ELECTRON TRANSPORT CHAIN RELAY RACE (table top race)

Helpful suggestion: Before you begin preparing, watch the video demonstration of this activity. It can be accessed via the YouTube channel for this curriculum (YouTube.com/TheBasementWorkshop, "Cells" playlist, chapter 3 videos).

You will need:

- colored card stock (8 sheets per relay set-up)
- the patterns on the following pages
- clear tape and/or glue stick
- scissors
- some small tokens to represent electrons, protons and oxygens (I used red and white dried beans for the electrons and protons, and walnuts for the oxygens, but you can use whatever you have on hand. Just make sure they are small, like dried beans.) For each relay set-up you will need a minimum of 4 tokens for electrons, 12 for protons and 2 for oxygens.
- plastic or paper cups (two per relay set-up)
- a cardboard tube that has a diameter smaller than the bottom of the cups (one tube per set-up)
- something to represent ATPs (large and small marshmallows on a toothpick, paper circles taped to a toothpick or whatever works well in your situation—even Legos®) You will need 4 ATPs per set-up.
- black marker

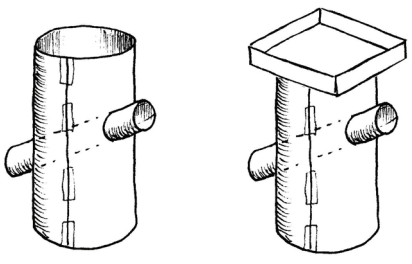
How to prepare:

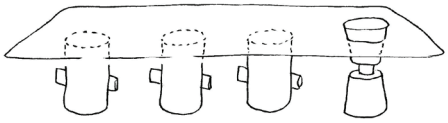
1) Print or copy the pattern pages onto the colored card stock. (If you did not purchase the CD version of this curriculum and you would like a digital (PDF) version of the patterns so you can print right from your computer, there is a free download of these patterns available online. Go to ellenjmchenry.com and click on "Curricula" then on "Cells." The downloads are at the bottom of this page.) Feed the colored card stock into either your computer printer tray or the manual tray of the copier you are using. For each relay set-up, print three copies of the first two pages (the one with the holes and the one with the two trays) and one copy of the other two pages.

2) Cut out the holes on the pages with holes, and then roll the paper into a tube. Secure with tape.

3) Cut apart the rectangles (each one being exactly one fourth of a sheet of 8.5x11 paper) and roll each lengthwise so form a small tube. You don't need to tape these smaller tubes—you can just insert them into the large cylinders and then let the small tubes expand to fill the hole, thus holding them in place (see illustration below).

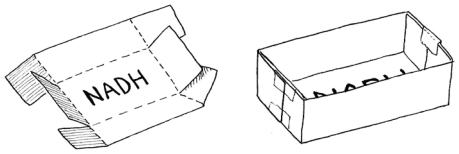
4) Cut and assemble the large, shallow trays, cutting on the solid lines and folding on the dotted lines. Tape the corners so you have a square tray. Then tape a tray to the top of each large cylinder.





NOTE: An arrangement like this would be a more realistic representation because it would show that the pumps and the synthase machine are all connected to the same membrane, but this configuration would be more difficult to make as well as more difficult to play. Make sure the students understand that the pumps don't really have individual trays on top.

5) Cut and assemble the deeper rectangular trays, cutting on the solid lines and folding on the dotted lines. Bend the ends in to make a square corner and secure with tape. Mark one "NADH." The other two will be the shuttles between the ion pumps. The first shuttle can hold two electrons, the second only one. You may want to label the bottom of the tray to this effect so the students won't have to remember this. They'll just look at the bottom of the tray, read the number, and know how many electrons can be shuttled. If you want to put the names of the shuttles on the trays, the first shuttle (between pumps 1 and 2) is called "Ubiquinone" *(you-BICK-wih-noan)* and the second (between pumps 2 and 3) is "Cytochrome C."

