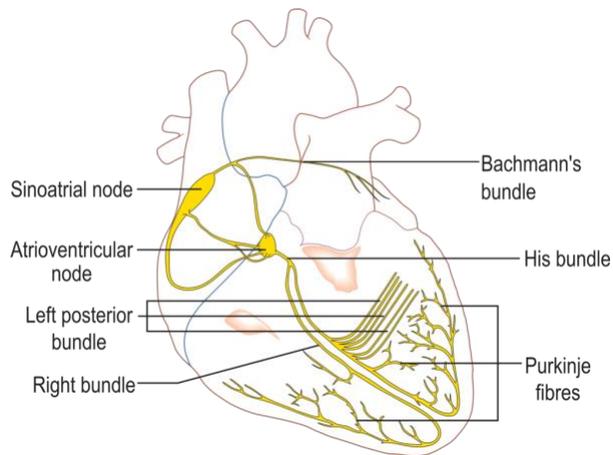


Challenge: Model the Human Four-Chamber Heart

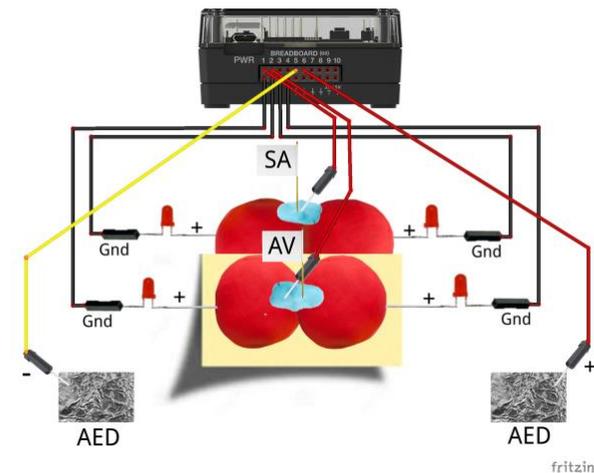
PROJECTS WITH THE TI-INNOVATOR™ SYSTEM FOR TI-NSPIRE CX

Overview:

This project extends on [The Plumber](#) activity and assumes the student has completed that project and understands the basic anatomy and circulation of the heart. The project extends [The Plumber](#) model and explores the electrical system of the heart by adding the SA and AV nodes. Students also learn how a pacemaker works in patients with heart disease. Students have an opportunity to build electrical circuits, explore material conductivity, and write code. Additionally, students are challenged to build a model of an automated external defibrillator (AED) for their model heart.



The Electrician-How the Heart Beats



Possible NGSS topics to explore with student

Disciplinary Core Ideas:

- MS-LS1-3 – Body is a system of interacting subsystems.
- MS-LS1-3 – Chemical reactions release energy as matter moves through the organism

Science & Engineering Practices:

- Developing and using models
- Constructing explanations & designing solutions
- Asking questions & defining problems

Crosscutting Concepts:

- Systems & System Models
- Cause & Effect
- Energy & Matter

Background:

The heart is a pump that circulates blood through the body, as described in the previous activity; “The Plumber.” In this activity, “The Electrician,” explores the system that causes the heart muscle to beat. The heart beats with a rhythm established by a group of cells called the sinoatrial (SA) node that serves as a pacemaker. These cells naturally and periodically depolarize causing an action potential that spreads across the heart muscle. The SA node depolarization is then conducted to both atria via the Bachmann’s bundle; a narrow band of conductive cells. This depolarization causes the muscle tissue of the two atria to squeeze at the same moment forcing the blood from the upper heart, the two atria, into the lower heart, the two ventricles. The original depolarization started in the SA node is also conducted to the AV node a bundle of cells that depolarize as a result of the SA node action potential. The AV node amplifies and delays the depolarization signal. The AV depolarization conducts into the bundle of His and the Purkinje fibers causing the ventricles to squeeze at the same moment but out of phase with the atria. It is essential that the upper and lower sections of the heart contract out of phase to make a pumping action.

