Smithsonian
Marine Station Fort Pierce

BUILD AN UNDERWATER ROV AT HOME

Learn how to build, wire, and set up a submersible robot from home.

ROV = REMOTELY OPERATED VEHICLE

Please make sure to get a parent's or guardian's help, and always use proper safety gear!

Follow along with us!

This packet is designed to accompany our full-length instructional video that you can watch on YouTube.

Follow us @SmithsonianSMS for lots of other fun and educational content!

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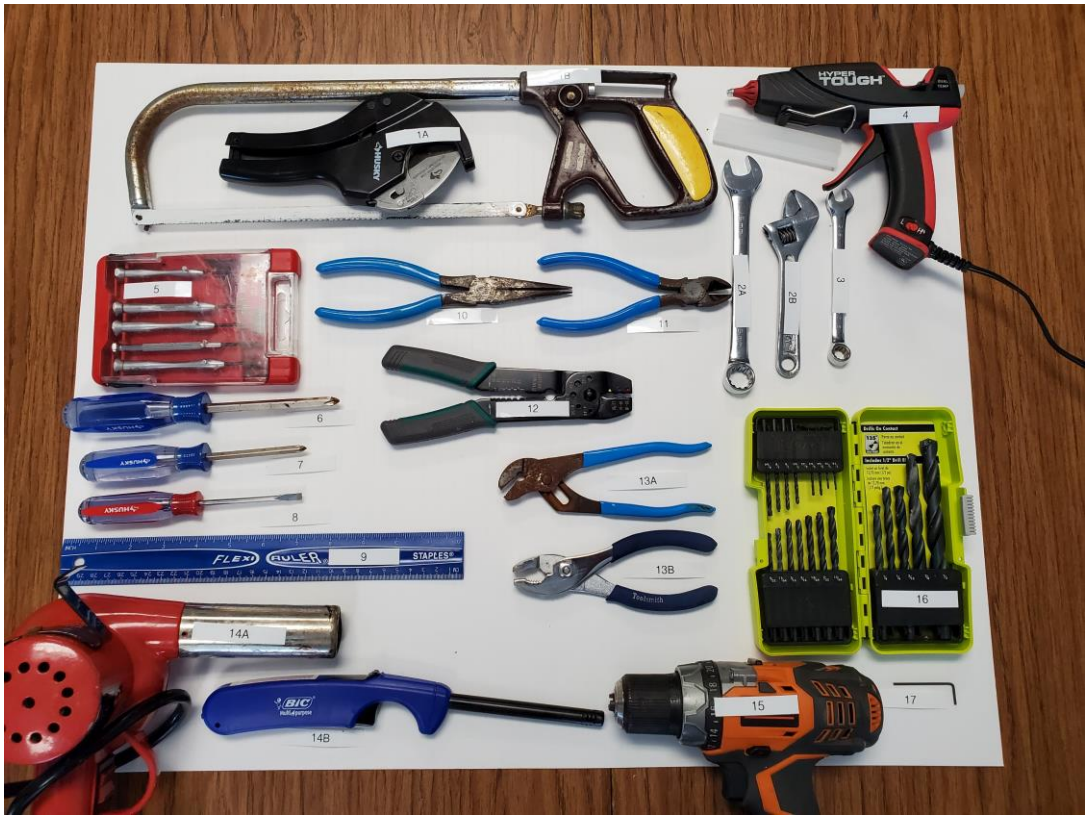
Tools you will need:



Please always ask for a parent or guardian's help when handling power tools or sharp tools.

