ElectroTutor:

Test-Driven Physical Computing Tutorials

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AUTODESK RESEARCH

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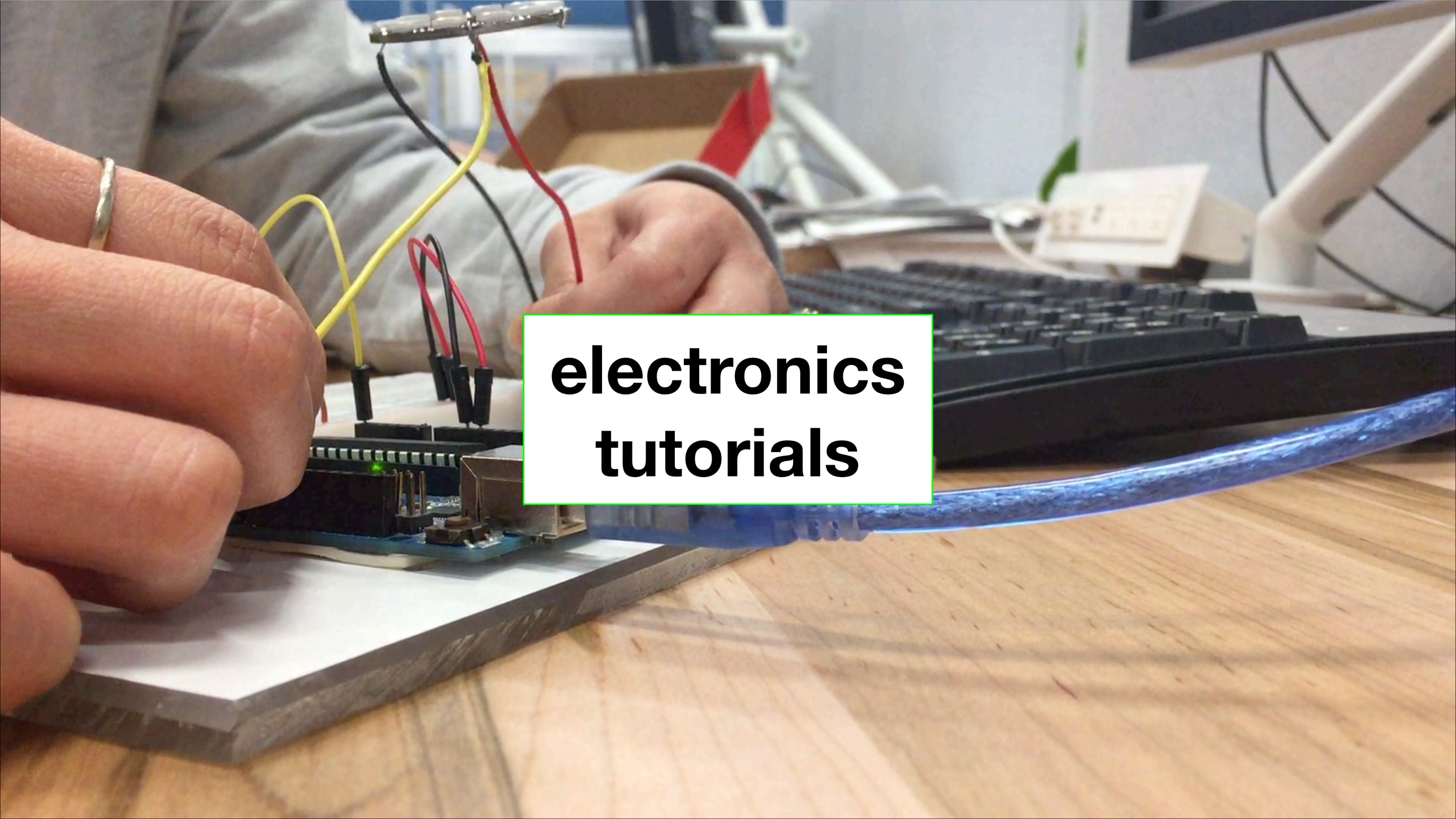
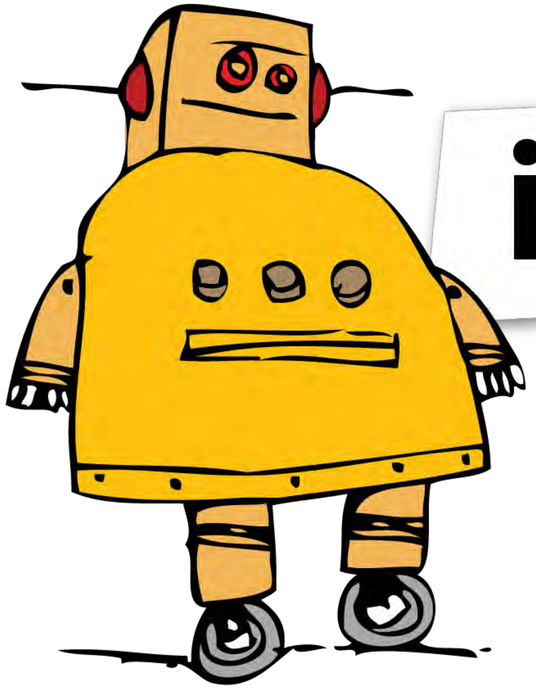
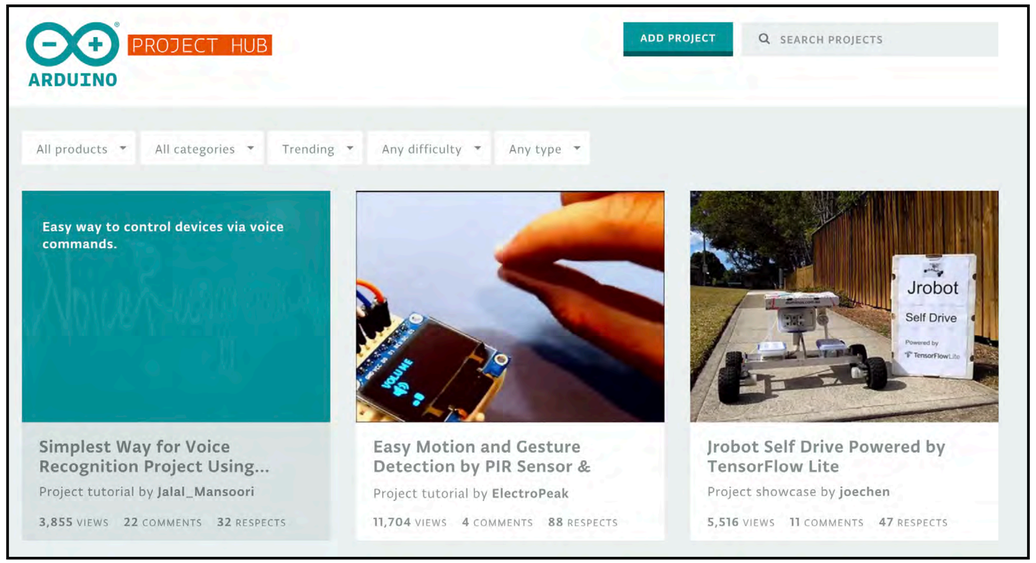
UNIVERSITY OF TORONTO


