Teacher's Preparatory Guide

Lesson 2: Ultimate Transistor Design Challenge

Purpose: This activity is designed as a follow-up to lesson one's guided model transistor construction lab. This inquiry-based challenge encourages students to apply their background knowledge of transistors to creatively tackle a problem. Students will construct model transistors from various everyday objects and devise a way to connect their transistor models in series. Advanced challenges invite students to devise simple "OR" gates or "AND" gates. This lab uses critical thinking and scientific method skills, such as experimental design and implementation.

Level: Middle or high school; physical science & physics

Time required: (1) 50-minute class period

Materials for Model Construction Because of the inquiry-based nature of the lab, *each group of 4 students* may choose different materials to build their model. Encourage students to bring items from home that they would like to use, but also provide some other materials for those students that forget to bring their own. This is a creative endeavor; so many different materials can be used! Below is a starter list of materials that would work for each piece of the model (you can always add to the list).

Source	Drain (tube)	Drain (side hole cover)	Gate (stopper)	Gate (lever)
• plastic cup • styrofoam cup • paper rolled into a cone • water bottle	• paper towel tube • toilet paper tube • plastic cup • postage tube • paper rolled into a tube • paper plate rolled into a tube • water bottle	• balloon • plastic wrap • aluminum foil	• soda bottle cap • Gatorade bottle cap • play-dough • cardboard • rubber stopper	• bendy straw • popsicle stick • pipe cleaner • malleable wire • pencil

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Additional Materials for Model Construction

- Elmer's glue
- hot glue gun with glue sticks and paper plate
- clear tape
- masking tape
- scissors

Materials for Model Testing

- sprinkles
- large cardboard square (open pizza box)
- miscellaneous cardboard pieces (shoe boxes, soda can boxes, etc.)
- student worksheets and pencils/pens

Safety Information Scissors can be a cutting hazard. You may wish to supervise students depending on the maturity level of the students. The hot glue gun gets VERY hot. If you do not trust students to be responsible with this tool, have groups bring you their models and complete this step for them. Although the sprinkles are edible, discourage students from eating them so that they can be reused for multiple classes.

Advance Preparation

1. ASK STUDENTS TO BRING IN MATERIALS FOR MODEL CONSTRUCTION
   - This lab requires a number of everyday materials, so start to gather them *early*! Ask other teachers, friends, family, and students to start collecting toilet paper tubes, bottle caps, water bottles, pizza boxes, etc.
   - Have a place in your room to store items before the lab.

2. PLUG IN THE HOT GLUE GUNS
   Plug in the hot glue guns at the start of class to allow them time to warm up. Make sure the glue guns stay on the paper plates at all times to catch any glue drips.

Teacher Background Please refer to the teacher background section in *Lesson 1: Transistor Mania.*

Resources Background information and inspiration for this lab are from these pages of this website:

How Boolean Logic Works These links explain simple gates, such as AND and OR gates.
http://computer.howstuffworks.com/boolean.htm
http://computer.howstuffworks.com/boolean1.htm

Teaching Strategies This lab works best in groups of 4 students each. Depending on the level of your students, choose which Student Worksheet you feel they can do—either the Independent Inquiry worksheet or the Guided Inquiry worksheet. An *Instructional Procedure* is provided on the next page.

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Instructional Procedure: Lesson 2, Inquiry-based Lab

Time	Instruction	Reasoning
5 min	Warm-up: Have students write or draw 3 facts/ideas concerning transistors that they remember from the previous lesson. Ask each student to share orally one idea with a partner at their table.	Students review concepts so they can consider what information from the previous lesson may help them in this lesson.
5 min	Guide a discussion based on this question: “What parts of the transistor model can be changed to produce different effects in flow rate?” List ideas on the board.	This brainstorm will help students gather ideas about what parameters to keep in mind in order to build working transistors and circuits.
5 min	Show students all the materials that are available for model construction. *Before* allowing them to bring items to their table, have each group of 4 students plan a “recipe” detailing the specific materials they want and how they plan to use them in the model. Remind them that the final challenge is to link several transistors together.	Students have a structured planning time so that they *must* have an organized idea before irreversibly gluing materials. This is a great way to develop critical thinking skills. Electrical engineering uses the term *recipe* to describe this planning process. Encourage students to use the scientific terminology!
25 min	*After* the group has shown their plan (written or drawn with explanations) to the teacher, allow them to gather materials and begin construction. When groups have working transistor models, ask the class: “How can you make one transistor turn on another transistor?” Write ideas on the board. Offer groups a large cardboard “circuit board” piece if they would like to incorporate it into their final design.	A lot of the inquiry and critical thinking occurs at this point in the lab. Students may struggle with their designs. Allow students time to work it out before intervening. Linking the transistor models together so that one turns on the next (and so on) may be difficult for students to visualize. If the whole class brainstorms together, they will have a better chance of arriving at a solution. The teacher also has the opportunity to guide them if they need an extra hint or two.
10 min	Have each group share their final design with the whole class, including a demonstration of their model. *After* all the presentations, ask students to think of patterns they noticed amongst all the designs OR think of ways a group solved the same problem with a different design OR used the same material in a different way (see *Draw Conclusions* section of Student Worksheet).	This closure allows students to develop scientific communication skills through sharing their experiences. By comparing and contrasting the different designs, the students also develop their critical thinking skills.