- 1A PVC cutter, or
- 1B saw
- 2A 15 mm combination wrench, or
- 2B 6-inch adjustable wrench
- 3 3/8-inch combination wrench
- 4 hot melt glue gun
- 5 micro-screwdriver set, slot and Phillips
- 6 #2 Phillips head screwdriver
- 7 #1 Phillips head screwdriver
- 8 3/16-inch slot head screwdriver
- 9 SAE/metric ruler
- 10 long nose pliers
- 11 diagonal cutters
- 12 wire strippers
- 13A groove joint pliers, or
- 13B slip joint pliers
- 14A heat gun, or
- 14B grill lighter
- 15 power drill
- 16 drill bits (1/16, 1/4, 5/16, 3/8, 1/2 inch)
- 17 1/16-inch hex key ("Allen wrench")
- 18 (not pictured) rubber mallet
- 19 (not pictured) safety glasses

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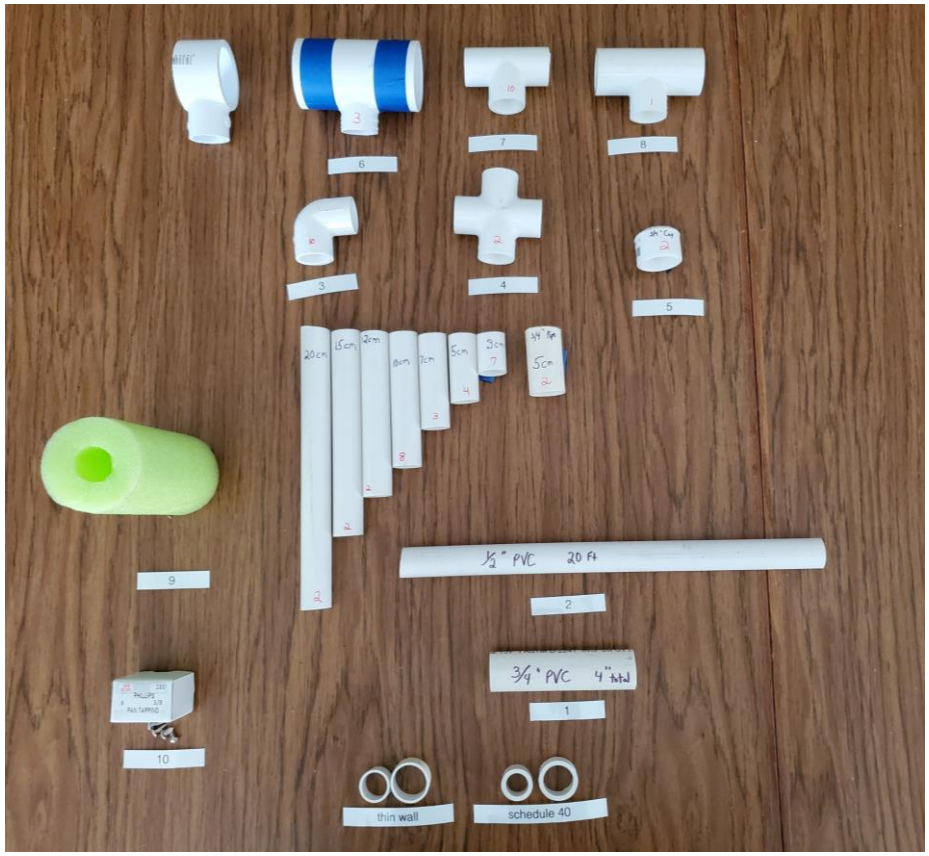
To build the frame:



Please always ask for a parent or guardian's help when cutting the PVC and make sure to wear safety goggles!

Note: Most hardware stores carry Schedule 40 PVC pipe. However, some carry a thinner walled PVC pipe, usually referred to as "thin wall." If possible, get the thinner wall PVC pipe for this project. It will make the ROV weigh less and may allow easier maneuvering. However, Schedule 40 will also make a satisfactory ROV. The fittings generally come in only one thickness. Lowes, Home Depot, or your local hardware store will carry these PVC pipes and fittings.