electronics
tutorials

motivation



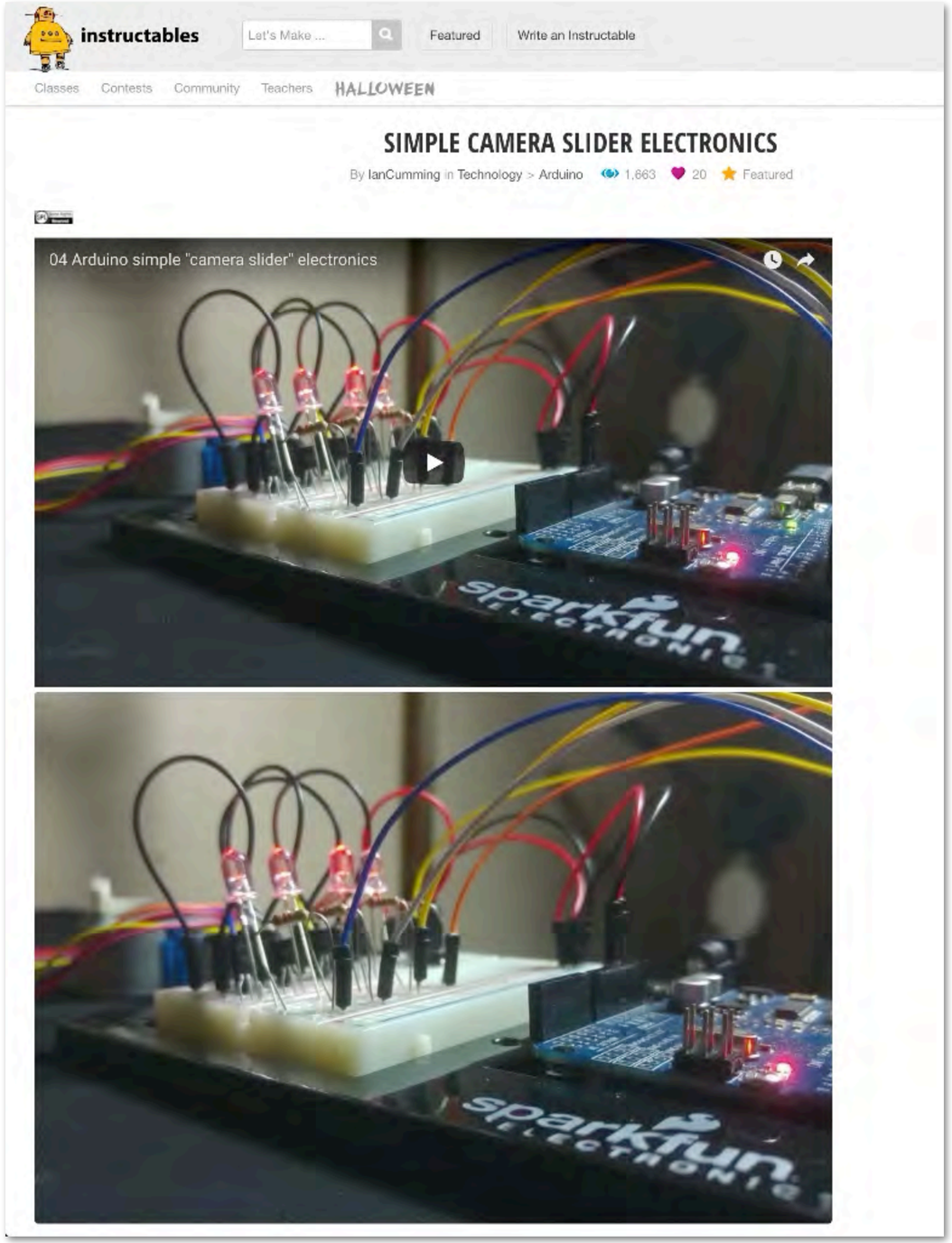
instructables

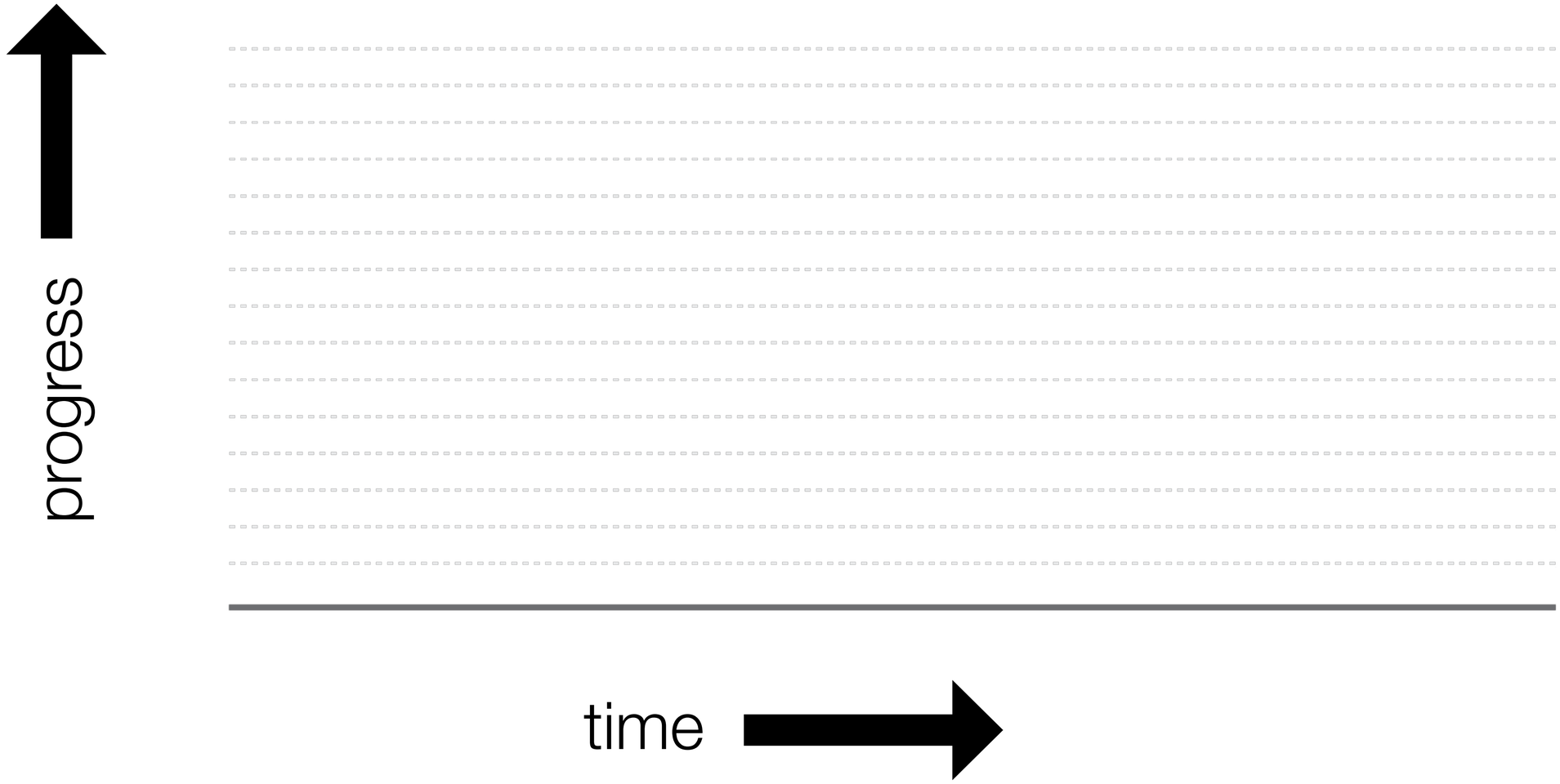