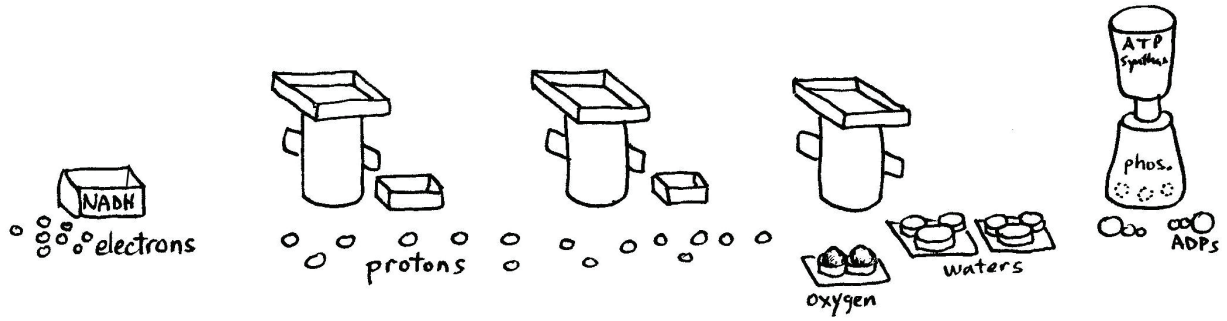


6) Cut out the squares with the H_2O molecules on them. For each H_2O, cut out two short strips and one long strip and roll them so the ends overlap until the strips are the same circumference as the printed circles. Secure with tape. Then secure the circles to the "platform" by taping the tabs down. (Refer to the assembly picture on the pattern page.) Assemble the O_2 molecule the same way, using two long strips. If you are going to play the shorter format of the race (see "How to play" instructions) you won't need the O_2 molecule, and you'll only need one H_2O.

7) Now you need to make the ATP synthase "machine." Cut holes in the bottoms of the cups, the same size as the diameter of your tube. If you are making a tube out of card stock you can just cut the holes whatever size you want, roll the card stock, stick it into the holes, then let it expand (just like you did for the small tubes in the sides of the cylinders). If your synthase machine is wobbly, add some tape to make it more sturdy. You may want to label the machine, either on the cup or by adding a paper label sticking up out of the top cup. You might also want to add: 3 protons → 1 ATP so they don't forget how many proton tokens to put into the machine to get an ATP.

8) Prepare your ADPs and phosphates. Use whatever materials you think will work well in your situation. You may have some craft parts or food items on hand that work well. They don't even have to be round—you could use Lego® bricks. Just make sure you have three small items and one large one for each ATP. Assemble ADPs (one large and two smalls) and leave the third phosphates unattached. The phosphates will be hidden in the bottom of the synthase machine.

9) If you want to do more labeling, the names of the ion pumps (in order) are: "NADH Dehydrogenase," "Cytochrome b-c_1" and "Cytochrome Oxidase."



How to set up the relay:

You can have any amount of space between the objects. Even though the race was designed to be a table-top race, you don't necessarily have to use a small space. If you have a large playing area and want to make the players run, you could set these quite a distance apart.

You can put out a whole bunch of tokens, enough so that every player can take their turn without having to worry about resetting the relay at the end of each turn, or you can have the last step of each turn be to reset the relay for the next player. (The shuttles, the O_2 and the H_2O molecules will have to be re-set anyway.) If you are doing timed individual runs, you'll have plenty of time to reset. If you have multiple players going through, one after another, you'll have to make them do a quick reset.

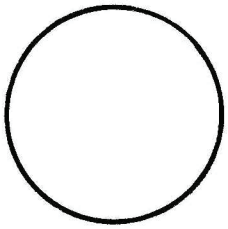
How to play:

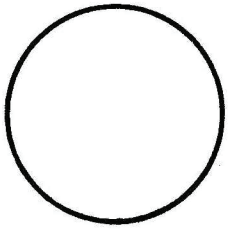
(Reminder: Don't forget about the video clip that demonstrates the relay, on the YouTube channel.)