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Guided Dialog After the warm-up activity (see *Instructional Procedure* section), but before beginning the lab, conduct a whole class discussion based on the following question:

"What parts of the transistor model can be changed to produce different effects in flow rate?"
Example answers:

- *the size of the opening in the source*
- *the size of the drain tube*
- *the length of the gate lever*
- *the size of the gate cork*

This brainstorming session will help students gather ideas about the parameters that can be changed to yield different outputs. This in turn will allow them to design a thoughtful "recipe" before building their model, versus just gluing materials together without a plan.

List any last minute details that the students must remember, including reiterating all safety precautions. Now, begin the lab.

Cleanup The students can dismantle their transistors, or take them home. You may want to keep a few examples. Students most likely had some sprinkle spills, so have a broom and dust pan ready. Any leftover materials can be collected and stored for use with another class.

National Science Education Standards (Grades 5–8)
Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

National Science Education Standards (Grades 9–12)
Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

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Name:________________________________Date:_______________Class:________________

Student Worksheet

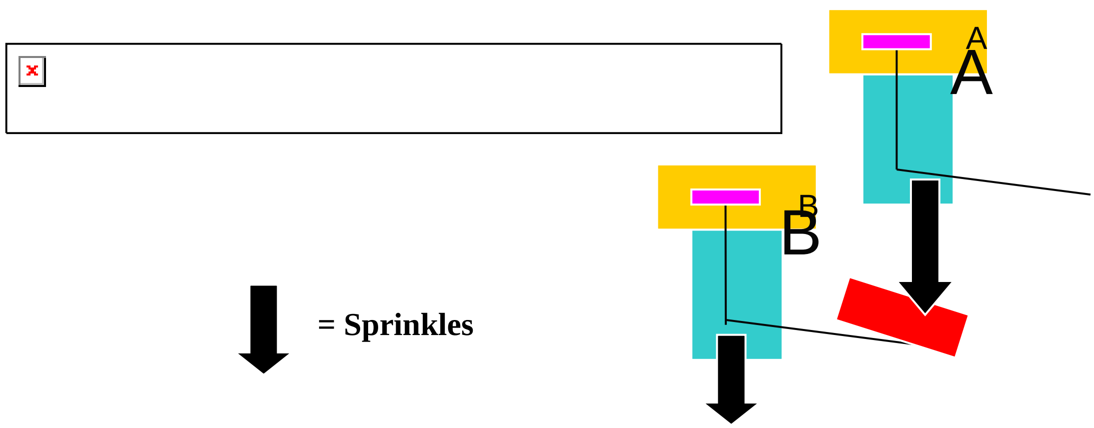
Ultimate Transistor Challenge: Independent Inquiry

Safety
Hot glue guns can burn. Scissors can cut. Use them with care.

Challenge #1

Build two model transistors and connect them so that the first one activates (or switches on) the second one.

Example design…



Challenge #2

Build three model transistors and connect them so that either one OR the other can activate (or switch on) the third one. (This is called an "OR" gate.)

Challenge #3

Build three model transistors and connect them so that the first two must combine at the same time to activate (or switch on) the third one. (This is called an "AND" gate.)

Challenge #4

Build three model transistors and connect them so that the one transistor activates (or switches on) the other two. You must use the same amount of "electrons" as in the previous challenges. (This is called a "NAND" gate.)

Challenge #5

Build three model transistors and connect them so that the one transistor activates (or switches on) the other two EQUALLY. You must HAVE the same amount of "electrons" in the "drain" in the 2 transistors that are switched on. (This is called a "NAND" gate.)

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Draw Conclusions

1. Which challenge was the most difficult and why? *Example answer: Challenge number 5 because you not only had to make the models work, but you had to make sure that the amount of electrons in each of the models remained equal. In other words, you had to keep several issues in mind during the design and construction processes.*

2. Did your model design change after you attempted each challenge? Why did this happen? *Example answer: In our first design, we only needed to have one model turn on one other. For the next challenges, we had to turn on multiple models with the same amount of electrons. We had to change our original model to supply more force with its electrons because energy was lost farther down the line due to friction. We made our drains smaller so less energy was lost.*

Going Further

Design a circuit that can complete simple calculations. *Answers will vary. Encourage diagrams!*

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Name:________________________________Date:_______________Class:________________

Student Worksheet

Ultimate Transistor Challenge: Guided Inquiry

Safety
Hot glue guns can burn. Scissors can cut. Use them with care.

Introduction

The secret is out! Because of the high demand for electronics, the Earth's supply of transistor materials, titanium and chromium, has run out! The world's richest computer companies are offering huge rewards to the team of scientists that can build a working circuit of transistors out of everyday objects. Do you have what it takes to turn a pile of household clutter into a mechanical marvel?