TINKERCAD

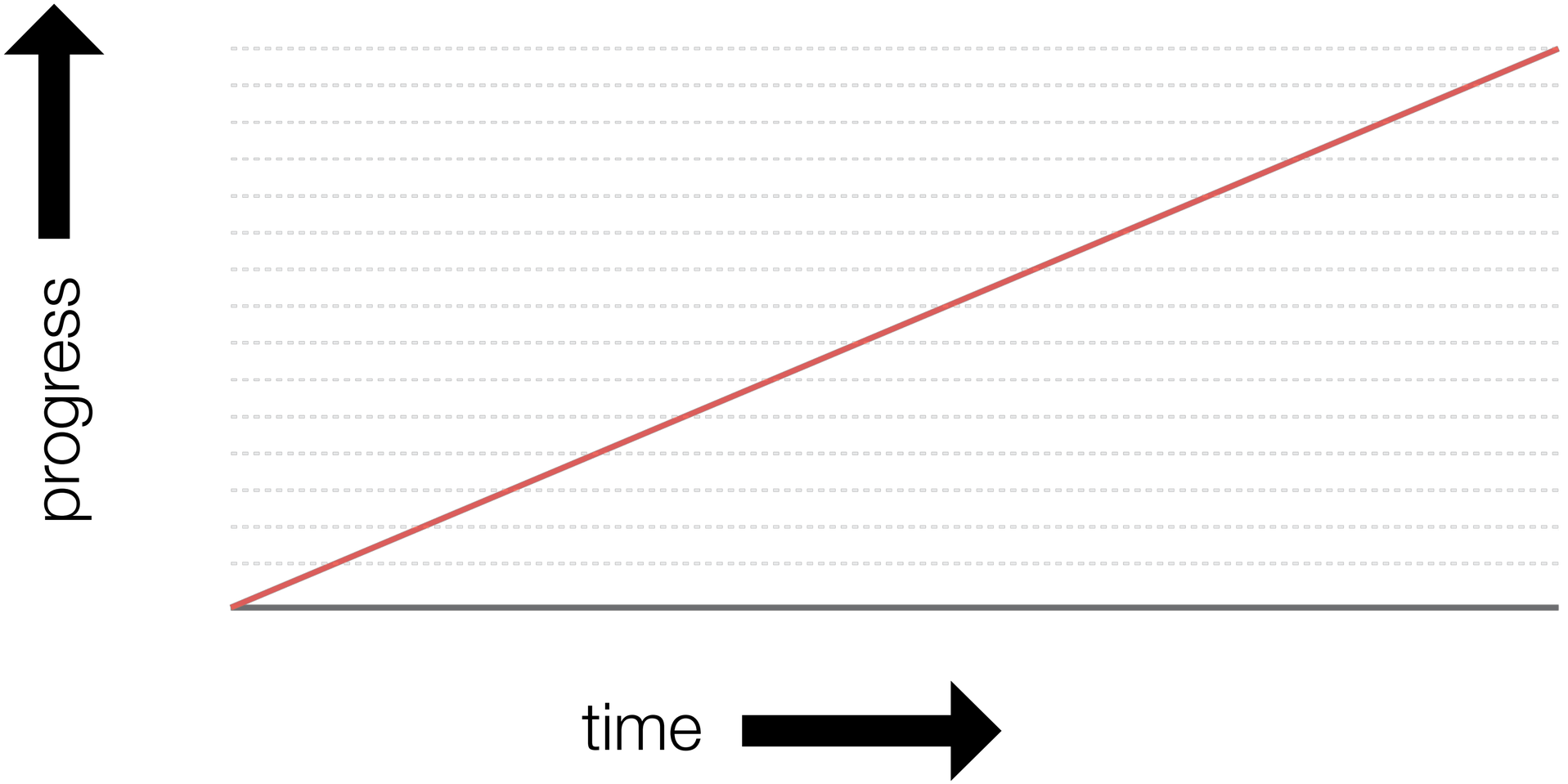
motivation

What if we could embed checkpoints to improve the tutorial experience?