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Command Background:

Command	Example	Behavior
CONNECT DIGITAL.OUT <number> TO <bread board pin>	Send "CONNECT DIGITAL.OUT 1 TO BB1"	Associates BB 1 port with a software object named DIGITAL.OUT 1. Note: The DIGITAL.OUT object has more power than the LED object used in The Plumber project.
SET DIGITAL>OUT <number> TO <state>	Send "SET DIGITAL.OUT 1 TO ON"	Switches the PORT associated with the corresponding "CONNECT DIGITAL.OUT 1 ..." command to ON. The state may also be OFF.
CONNECT ANALOG.IN <number> TO <port>	Send "CONNECT ANALOG.IN 1 TO BB5"	Configures the port to measure the voltage on the associated port relative to the Hub ground. This object can only be used with IN1, IN2, IN3, BB5, BB6, and BB7
READ ANALOG.IN <number>	Send "READ ANALOG.IN 1"	Reads the analog voltage value associated with the corresponding "CONNECT ANALOG.IN 1 ..." command in binary, ranging in value from 0 to 2 ¹⁴ . A Get command must immediately follow the READ command.
Get <variable>	Get a	Gets the value returned from the Hub from the previous READ command and stores the value into the variable named "a".
SET SOUND <frequency in Hz> TIME <duration in Sec>	Send "SET SOUND 440 TIME 3"	Sets the speaker on the Hub to make a 440 Hz tone for 3 seconds.
getKey()	key:=getKey()	getKey() returns the name of the last key pressed as a text string (e.g. "esc"). In this example the key name is stored to a variable named "key".

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Supplies and Equipment:

- TI Nspire CX family calculator and TI-Innovator Hub
- 4 x Male/Female (M/F) Jumper Wires
- 3 x Male/Male (M/M) Jumper Wires
- Printout of TI Modeling Four Chambered Heart build mat
- 4 x LED
- 4 x Toothpicks with labels
- 3oz. conductive Play-Doh (do not use plasticine or modeling clay)
- 2 x small square of aluminum foil
- 2 x small pieces of an alternate color of Play-Doh (teams may share)

Setup Project Model:

The four separate chambers of the heart are formed using electrically conductive Play-Doh. Similarly, two small pieces of an alternate color of Play-Doh are used to form the SA and AV nodes. The heart's electrical stimulation is modeled using the Innovator Hub and four LEDs controlled by a TI-BASIC program.

The model of the heart should include these events:

1. The firing of the SA node
2. The firing of the AV node
3. Conduction of SA node signal to the atria
4. Conduction of the AV node signal to the ventricles.

The model of the AED should include these events:

1. Detecting the presence of two AED paddles touching the heart
2. Reviving the heartbeat once the AED detects paddle on the heart

The Student Activity

Sit in small groups of 2-3 students with calculators and supplies for this activity.

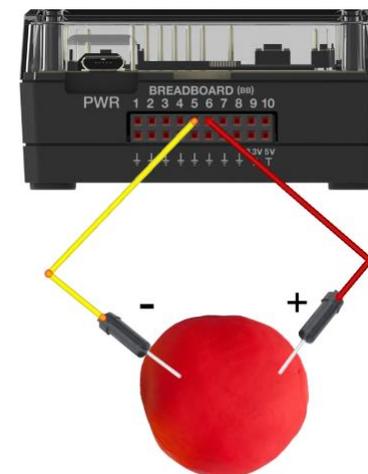
Challenge 1: Use the hub with an ANALOG.IN and a DIGITAL.OUT to make a conductivity tester. The tester should make a tone on the speaker when the material is conductive and no tone when an insulator. As an extension, see if your tester will work across several balls of Play-Doh that are touching together.

The Teacher Activity

Introduce the overall engineering goal of the project and how the model should represent some of the electrical aspects of the human heart. The project will be built stepwise with three student challenges. Discuss possible prototypes. Have students draw a picture of their prototype and describe how it will work. Share ideas with the class.

Guidance during challenge 1:

Play-Doh is a water suspension of a mixture of flour (carbohydrate polymers), table salt (NaCl) and cream of tartar (sodium salt of tartaric acid). The cream of tartar and table salt gives the mixture its plasticity. A secondary property of these salts is electrical conductivity. In water, table salt splits into sodium cations and chloride anions, a process is known as ionization. These mobile ions can transport an electrical charge between the pins of the jumper wires from the Hub. When the DIGITAL.OUT 1 is set to ON; electrons begin flowing out of the BB6 port and through the jumper wire and into the Play-Doh. Inside the Play-Doh the



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electrons are transported to the cathode of the LED via the charged mobile ions. As the electrons move through the LED, their electrical potential energy (voltage) is converted into red light. The electron then flows out of the anode and back into the Hub where it is reenergized and recycled. This flow of electrons via ions is very similar to how an action potential propagates through the Brachman's and His bundles and the Purkinje fibers of the heart's electrical system.