Warm-up! Write down ideas from the class discussion…

1. Write or draw 3 ideas about transistors.

   a. *Example answer: The electrons can only flow from the source to the drain if the gate is triggered.*

   b. *Example answer: Smaller transistors make for faster signals.*

   c. *Example answer: You can change the rate of the electron flow through the transistor by changing the power applied to the gate.*

2. What can be changed in a transistor model to produce different effects in flow rate?

   a. *the size of the opening in the source*
   b. *the size of the drain tube*
   c. *the length of the gate lever*
   d. *The size of the gate cork*

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Materials

- plastic cup
- styrofoam cup
- paper
- water bottle
- paper towel tube
- toilet paper tube
- poster tube
- paper plate
- balloon
- plastic wrap
- aluminum foil
- soda bottle cap
- Gatorade bottle cap
- play-dough
- Elmer's glue
- hot glue gun with glue
- clear tape
- masking tape
- scissors
- sprinkles
- large cardboard square
- student worksheet
- cardboard
- rubber stopper
- bendy straw
- popsicle sticks
- pipe cleaner
- wire

Challenge: Can your group build model transistors that trigger each other in a circuit?

Make a Recipe With your team of scientists, devise a plan of action! In the box on the left, circle the materials you intend to use. Then, in the space below, explain how you will use them. Draw a diagram of your model in the space below and label its parts before you begin to build.

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Transistor Recipe

Material	Explanation	Schematic
Example answer: toilet paper tube	*Example answer: This will be our drain. We can cut a hole in the side for the base to fit through.*	
Materials will vary for each group.	*Explanations will vary for each group.*	

National Nanotechnology Infrastructure Network *www.nnin.org*

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Record Your Observations

1. What is going on? During the construction process, record 3 intriguing observations:

   a. *Example answer: We made the hole in the source the same size as the bottle cap "stopper" of our base, but the electrons would leak. We put play-dough around the hole to prevent the electrons from leaking.*

   b. *Example answer: When we push the base lever lower into the drain tube, the electrons flow from source to drain at a smaller angle! It takes less power to turn on the transistor.*

   c. *Example answer: If too many electrons are in the source cup, then our transistor does not work.*

2. Sketch your device. Label the *source, drain, gate*, and any other parts that allow your model transistor to function.

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Analyze the Results

What types of design problems did your group run into? Explain how you fixed these issues.

1. Problem: *We put a cup on the end of the base lever of transistor "a" so transistor "b" could trigger "a," but it kept dumping out the electrons.*

Solution: *To stabilize the cup, we cut a small square of cardboard and taped it to the underside of the cup and to the base lever of transistor "a." It worked!*

2. Problem: *Answers will vary.*

Solution: *Answers will vary.*

Draw Conclusions

After all teams have presented their transistors, answer the following questions:

1. Name one aspect of the transistor design that was similar for all the teams. Why might this be so? *Example answer: All the teams used toilet paper or paper towel tubes as the drain. This might be because they were made of cardboard, so were sturdy, but you could easily cut through it to make a hole for the base lever.*

2. Name one aspect of the transistor that another team designed differently than your team. Which design worked better, and why? *Example answer: One team used a piece of paper rolled into a cone as their source. This design worked better than our cup with a cut-out hole because their base bottle cap fit more snuggly into the cone and made a better seal*

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so no electrons could leak out.

3. Name one material you used that another team used differently. How else could this material have been used in the transistor model? *Example answer: We used a styrofoam cup as our source, but another team used the styrofoam cup with the bottom cut off as their drain. If we cut the bottom of the cup off, we could have used that part as the stopper of our base.*

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Enhancing understanding Cover this section *after* the activity.
In this activity we used many different kinds of materials. Can engineers really use any type of substance to build a transistor? Why or why not? *Example answer: No, they cannot use any type of material because real electrons can only easily move through conductive or semi-conductive material. For this reason, electrical engineers build transistors out of metals, like titanium, and semi-conductors, like doped silicon.*

Going Further Students who have a good grasp of the content of the lab can be further challenged with this question:
What kinds of problems do engineers need to think about when designing circuits using transistors? *Example answer: In our experiment, the transistors had to be very close together in order to trigger the next transistor in the circuit. This means that engineers also have to think about the length between each of their transistors when designing circuits.*

Assessment

Formative Assessment Opportunities

1. The guided discussion at the beginning of the lesson prompts students to write down facts about transistors learned in the previous lesson. The teacher monitors student responses to look for concepts students are struggling with, which then allows the teacher to review the specific content that students need help understanding.
2. During the construction of the models, the teacher can monitor student progress and the problems that they encounter. This information can help the teacher formulate questions for the closing discussion that will guide students to think critically about their experience.

Summative Assessment Opportunities

The students will each turn in their completed worksheets at the end of the lab. This provides the teacher with several opportunities for assessing what the students were able to gain from the lab. Points can be given for the following categories:

1. The students' abilities to perform scientific skills, such as developing procedures (recipes), making observations, and problem solving during the construction process.
2. The students' overall understanding of the model transistor and how it relates to the real thing can be assessed by analyzing their responses to the questions in the *Draw Conclusions*, *Enhancing Understanding*, and *Going Further* sections. These sections require the students to compare designs from different groups, analyze these differences, and apply what they learned to a new situation.

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