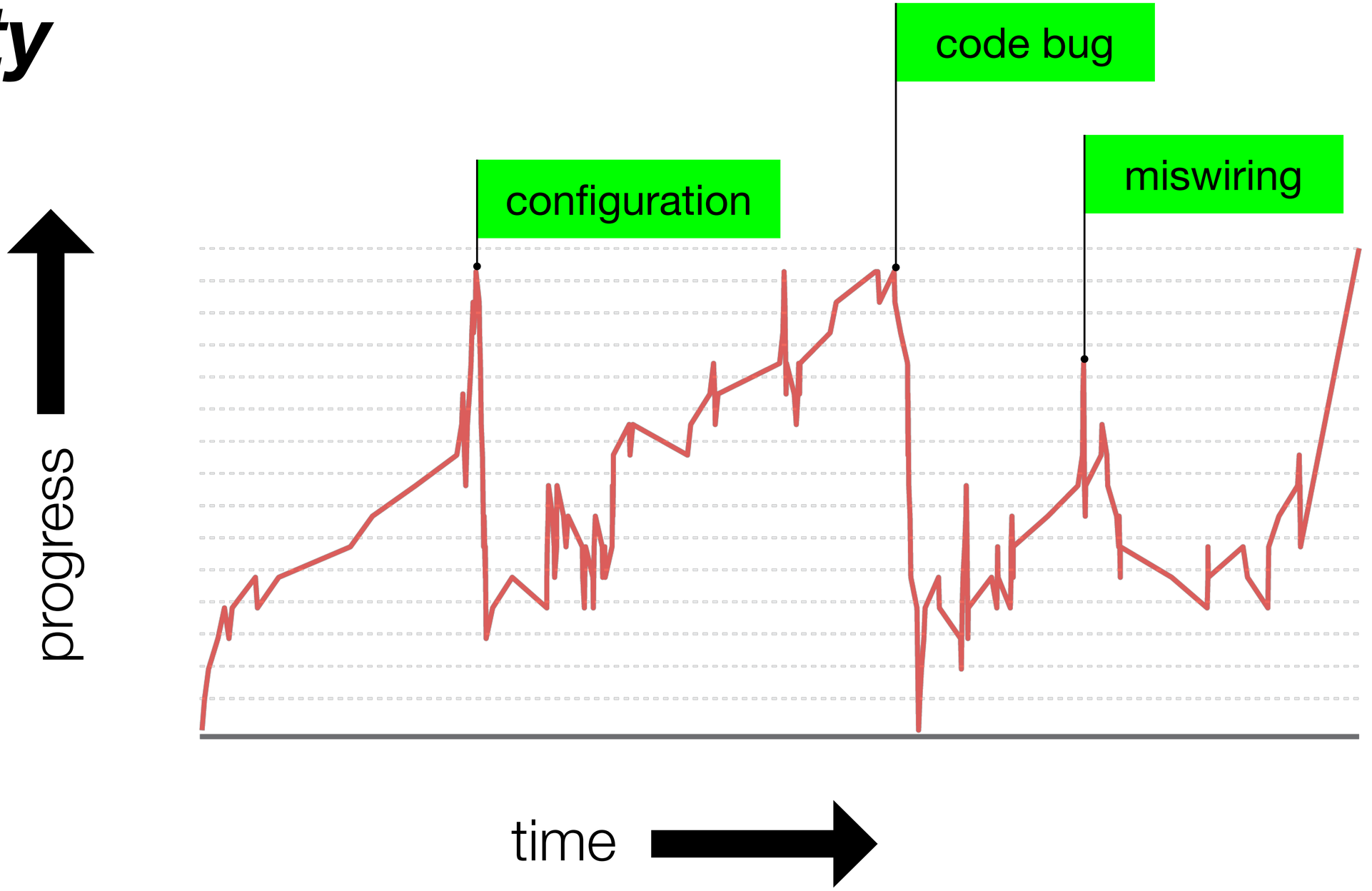



progress
time

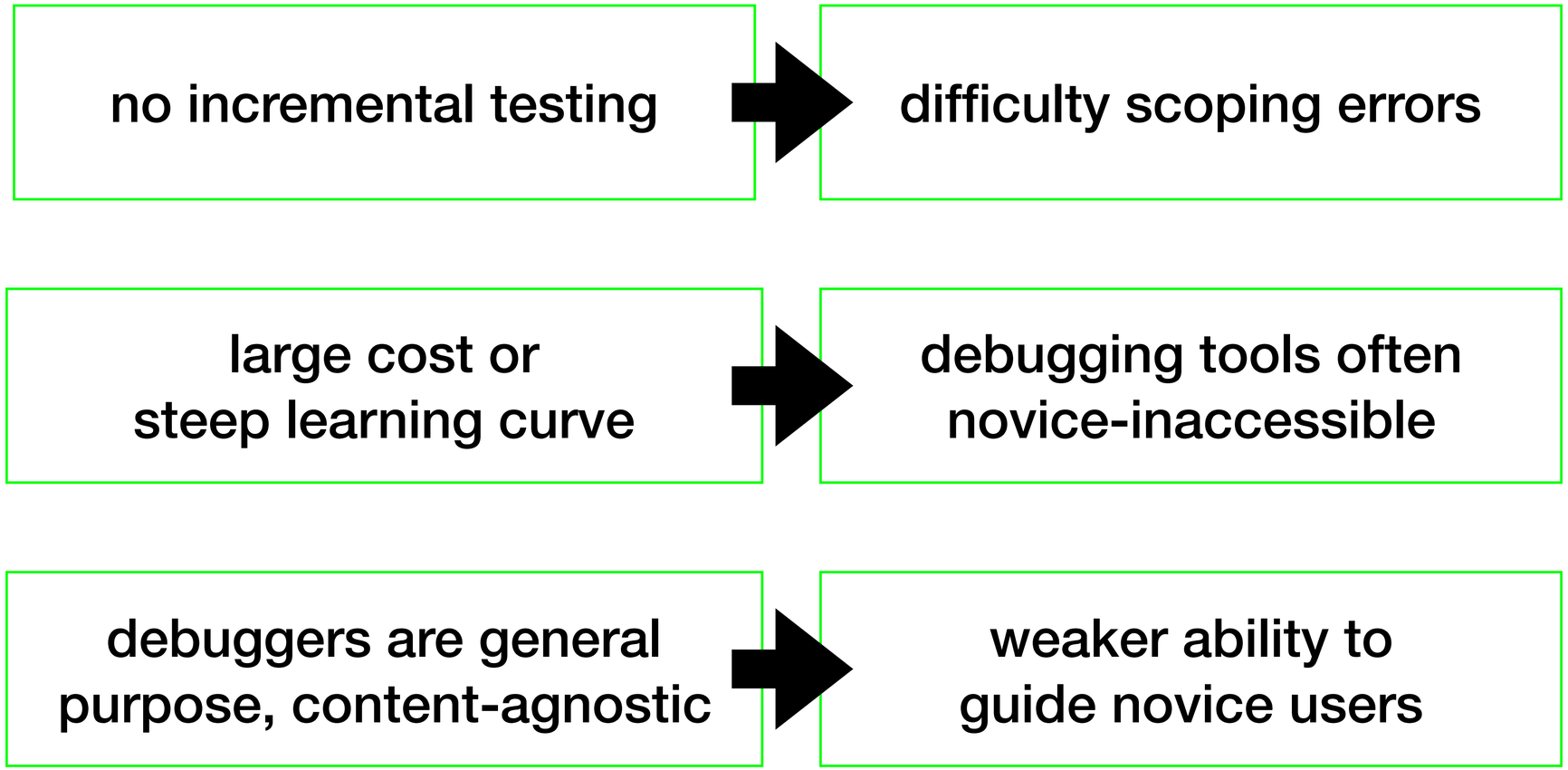
ideality



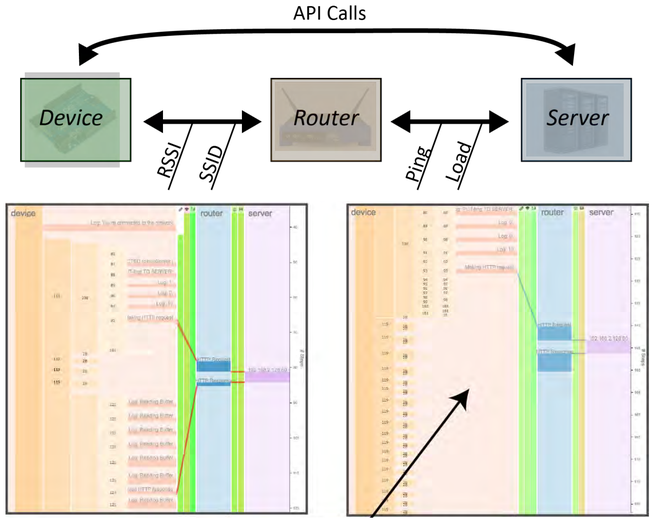
reality



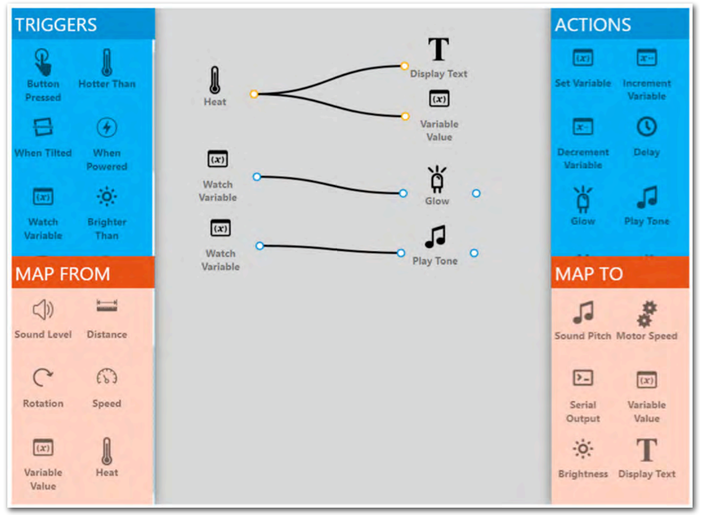
challenges


no incremental testing
difficulty scoping errors
large cost or
steep learning curve
debugging tools often
novice-inaccessible
debuggers are general
purpose, content-agnostic
weaker ability to
guide novice users