1. Review concepts from 10 Minutes of Code for the Innovator Hub including the For-EndFor loop.
2. A conductor is a material that freely passes electrical current when a voltage is applied to it. Metal is a good example of a conductor. An insulator is the opposite; the material does not pass an electrical current. Plastic is an example of an insulator.
3. When an ionic compound such as salt (NaCl) is dissolved in water, the mobile ions in the solution pass the electrical current freely.
4. The DIGITAL.OUT object will control the ports of the Hub to be either 3.3 Volts or 0. When set to ON the port will pass an electrical current out of the port.
5. The ANALOG.IN object will sink and measure electrical current that flows into the associated port on the Hub. When the object is read, it returns a value from 0 to 16384 (2^{14}). This reading can be used to measure the amount of current flowing out of the DIGITAL.OUT and into the ANALOG.IN.
6. To build a conductivity tester, use the DIGITAL.OUT to pass electricity into the test material. If it is a good conductor, much of the current will flow into the ANALOG.IN and the value read from that port will be

The Electrician-How the Heart Beats

```
Define c1()=
Prgm
Send "CONNECT ANALOG.IN 1 TO BB5"
Send "CONNECT DIGITAL.OUT 1 TO BB6"
Send "SET DIGITAL.OUT 1 TO ON"
key:=" "
a:=0
DispAt 8,"Press [esc] to Quit"
While key≠"esc"
  Send "READ ANALOG.IN 1"
  Get a
  DispAt 3,"a=",a
  If a>7000 Then
    Send "SET SOUND 500 TIME .5"
    DispAt 4,"Material is a Conductor"
  Else
    DispAt 4,"Material is an Insulator"
  EndIf
  key:=getKey()
  Wait 0.1
EndWhile
Send "SET DIGITAL.OUT 1 TO OFF"
EndPrgm
```

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large, e.g. $a > 7000$.

7. If the test material is an insulator, only a little current will flow between the two ports and the reading will be small.
8. Use an If-Then-Else-EndIf to decide if the material is a conductor or insulator.

Challenge 2: Build a model of the four-chambered heart's electrical system. Your model should be similar to the one used in The Plumber, but the wiring is different.

Be sure to insulate the upper from the lower heart using a piece of paper. The paper functions similarly to the non-conducting collagen fibers in the cardiac skeleton.

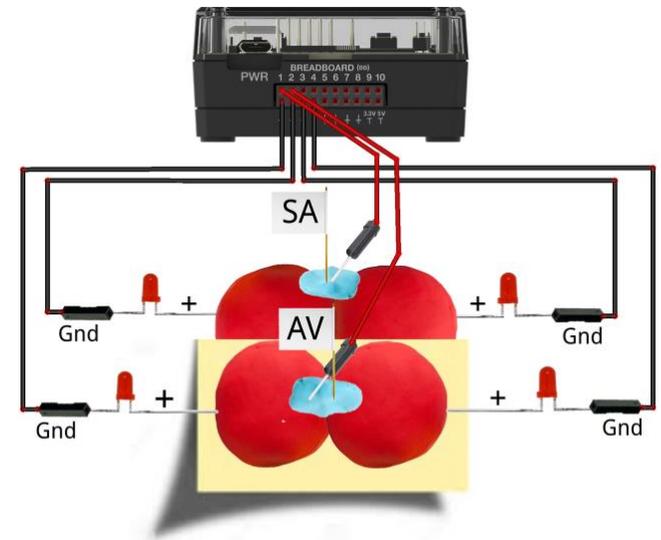
BB1 should deliver electrical signal to the SA node while BB2 will deliver signal to the AV node. Model each node with an alternate color of Play-Doh and an M/M jumper wire. Each node should bridge two chambers to model the function of Bachman's bundle and the His bundle.