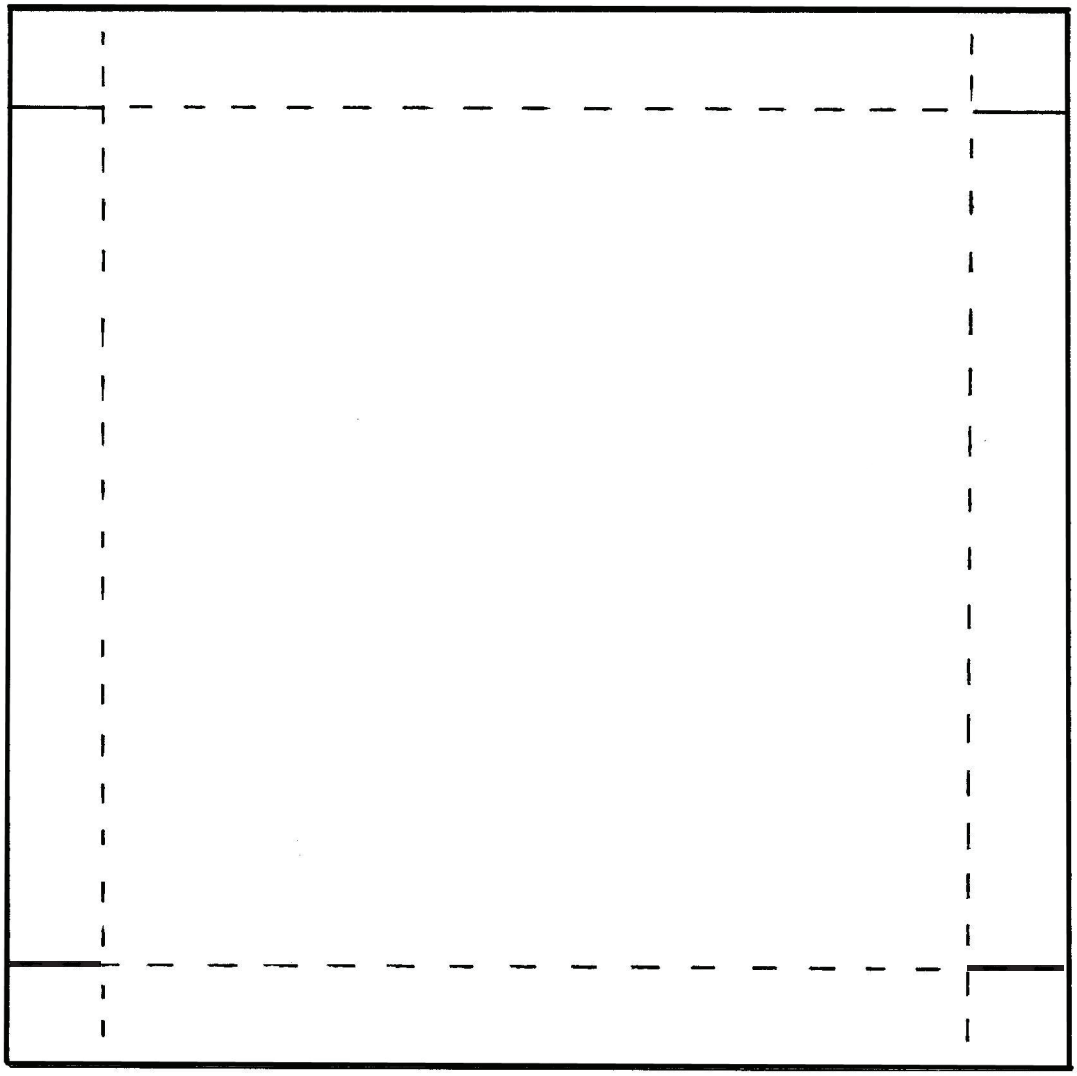
1) The first player comes to the NADH "shuttle bus" and puts two electrons into it. He then slides the NADH box across the table until it reaches the first ion pump.