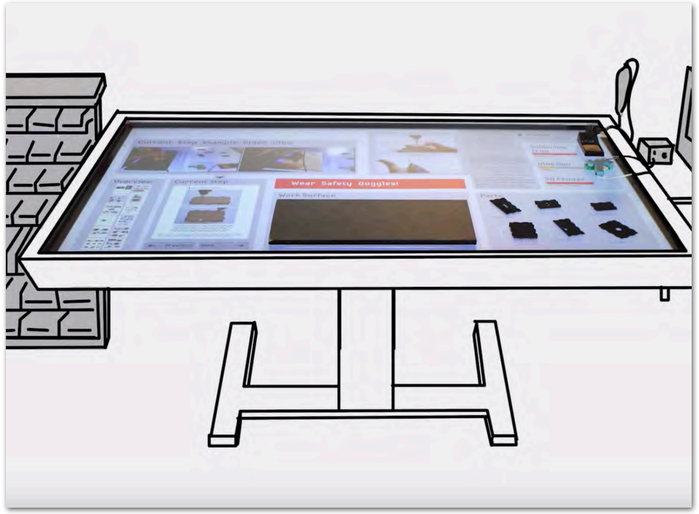
related



WiFröst
McGrath et al. UIST 2018

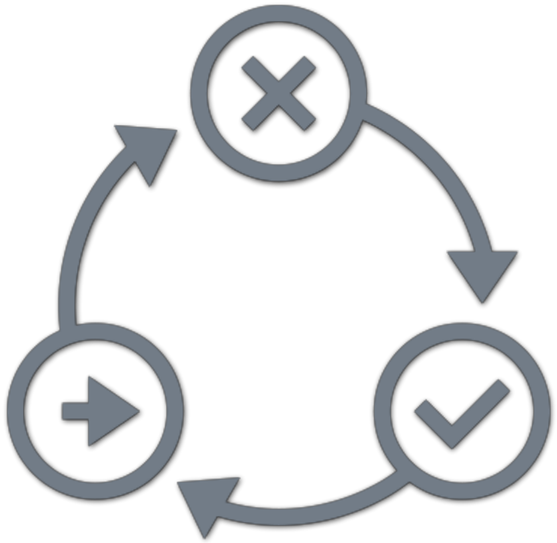


Trigger-Action-Circuits
Anderson et al. UIST 2017



Smart Makerspace
Knibbe et al. ITS 2015

related

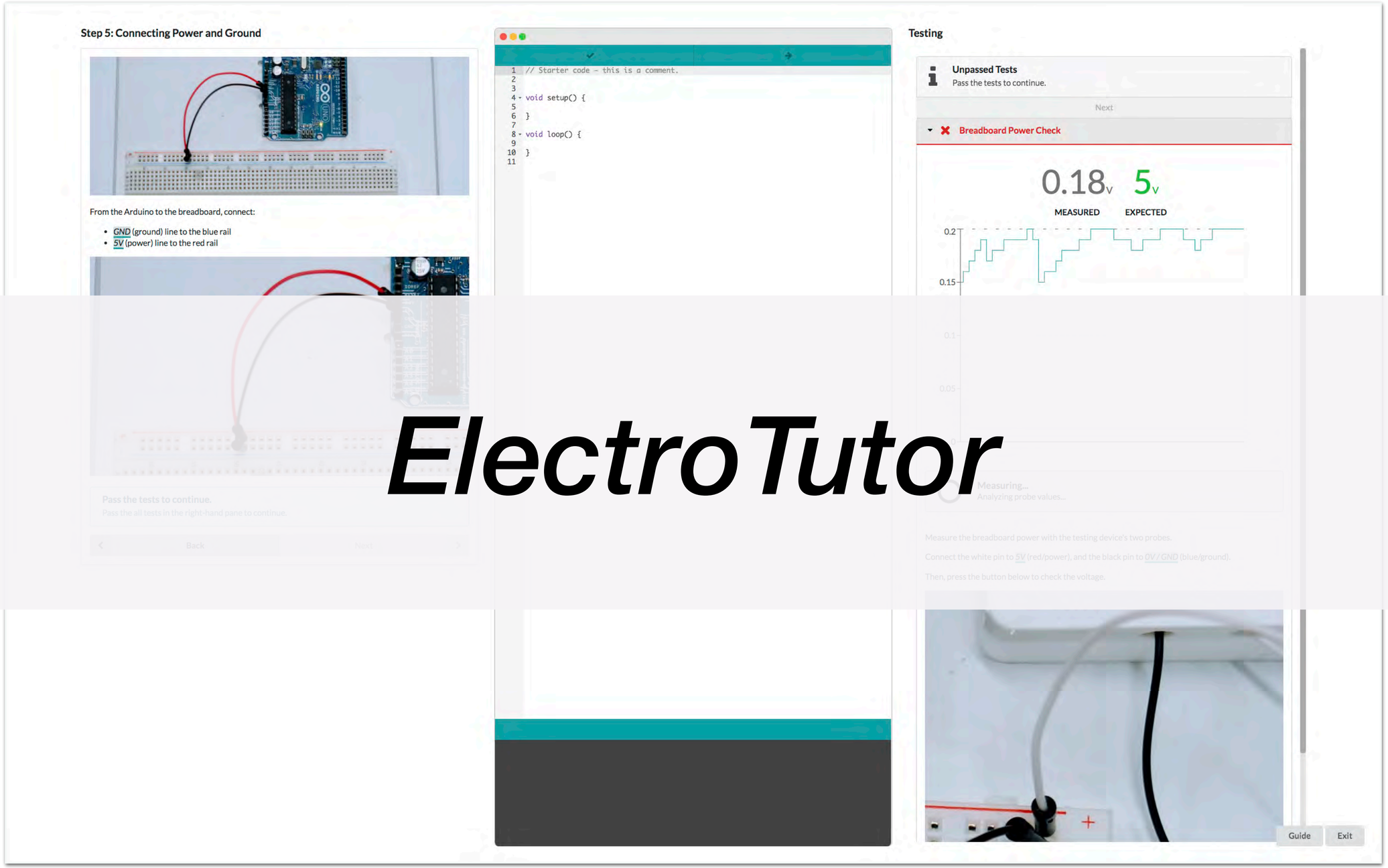