Insert the LED (+) cathode into each Play-Doh chamber to illustrate the electrical activity in that chamber. The LED (-) anode is grounded. This circuit is opposite of The Plumber. Pay close

Guidance during challenge 2:

The SA and AV nodes are modeled by two additional pieces of differently colored Play-Doh. Each piece is electrically energized by a single wire connected to a BB port pin on the Hub. The charge from the Hub is then conducted through the heart by the conductive Play-Doh. The broad Play-Doh piece labeled SA node bridges the two atria, in addition to the SA node, it also models Bachmann's bundle. The broad piece labeled AV node bridges the two ventricles, in addition to the AV node, it also models the His bundle and Purkinje fibers. Conduction of the depolarization action potential from the SA node is blocked between the upper heart and the lower heart by a sheet of non-conducting collagen fibers in the cardiac skeleton. This insulating collagen sheet forces the action potential to conduct only through the AV node which crosses the collagen barrier and produces a timing delay of about 50 milliseconds (mS). The timing difference between the contraction of the atria and the ventricles is essential to the pumping action of the heart, without which, the upper and lower heart would work against each other and not result in a pumping action. The non-conducting collagen sheet is modeled by the non-conducting sheet of paper placed between the Play-Doh chambers. The timing difference in the model is created using a Wait command between setting the BB output pins on and off. Refer to the comments in the code on the right.

The Electrician-How the Heart Beats



```
Define c2 () =
Prgm
Send "CONNECT DIGITAL.OUT 1 TO BB1"
Send "CONNECT DIGITAL.OUT 2 TO BB2"
key:=" "
DispAt 8,"Press [esc] to Quit"
While key#"esc"
©Upper heart contraction.
Send "SET DIGITAL.OUT 1 TO ON"
©Time of P wave on EKG. Atria contract.
Wait 0.1
Send "SET DIGITAL.OUT 1 TO OFF"
©Time to conduct between SA to AV nodes
```

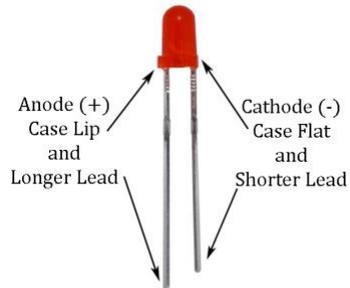
Challenge: Model the Human Four-Chamber Heart

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attention to this difference in polarity.

1. Ensure students can identify the polarity of an LED.

Write a program that blinks each node alternately. Comment your code with the different events represented in the PQRST wave.



2. The LED polarity in this activity is connected opposite of the “Plumber” activity.
3. Demonstrate to students how to bend the leads of an LED, so they insert. Repeated bending will break the lead.
4. Insert the cathode (-) lead into the receptacle of an M/F jumper wire.
5. The same wire’s pin should be inserted into any ground pin on the Hub.
6. The LED anode (+) lead should be inserted into the Play-Doh. Do not push the LED in so far that both leads touch the conductive material and cause a short circuit within the LED.
7. Repeat for all four chambers.
8. Place a piece of insulating paper between the atrial (upper) and ventricle (lower) halves of the heart. This has the effect of preventing the SA node from stimulating the ventricles and the AV node from stimulating the atria.
9. Use two small pieces of different colored Play-Doh to create these nodes.
10. Place the nodes on the heart with the SA touching both atria and the AV touching both ventricles.

The Electrician-How the Heart Beats

```
Wait 0.4
```

```
©The sum of the two waits above is the PR interval on an EKG
```

```
©Lower heart contraction
```

```
Send "SET DIGITAL.OUT 2 TO ON"
```

```
©Time of QRS complex and ST segment on EKG. Ventricles contract.
```

```
Wait 0.1
```

```
Send "SET DIGITAL.OUT 2 TO OFF"
```

```
©Time of T wave on EKG. Heart relaxes
```

```
Send "SET SOUND 500 TIME .1"
```

```
Wait 0.4
```

```
key:=getKey()
```

```
EndWhile
```

```
Send "SET DIGITAL.OUT 1 TO OFF"
```

```
Send "SET DIGITAL.OUT 2 TO OFF"
```

```
EndPrgm
```

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11. Label the two nodes with SA and AV accordingly.
12. Insert one pin of an M/M jumper cable into each node.
13. Insert one jumper wire pin from the SA node into BB1 and the other jumper wire pin from the AV node into BB2. The two separate circuits provide for independent control of the upper and lower portions of the heart.
14. When the DIGITAL.OUT 1 port is set to ON, the current is conducted via the Play-Doh to both atria LED's cathode. The circuit is completed by return the current to the Hub via the ground wire on each LED's anode.
15. When the DIGITAL.OUT 2 port is set to ON, the current is conducted in the same fashion to both of the ventricle LEDs.