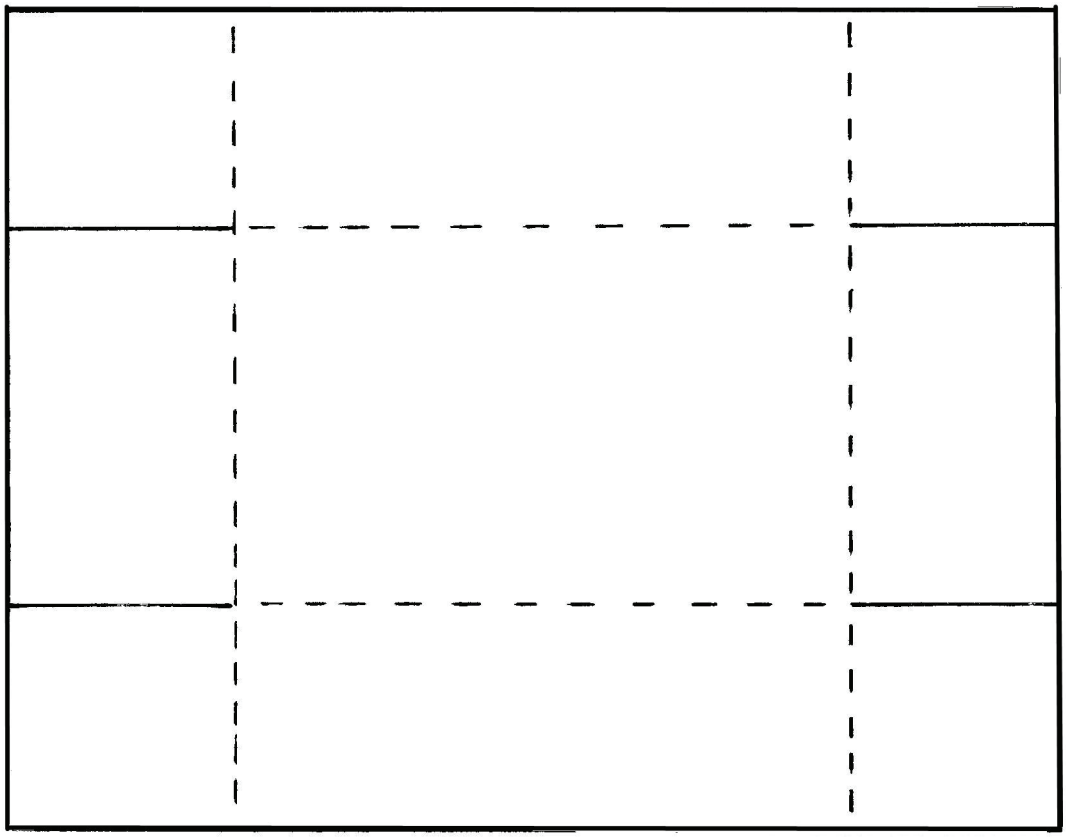
2) The player then puts the electrons into the top of the small tube in the first pump. The electrons will slide through and come out the other side. (The player can position the next shuttle so that it catches the electrons as they come out of the tube.) After they come out the other side and drop into the waiting shuttle, the player moves two protons from the table up to the tray on top of that pump.

3) The player then moves the shuttle box to the second pump. This time he must put the electrons through one at a time because the shuttle waiting on the other side can only carry one electron.

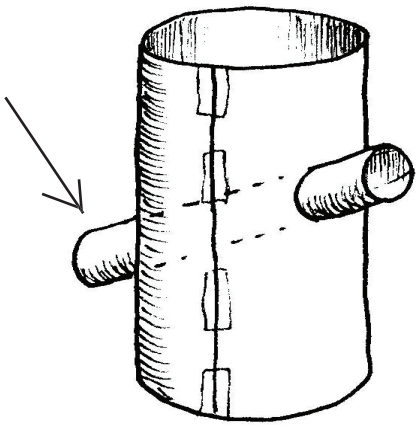


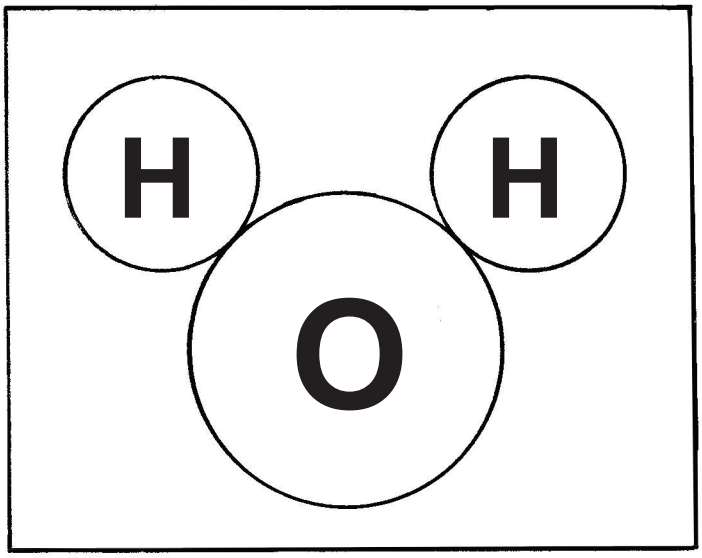






Use these three rectangles for the smaller tubes that insert into the larger tubes. (Roll them lengthwise.)