Test Driven Development
Kent Beck

incremental testing with
specific test cases

mitigating fear,
inspiring confidence

ElectroTutor



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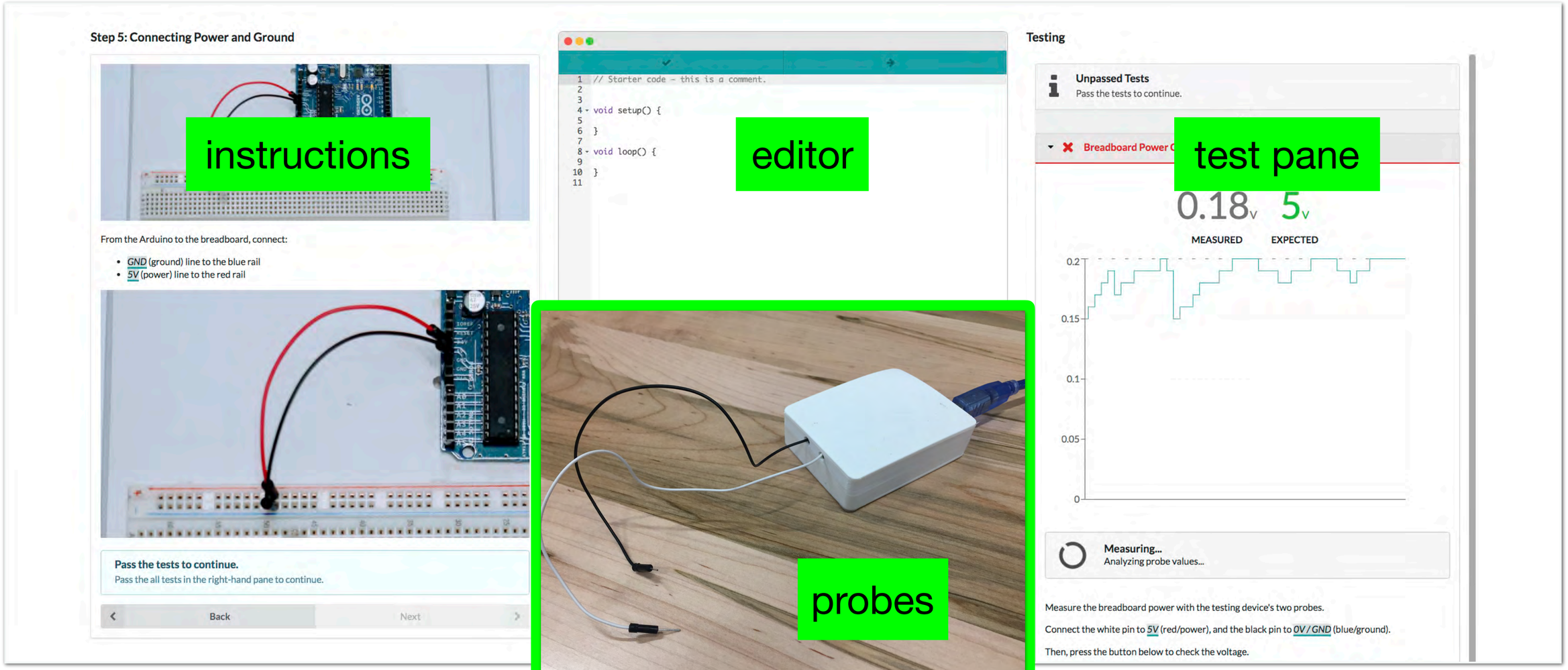
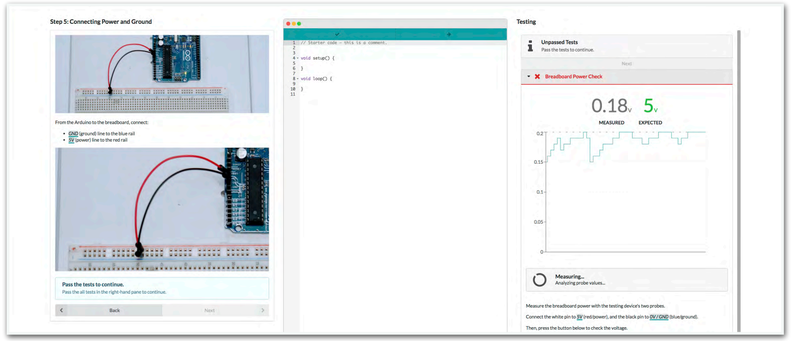