The Electrician-How the Heart Beats

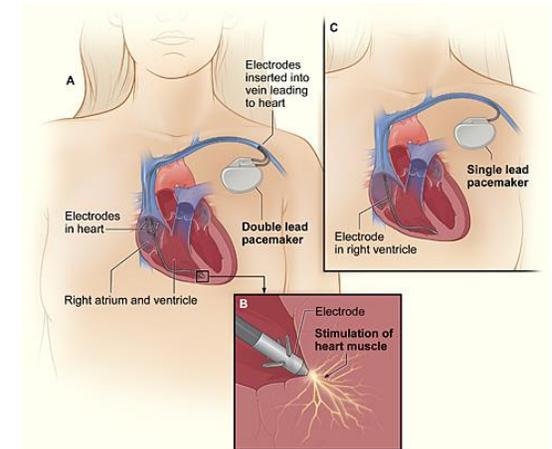
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Medical crosscutting principle of the project

In this activity, the Hub, wires, and code used are very similar to a cardiac pacemaker. When a patient has a disease of the SA and AV nodes an intervention the cardiologist may do is to destroy (ablate) the nodes and replace their functionality with a device called a pacemaker. This device has a microcontroller chip very similar to the one within the Hub, the TI-MSP432, and runs a program like the one students write in this activity! During the procedure, the surgeon places the device under the skin of the chest and inserts wire electrodes from the device into the heart muscle. Once installed, the device delivers an electrical charge similar to the function of healthy nodes. This charge stimulates the heart to beat in normal sinus rhythm. After the surgery, the cardiologist may change, or tune, certain parameters of the computer code that runs on the implanted device to adjust the speed and intensity of the electrical impulses that are delivered to the heart. This adjustment occurs via a “wand” that creates a wireless data connection between the implanted device and the physician’s computer, similar to how Bluetooth is used to connect a cell phone to a headset. The cardiologist modifies the program on a laptop and then uploads it to the pacemaker during the patient's office visit.

The Electrician-How the Heart Beats An Implanted Pacemaker



A computer used to adjust the computer code within the pacemaker



Images courtesy of Wikimedia Commons

Challenge: Model the Human Four-Chamber Heart

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Challenge 3: Build a model Automatic External Defibrillator to recover from a simulated heart attack.

For this challenge, modify the model built in challenge 2. Add two M/M jumper wires in BB5 and BB6 to model two AED paddles. You may choose to use aluminum foil on the ends of the jumper cable pins.

Use the concepts and code for detecting a voltage and material conductivity explored in challenge 1.

Use the concepts and code for a normal beating heart explored in challenge 2.

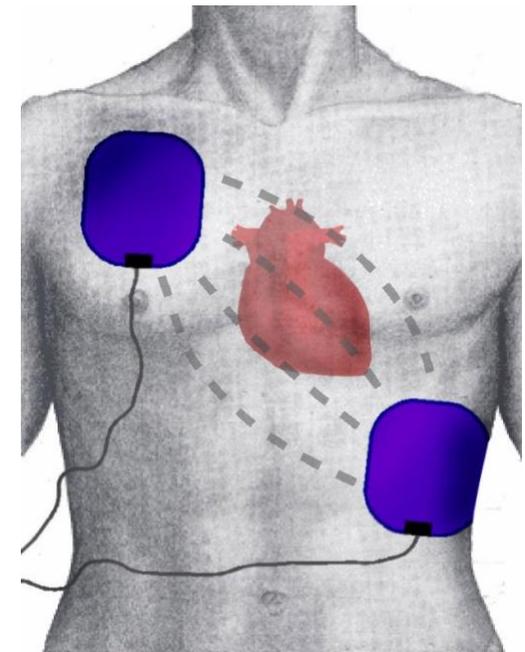
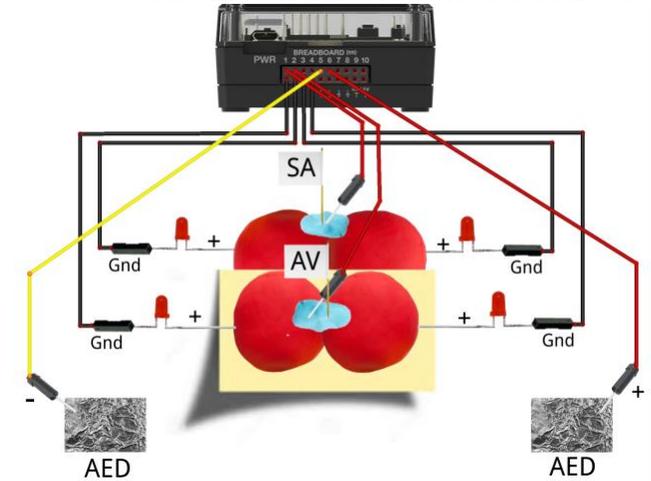
Your program should begin with several beats of the heart in sinus rhythm as done in challenge 2. Then, an attack is simulated by the absence of a heartbeat accompanied by a flatline tone. When the AED paddles are touched to the model and conductivity is detected, as in challenge 1, sinus rhythm resumes as in challenge 2.