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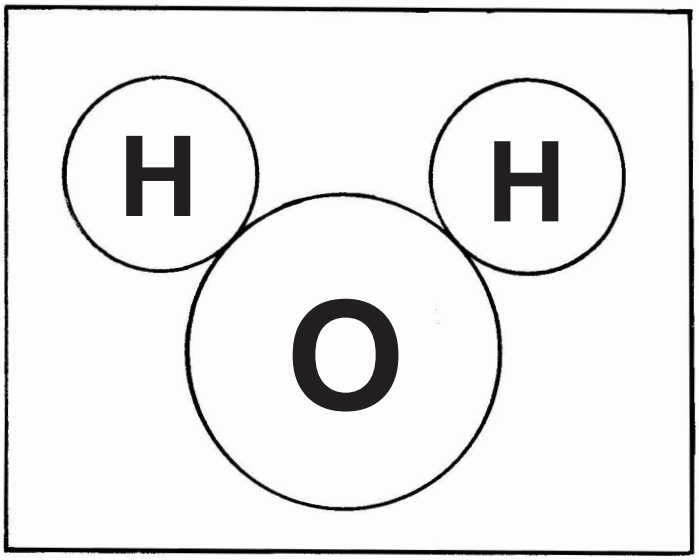
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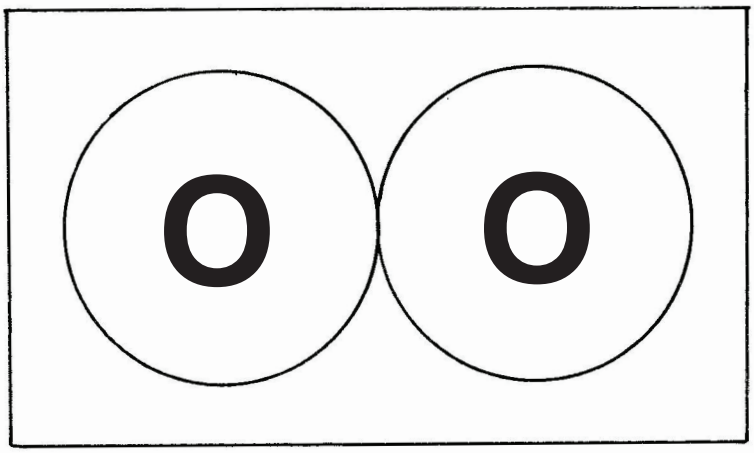
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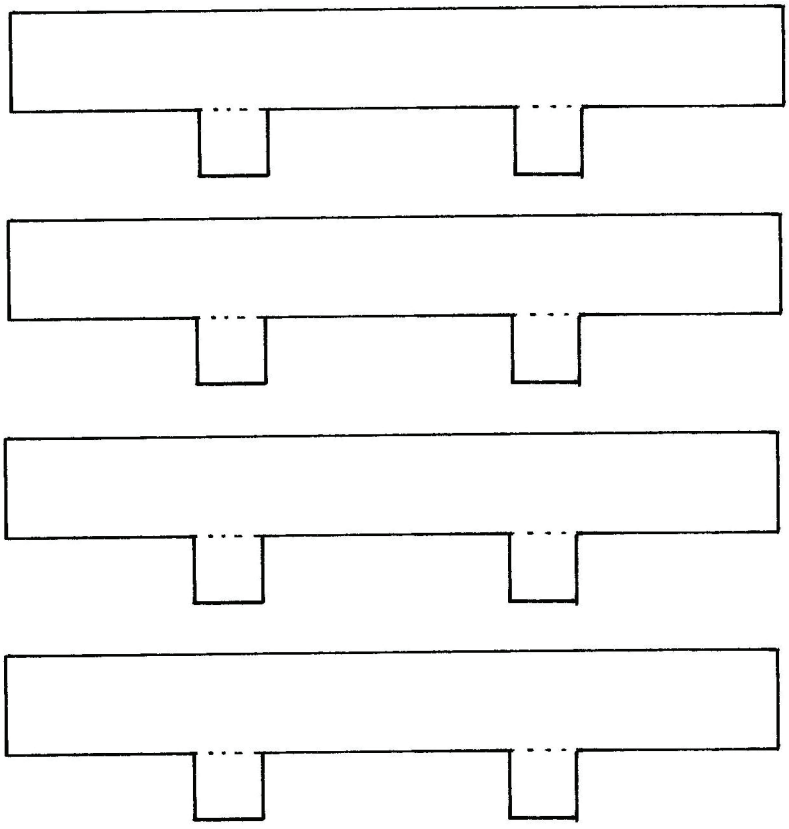