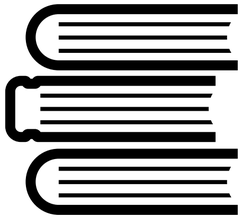
system

user interface



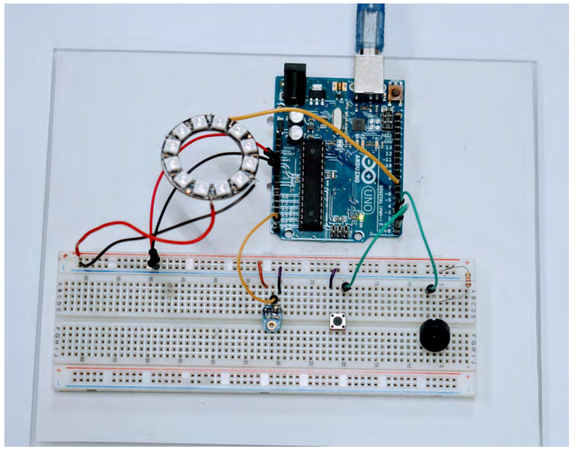
backend

tutorial content

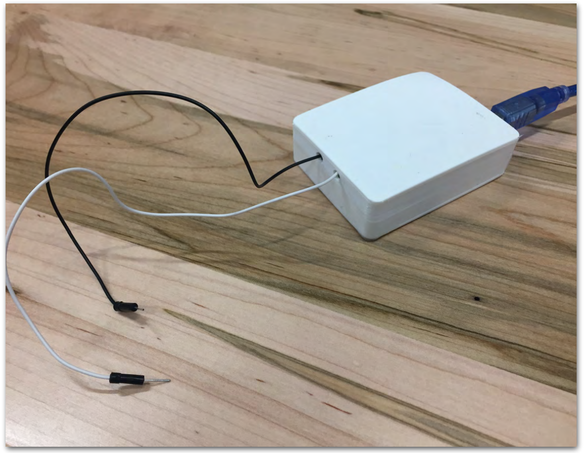


serial

tutorial project

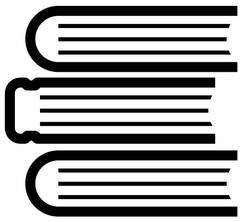


probes



system

tutorial content

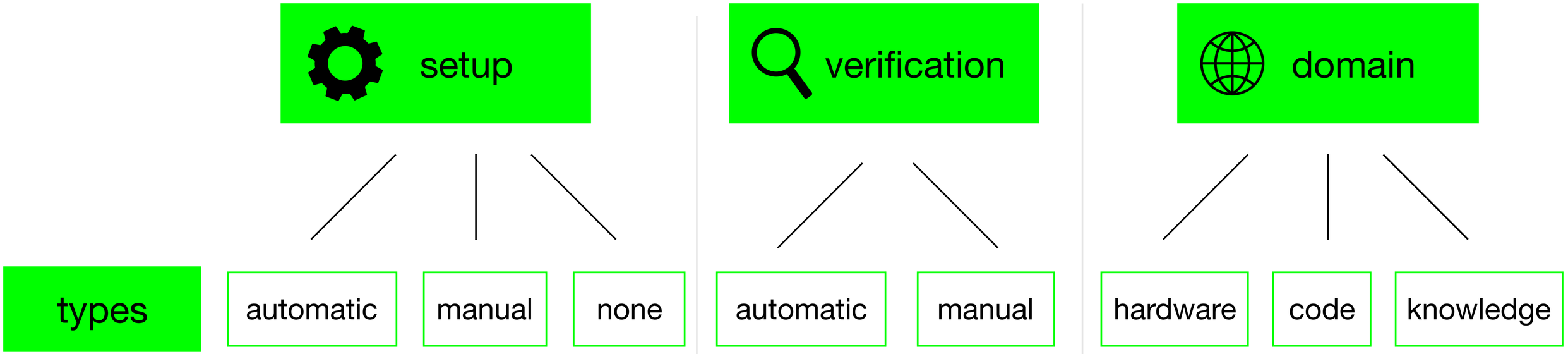


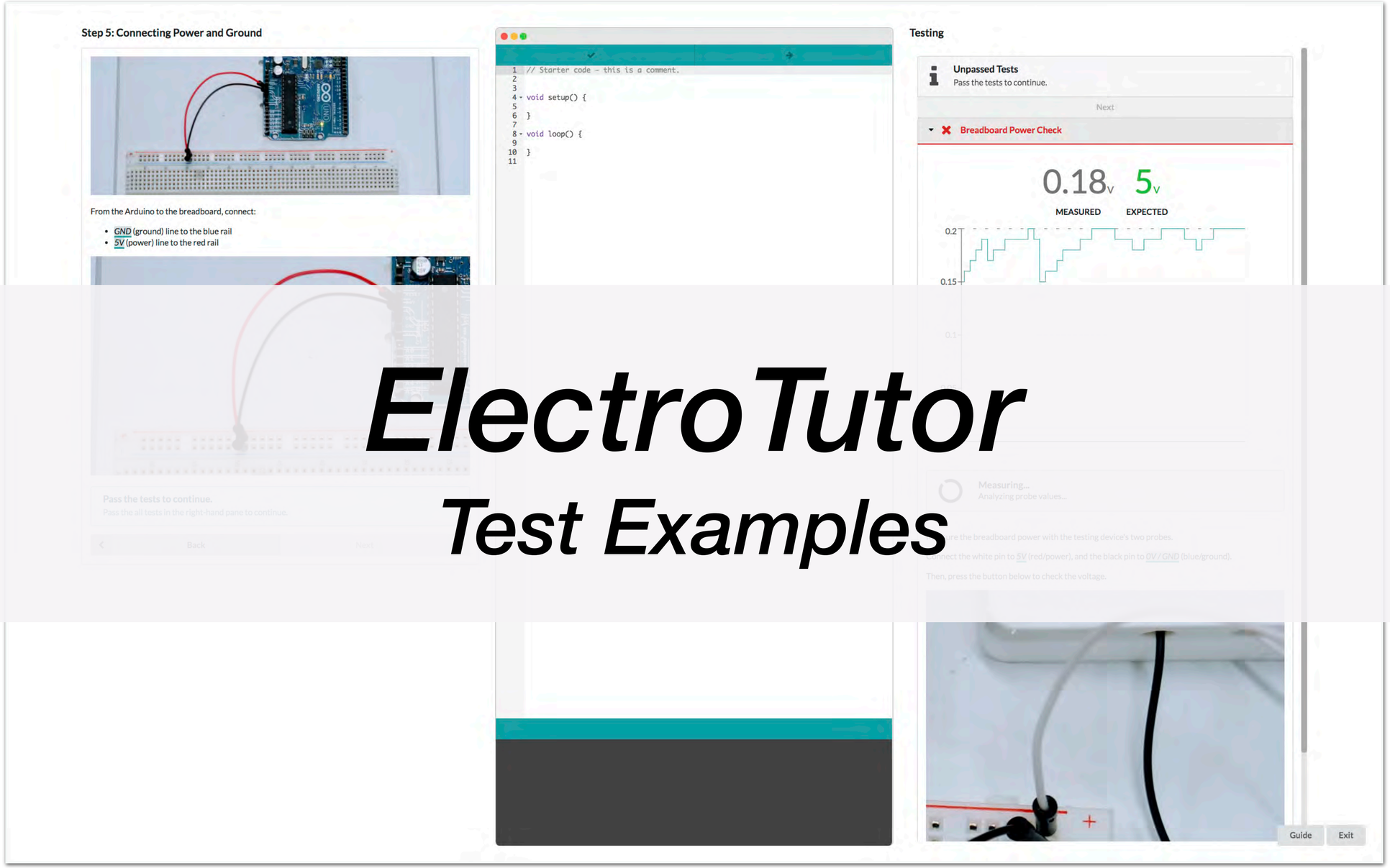
<YAML>

```yaml
---
title: Neopixel Ring Wiring
description: |
  ![neopix](neopixel.jpg)

  Connect the *Power (red)* and *Ground (black)* ends of the Neopixel ring to the positive and ground rails.

  ![neopix](neopixel-crop1.jpg)

  Connect the *Data In* yellow LED pin to the *digital 7* on the Arduino.

  ![neopix](neopixel-crop2.jpg)

tests:
  -
    title: Hardware Wiring Check
    description: |
      The system will now check to see that you have wired up the LED ring correctly.

      If the lights are wired up correctly, you will see a glowing pattern.

      Does the LED ring rotate though the rainbow?

      Click below to setup the test.

      ![neopix](rainbow.gif)
    onerror: Make the sure data pin is connected to pin 7, and the power/ground pins are connected to 5V and GND respectively.
    jsondata: '{"file":"3_lights.ino"}'
    form: autoupload
```

