - Solar Array: To provide electrical power.
  - Other subsystems on Deep Space 1.
  - Camera: To take pictures.
- Think things through using the algorithms as a basis for an improvisational scenario.
- Use movement expression and words to bring your ideas to life. Create costumes and props.

VISUAL ARTS EXPLORATION

ALGO-RHYTHM STORYBOARD

- Work with your group to transform your written algorithm into a storyboard, a cartoon-like visual flow chart of each step in the process.



- Draw a picture of a real-life situation that calls for a decision-making process in order to take the right action.
- Test the algorithm in different situations and fix it if you find places where it doesn't work.
- Make props for your improvisational scenario out of found objects (cereal boxes, aluminum foil, milk jugs, string, paper, cardboard etc.).
- Create costumes to go with the Beacon Monitor improvisational scenario.

HANDS-ON EXPLORATION

SIGNAL CIRCUITRY

- As a project team, design and then construct your own simple circuitry to make a beacon monitor signaling device.
- Materials: Batteries, four differently colored small light bulbs and sockets, four switches, two junction blocks that can each handle four connections, electrical wiring, a flat piece of wood to work as a base, some screws and some screwdrivers to mount the beacon monitor to the base.
- Design a simple circuit that connects the lights in a series that can be triggered by the switches.
- Use the beacon signal device as a prop in your improvisation.
- Create a Beacon Monitor game show! Read aloud a hypothetical *decision space* scenario. Use the algorithm approach to assess the situation and gauge a response, then hit the right switch!
- Discuss the logical reasoning involved. Did the algorithm lead to the best response? Are there alternative responses that the algorithm didn't consider? Should the algorithm be reworked? Are there ambiguities in some situations that require a different approach altogether?
- Design and construct a simple circuit that uses a signal other than light. Sound? Motion?

Richard Shope, the creator of this activity, is the Space Science Education Outreach Liaison at NASA's Jet Propulsion Laboratory in Pasadena, California. He has an M.S.Ed. in science education and, incidentally, is a professional mime artist. He uses mime and other kinesthetic techniques to teach writing, reading, and content across the curriculum.