List of materials to build the ROV frame:

1. **4 inches** of ¾" PVC pipe (preferable "thin wall")
   (you may have to buy a 10-foot length)
   You will need to cut 2 pieces, 5cm long.
2. **20 feet** of 1/2" PVC pipe (preferably "thin wall")
   You will need to cut 2 pieces 20cm long, 2 pieces 15cm long, 2 pieces 12cm long, 8 pieces 10cm long, 3 pieces 7cm long, 4 pieces 4cm long, and 7 pieces 3cm long.
3. **10 each-** 1/2-inch 90-degree elbows, socket by socket (smooth inside the ends for sliding-in pipe, NOT THREADED).
4. **2 each-** 1/2-inch crosses, all ends socket
5. **2 each-** 3/4-inch caps, socket
6. **3 each-** 1 1/4 inch by 1/2-inch tee, socket by socket (This means that the two ends 180 degrees apart that will accept 1 1/4-inch PVC pipe, and the middle of the tee will accept a 1/2-inch pipe. In the picture you can see that this fitting will eventually get cut to form the piece to the left)
7. **1 each-** 3/4-inch x 1/2-inch tee, socket by socket. (This means that the 2 ends 180 degrees apart that will accept 3/4-inch PVC pipe, and the middle of the tee will accept a 1/2-inch pipe.
8. **1 each-** 3/4-inch x 1/2-inch tee, socket by socket. (This means that there are 2 ends 180 degrees apart that will accept 3/4-inch PVC pipe, and the middle of the tee will accept a 1/2-inch pipe)
9. **1 each** - pool noodle, about 2 1/4-inch diameter
10. **1 box of 50-** #6 by 3/8-inch stainless steel pan head tapping screws

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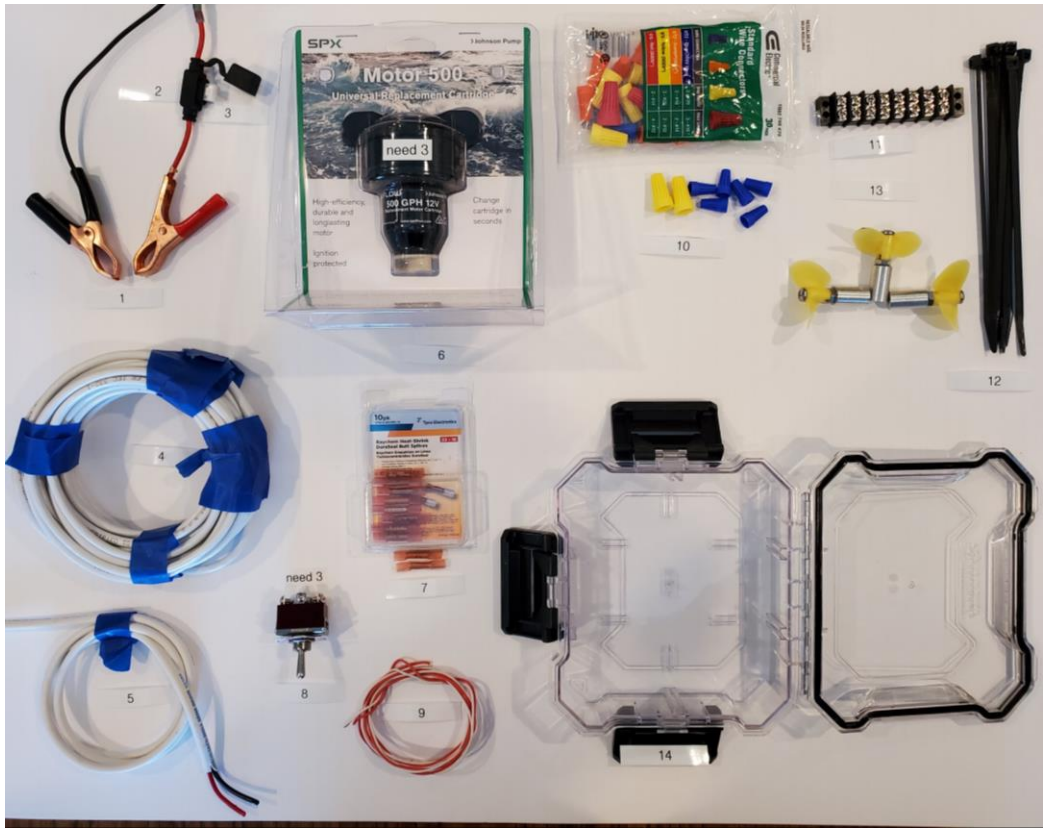
To wire the electrical:



Please always ask for a parent or guardian's help when working with electrical circuits. ALWAYS make sure power is off and that you are wearing shoes!