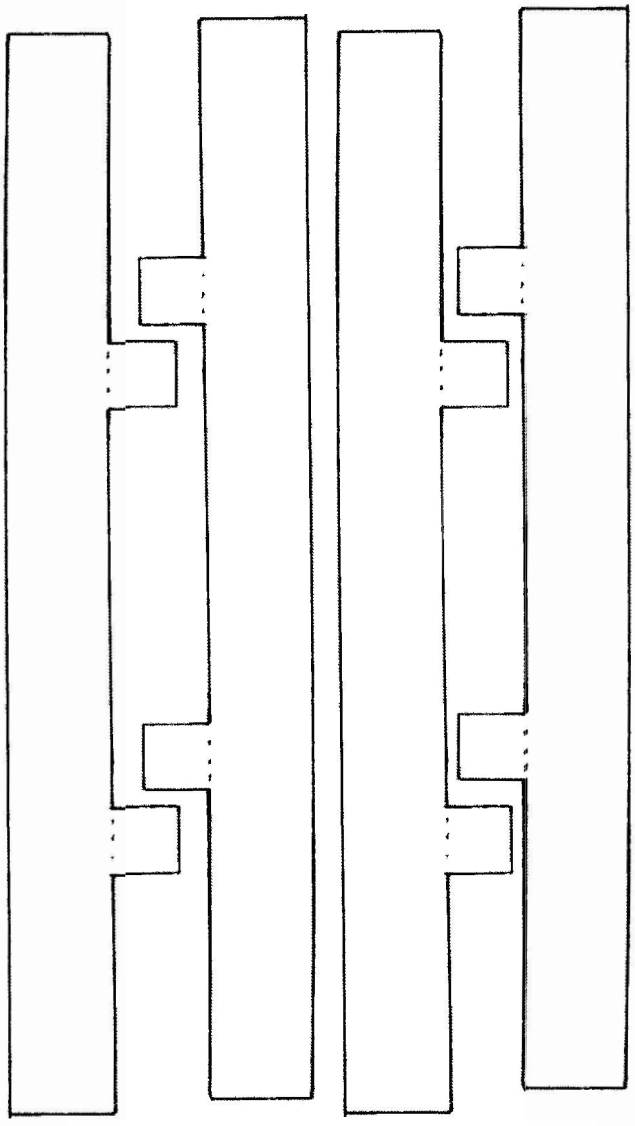

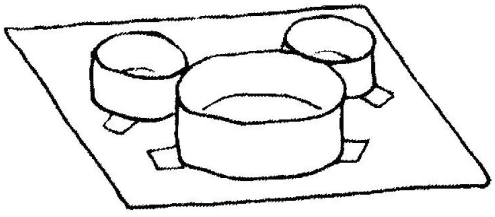

He puts one electron through and moves one proton up. Then he must empty the second shuttle. So he pushes it over to the third pump, puts the electron through, and puts it into one of the "H" circles on a water molecule. Then he can go back and repeat this for the second electron. (Put it through the second pump, shuttle it over to the third pump, put it through the third pump then drop it into an "H" circle.)

4) Now the cycle starts again. The player goes back to the beginning and puts another two electrons into the NADH shuttle. The whole process in repeated until you end up with four "expended" electrons, one in each of the "H" circles.

5) Now the player must complete the water molecules by picking up four protons from the table and putting a proton with each electron. Then the oxygen molecule is "split" and one oxygen token is put into each "O" circle on the waters. Now the waters are complete and the trays can be pushed out and away, perhaps to the edge of the table.

6) The last step is to put protons down through the ATP synthase machine. There should be a total of 12 potons available, four on top of each ion pump. Drop three protons into the top cup of the synthase machine (down through the tube, if your tube is hollow), then tilt the machine and remove a phosphate from underneath it. Put this phosphate onto an ADP to make an ATP. Repeat this process until you have made 4 ATPs.

7) Now the turn is over. If you have limited tokens, the player will have to put all the protons back onto the table, the electrons back at the start, and the shuttles back at their starting points. If you have limited ATPs, perhaps the adult helping with the race can dissemble them while the players is replacing all the electrons and protons.

SHORTER VERSION:

To play a shorter version of the relay, you can make just one water molecule instead of two. Making two water molecules is more accurate because when you split an O_2 molecule, the O's have to go somewhere. But for the sake of time and attention span, it may work better in your situation to run through the cycle just once and make just one water molecule and 2 ATPs.