Guidance during challenge 3:

Occasionally, some people suffer a life-threatening condition called ventricular fibrillation. This condition spontaneously arises in a person's heart when the electrical activity from the SA and AV nodes becomes electrically disorganized and the ventricles of the heart quiver erratically instead of regularly pulsing and pumping blood. When ventricular fibrillation occurs, it is necessary to "reboot" the heart's electrical system to avoid likely death. One method of reestablishing the heart's electrical rhythm is with an automatic external defibrillator (AED). An AED is a portable electronic device that senses the patient's heart activity and then smartly programs a series of electrical shocks that are delivered across the heart to reestablish the normal rhythm. The AED has electrically conductive pads that are placed on the patient's chest; it then analyzes the electrical activity of the heart and delivers the appropriate electrical shock across the heart.

1. Attach a small piece of aluminum foil to the lead of an M/M jumper wire.
2. A small piece of tape may be used to ensure good electrical contact between the wire pin and the foil.
3. Fold the foil over a few times to make a rigid paddle.
4. The paddle should be about one square inch.
5. Encourage students to try alternate materials for building their paddles.
6. Once paddles are constructed, plug one paddle into the BB6 of the breadboard connector and the other into BB5.
7. The READ ANALOG.IN command measures the voltage on pin 5 and returns a value between 0 and 16384 (2^{14}).

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This image courtesy of Wikimedia Commons

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When the two paddles are connected via the Play-Doh circuit, the ANALOG.IN pin “sees” the 3.3Volts from the DIGITAL.OUT pin and returns a value around 10,000. A program that monitors the ANALOG.IN value can “know” when the paddles are touching the heart.

8. Encourage students to reuse the code developed in challenges one and two.

The Electrician-How the Heart Beats

```
Define c3()=
Prgm
Send "CONNECT DIGITAL.OUT 1 TO BB1"
Send "CONNECT DIGITAL.OUT 2 TO BB2"
Send "CONNECT ANALOG.IN 1 TO BB5"
Send "CONNECT DIGITAL.OUT 3 TO BB6"
Send "SET DIGITAL.OUT 3 TO ON"
a:=0
DispAt 3,"Heart Beating Normally"
For n,1,10
  Send "SET DIGITAL.OUT 1 TO ON"
  Wait 0.1
  Send "SET DIGITAL.OUT 1 TO OFF"
  Wait 0.5
  Send "SET DIGITAL.OUT 2 TO ON"
  Wait 0.1
  Send "SET DIGITAL.OUT 2 TO OFF"
  Send "SET SOUND 500 TIME .1"
  Wait 0.5
EndFor
Send "SET DIGITAL.OUT 1 TO OFF"
Send "SET DIGITAL.OUT 2 TO OFF"
Send "SET SOUND 500 TIME 100"
DispAt 3,"Flatline! Use an AED!"
While a<7000
  Send "READ ANALOG.IN 1"
  Get a
  DispAt 2,a
  Wait 0.1
EndWhile
DispAt 3,"Heart Beating Normally"
```

Challenge: Model the Human Four-Chamber Heart

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The Electrician-How the Heart Beats

```
For n,1,10
  Send "SET DIGITAL.OUT 1 TO ON"
  Wait 0.1
  Send "SET DIGITAL.OUT 1 TO OFF"
  Wait 0.5
  Send "SET DIGITAL.OUT 2 TO ON"
  Wait 0.1
  Send "SET DIGITAL.OUT 2 TO OFF"
  Send "SET SOUND 500 TIME .1"
  Wait 0.5
EndFor
Send "SET DIGITAL.OUT 3 TO OFF"
EndPrgm
```