List of materials to wire the electrical for the control box and motors:

1. Battery clamps
2. Fuse holder
3. 15-amp fuse
4. 25 feet of 18-gauge, 6 conductor, stranded tether wire
5. 12 feet of 16-gauge, 2 conductor, duplex wire
6. 3 each, Johnson Pump 500 GPH bilge pump cartridges
7. 10 pack butt splices 22-18 heat shrink
8. 3 each, DPDT momentary-off-momentary switch, screw terminal
9. 3 feet twisted bell wire 20 gauge
10. 30 pack of standard wire connectors ("wire nuts"), need 6 blue and 2 yellow
11. Terminal strip, 22-10-gauge, 8 position
12. Cable ties, 1/4-inch x 8 inch long
13. 3 pack of propellers and shaft adapters
14. 6-inch X 6-inch compartment box

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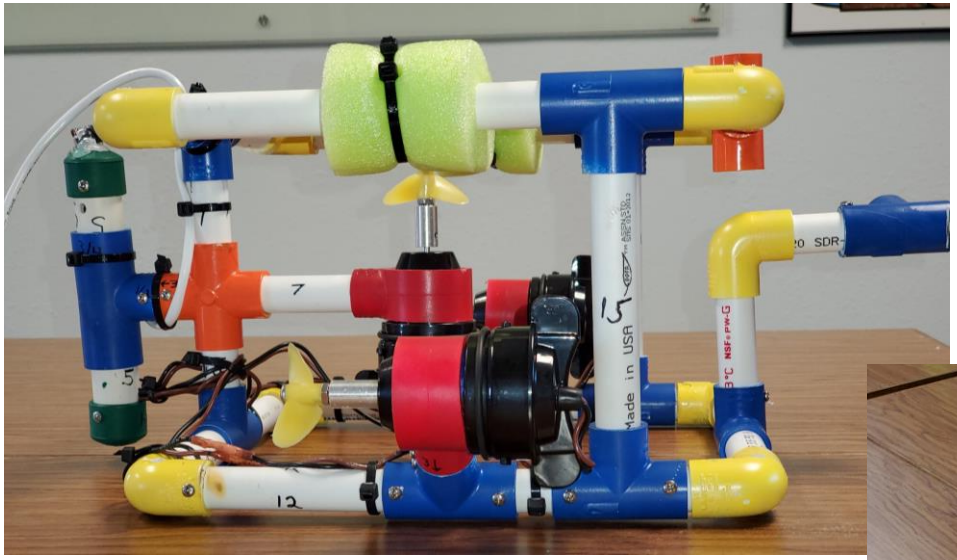
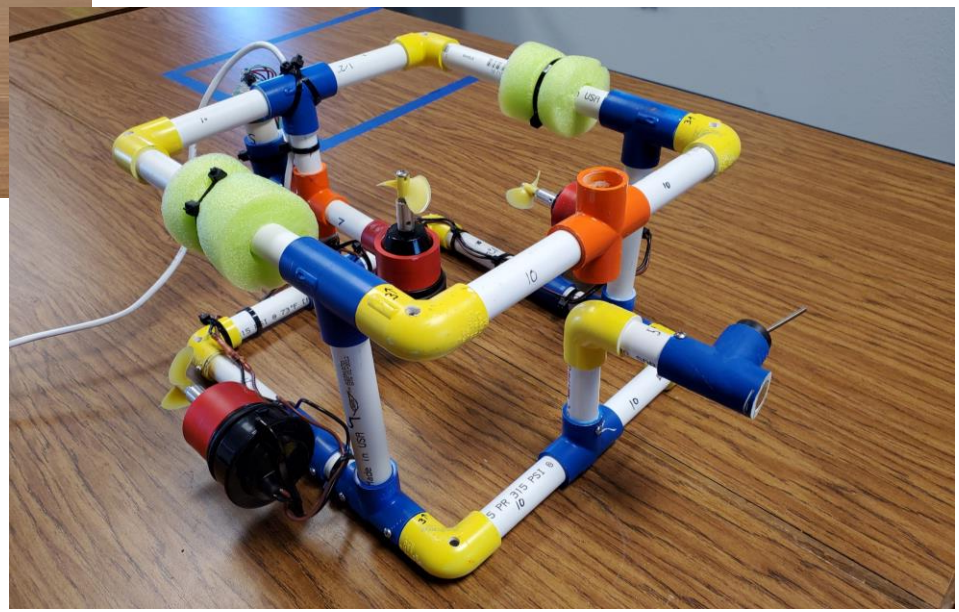
A finished ROV:





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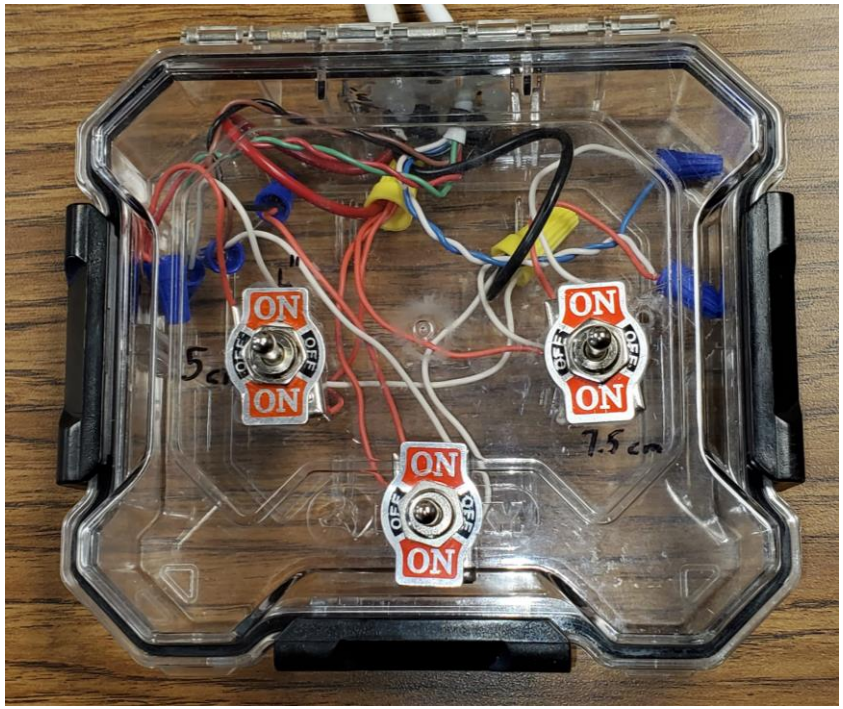
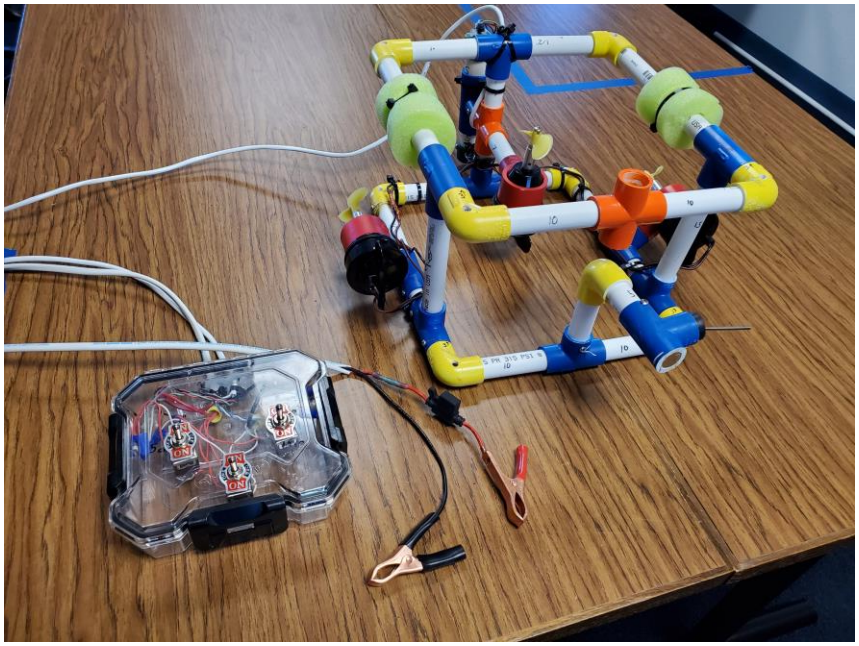
A finished ROV:





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Cost of parts:

Electrical and Wiring

	Vendor	Description	Cost	Quantity	Extended	Comments
1	Hardware Store	butt splices, 22-18 gauge, heat shrink, pack of 10	4.31	1	$4.31	pink
2	Hardware Store	8 inch cable ties, pack of 20	2.85	2	5.70	
3	Hardware Store	battery clamps, 1 set, black and red	3.54	1	3.54	
4	Hardware Store	terminal strip, 22-10 gauge, 8 position	6.29	1	6.29	
5	Hardware Store	Husky 6 inch x 6 inch compartment box, clear	5.97	1	5.97	
6	Hardware Store	standard wire connectors ("wire nuts") 30 pack	2.71	1	2.71	
7	Hardware Store	twisted bell wire, 20 gauge, foot long	0.24	3	0.72	
8	Marlin P. Jones	DPDT switch (mom. -off- mom.), screw terminal	1.95	3	5.85	https://www.mpja.com/DPDT-Momentary-Off-Momentary-Toggle-Switch/productinfo/16090+SW/
9	Sea MATE Store	Angelfish/Pufferfish tether wire, 18/6, 15 feet	25.00	1	25.00	https://seamate.org/products/seamate-angelfish-pufferfish-tether-wire
10	Sea MATE Store	Propeller kit for Angelfish ROV (3 propellors and parts)	24.00	1	24.00	https://seamate.org/products/3-seamate-pufferfish-propeller-kit
11	Amazon	Johnson Bilge Pump cartridges, 500 gph	22.39	3	67.17	
12	West Marine	16/2 duplex wire, foot long	0.79	12	9.48	
13	Amazon	Invincible marine fuse holder	6.67	1	6.67	
14		15 amp fuse (depends on type fuse hold bought)			0.00	
15	Lowes	2-1/4 x 4 feet swmming pool noodle	1.98	1	1.98	
					$169.39	**Sum of electrical/misc. parts**

Cost of parts:

PVC and Fittings

	Vendor	Description	Cost	Quantity	Extended	Comments
1	Hardware Store	1/2 inch thin wall pipe, 10 ft	2.06	2	$4.12	
2	Hardware Store	3/4 inch thin wall pipe, 10 ft	1.70	1	1.70	
3	Hardware Store	1/2 inch "T", S x S x S	0.46	10	4.60	
4	Hardware Store	1/2 inch 90^0 elbow, S X S	0.39	10	3.90	
5	Hardware Store	1/2 inch cross, S X S X S X S	1.44	2	2.88	
6	Hardware Store	3/4 inch X 1/2 inch "T", S X S X S	0.83	1	0.83	
7	Hardware Store	3/4 inch cap, S	0.64	2	1.28	
8	Hardware Store	1-1/4 inch x 1/2 inch "T", S X S X S	2.67	3	8.01	
					$27.32	**SUM of PVC Parts**

$196.71 Total Cost of Parts

SeaMATE offers a kit of all parts except the PVC parts for the Frame for $200 (includes shipping) The kit is different than the one described in this Smithsonian tutorial, but similar in function.

Follow along instructions:

These instructions are to accompany the ROV instructional video. Please use these abbreviated instructions to help you follow along. Keep in mind that is this NOT an exhaustive list! Please watch the video!

1) Obtain the first 8 items in noted quantities listed in the *List of Materials to Build the ROV Frame.*

2) Cut the ½ inch PVC pipe to the noted lengths and quantities as listed in the bold-face font under "Number 2." WEAR SAFETY GLASSES!

3) Assemble the PVC of the ROV as per the video starting at timestamp 0:4:31 to 0:11:51. You will need to cut the three 1-1/4 x 1/2 x 1-1/4 T's as marked by the blue tape in the video. Using a vise to hold the T while sawing will be very helpful.

4) Assemble the "tool post" as shown starting at timestamp 0:11:52 to 0:13:34. A correction to what is said in the video: a 7cm length of pipe is inserted into the T, and a 5cm length is inserted into the elbow. You will need to find something to fit inside the end of the PVC pipe such as a cork, stopper, or dowel to install the "hook."

5) Follow the video for installing the three 500gph Johnson cartridge bilge pumps, 0:13:35 to 0:17:48. **Do not use 1000gph bilge pumps as discussed in the video.** For a ROV this size these motors are too powerful to steer using the left and right thrusters.

6) Look at the video timestamp 0:17:49 to 0:19:02 to see if your ROV looks similar to the one in the video (except for the painted PVC fittings).

7) Running the thruster wires around and into the frame is shown in video sequence at timestamp 0:19:03 to 0:24:12. You can also use black electrical tape instead of cable ties to secure the wires to the frame. You may need an extra pair of hands to run the wires into the 3/4 x 1/2 x 3/4 T in the back of the ROV.

Follow along instructions:

8) View the video for wiring the thrusters to the tether at timestamp 0:24:13 to 0:39:24. Please use the "pink" butt connectors as listed in the electrical parts list (22-18 gauge). The 16-gauge thruster wires will fit into these connectors. In the video a small 1000-watt hair drier was used to heat shrink the connectors. That did not work, so you can use a real heat gun. If you don't have a heat gun, you can use a butane grill lighter, but be careful not to burn the butt connector or the wire jacket. **Please have adult supervision.**

9) Review the video of hole placement in the control box at timestamp 0:39:25 to 0:41:45. WEAR SAFETY GLASSES! Drill the holes carefully and without much downward pressure on the drill. Do not drill on furniture or the kitchen table. The drill bit breaks through the plastic very suddenly, and "grabs" the plastic. The plastic is brittle and may crack if the drill is pushed too hard. When drilling holes greater than ¼-inch, start with a ¼-inch bit, then widen whole with incrementally wider bits until you achieve the wanted diameter.

10) Wiring the control box is covered in the video from timestamp 0:41:46 to 0:48:55. Follow the dialogue.

11) When wiring the switches using bell wire, insert the loop created by using the long-nose pliers under the terminal screw such that the loop is tightened. If the loop is inserted in the wrong direction tightening the screw may spread the loop apart. (Video sequence at timestamp 0:48:56 to 0:58:25) A extra pair of hands could be helpful. Braided wire is difficult for wiring these switches because the terminal screws are small, and tightening the screws causes the loops to unravel, including when done in the loop is installed in the correct direction.

12) The video sequence for mounting the switches in the control box is at timestamp 0:58:26 to 1:01:27. Maintain the orientation of the three switches the same. Marking the switches with a black dot at the same end ensures that the left and right thrusters drive forward when the switches are pressed forward, and operate in reverse when the switches are pulled back. Also, maintaining the orientation of the switches enables quick troubleshooting if the switches are operating in the wrong direction (Section 16).

Follow along instructions:

It is difficult mounting the switches to the control box. The nuts on the switches are very thin, making it hard to tighten with a wrench. Once the control box is completed you may wish to add a dab of hot glue between the switch and lid (on the inside of the box) to help anchor the switch.

13) Wiring the switches to the tether is easier if first using wire nuts for future testing (video timestamp 1:01:28 to 1:09:28). It may seem difficult to keep track of all the wires and colors, but once power is applied to the control box it takes very little effort to make corrections. The builder in the video had crossed the right thruster wires to the left thruster switch and vice versa, but the correction took less than 2 minutes to accomplish. Also, the up/down switch was wired incorrectly, but correcting took less than a minute.

14) Using hot glue on the power cable and tether where they enter the box ensures that the wires will not pull out of the switch terminals or out of the control box (1:09:29 to 1:14:17). Other methods of strain relief are available, but this method has worked well for the 10 years we at the Smithsonian Marine Station have been building these ROV's. However, this method may not be "legal" for MATE ROV Competitions.

15) Attach the battery clamp and fuse holder to the positive power conductor that will attach to a 12-volt battery. (Video sequence at timestamp 1:14:18 to 1:21:23) The fuse should ways be on the conductor that goes to the positive terminal, and that wire is usually red. Attach the other battery clamp to the negative (usually black) conductor. The wires should be soldered to the battery clamps. This was not shown in the video. MATE ROV requires a different method for attaching the wires to a 12-volt power source for competitions, not covered here.

16) Trouble shooting switches is covered at video timestamp 1:14:18 to 1:21:23. Here is a relatively simple method for determining if the switch wires are wired correctly. WEAR SAFETY GOGGLES WHEN WORKING ON ENERGIZED CIRCUITS. ALWAYS DISCONNECT THE BATTERY CLAMPS WHEN THE CONTROL BOX IS OPEN TO WORK ON SWITCHES. THE PROPELLERS ARE VERY SHARP.

Follow along instructions:

As viewed from behind the ROV and looking toward the front, and with the control box in front of you with tether and power cords exiting the box toward the ROV, pushing the right switch forward should make the right thruster propeller rotate clockwise. Pushing the left switch forward the left thruster propeller should also rotate clockwise. If one or the other (but not both) are operating counter clockwise, disconnect the battery from the power cord, open the control box, and find the two wires from the errant switch that are connected to the tether, loosen the two wire nuts from the switch to the tether, and change the wires from the switch to the other wire nut. Then close the control box, re-clamp the power cable to the battery, and see that pushing either switch forward will make the appropriate thruster operate clockwise. If the right switch makes the left thruster operate (and vice versa), switch the wires from the front of the left switch to the tether wires of the right switch, and change the tether wires attached to the front right switch to that of the left switch. Close the control box, attach the power chord to the battery, and see if the left switch pushed forward operates the
left thruster clockwise and the right switch operates the right thruster clockwise. As viewed from above, pushing the up/down switch forward should make the propeller operate clockwise (which will make the ROV "dive"), and pulling the switch back make the propeller operate counterclockwise (ROV will rise to the surface). If not, change the wires at the front of the switch at the tether wire nuts. Some pilots prefer the switch for up and down to operate opposite, such as pushing the switch to make the ROV rise and pulling back to make the ROV dive, similar to raising and lowering the electric windows of a car.

17) Cable strain relief is covered in the video at timestamp 1:21:24 to1:23:15. In short, use cable ties and hot glue so that the tether wire or power cord will not become disconnected from the ROV or the control box.

18) I forgot to mention about making the ROV neutrally buoyant, or just slightly negative (sinks slowly). Once your ROV is finished, drill ¼-inch holes in the PVC elbows in all the top and bottom corners of the frame of the ROV. This will make the ROV quite negatively buoyant. Cut two 15 cm lengths of 2 ¼-inch diameter foam pool noodle and slit them lengthwise on just one side of the center hollow tube. The slit should fit over the 20cm piece of PVC pipe at the top, left and right sides, and toward the back of the ROV. Place the ROV into a pool, with out applying power to the ROV, and the ROV should float. Removing the ROV from the water, trim a few centimeters equally from

both the left and right floats, and install the foam noodle pieces again. Continue trimming the floats (left and right equally) until the ROV just sinks without power. This is typically the optimum buoyancy. If the front of the ROV sinks faster or lower than the back, two pieces of noodle can be slit and added to both sides of the top 10cm long pipes on either side of the cross fitting. Then trim both foam floats equally until the ROV sits level and sinks ever so slowly. The ROV should be well trimmed and operate well.

19) HAVE FUN! Experiment with the design of the PVC frame to make it better.