<Markdown>

test taxonomy





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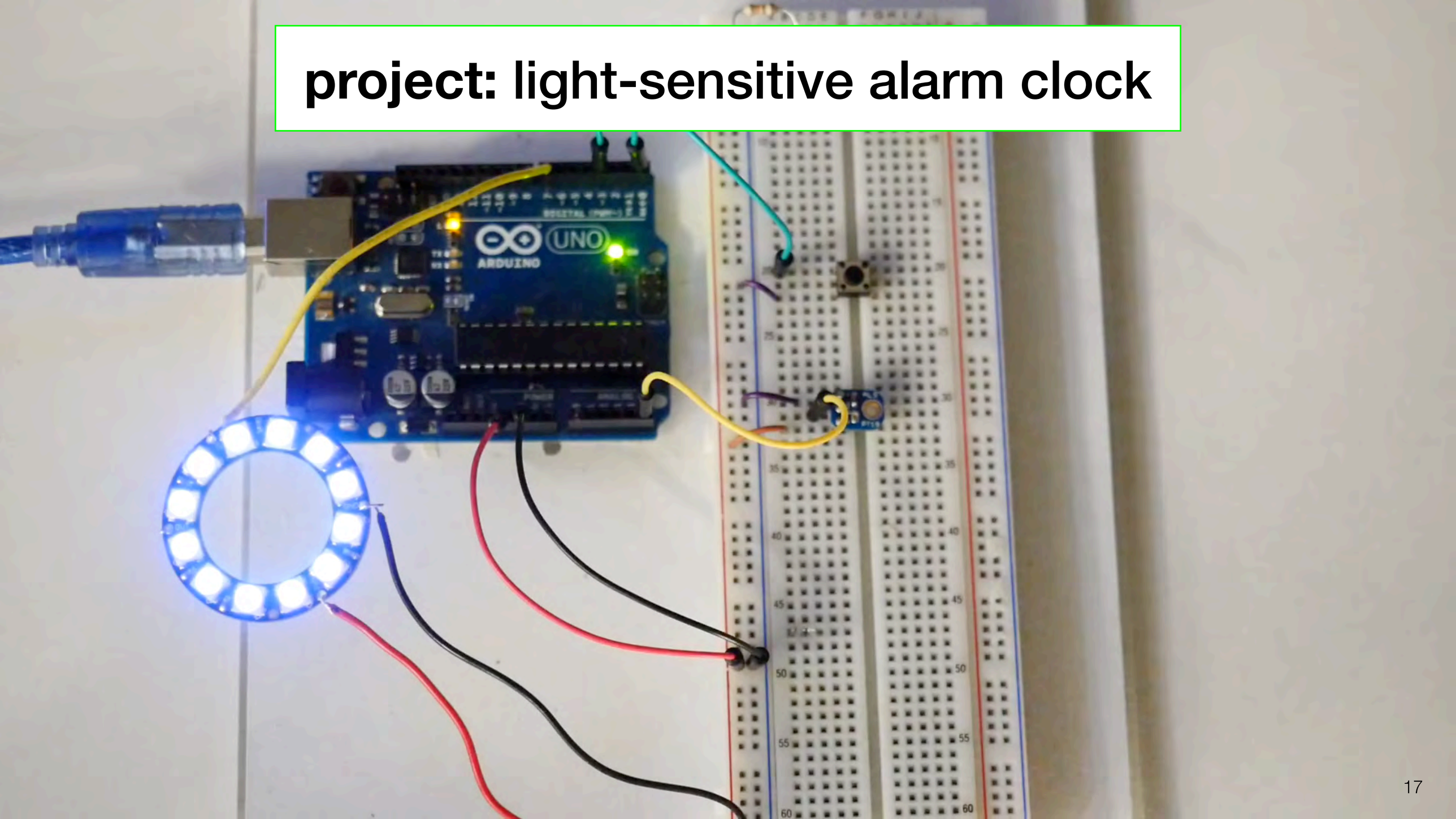
Test Examples

project: light-sensitive alarm clock

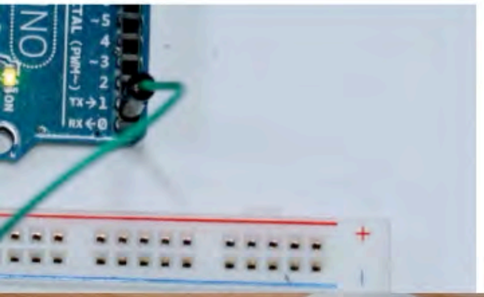


runtime hardware test

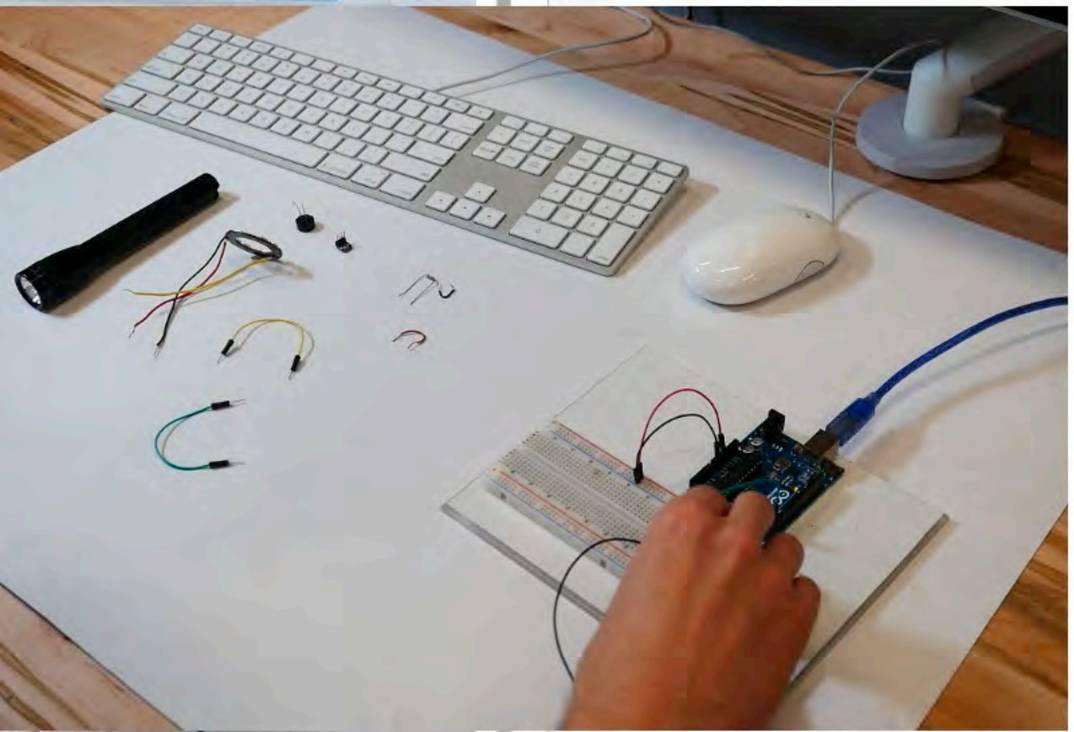
ured.

ue/ground) with a jumper wire.

rduino board.



```
// Starter code - this is a comment.

void setup() {

}
void loop() {

}
```



Unpassed Tests

Pass the tests to continue.

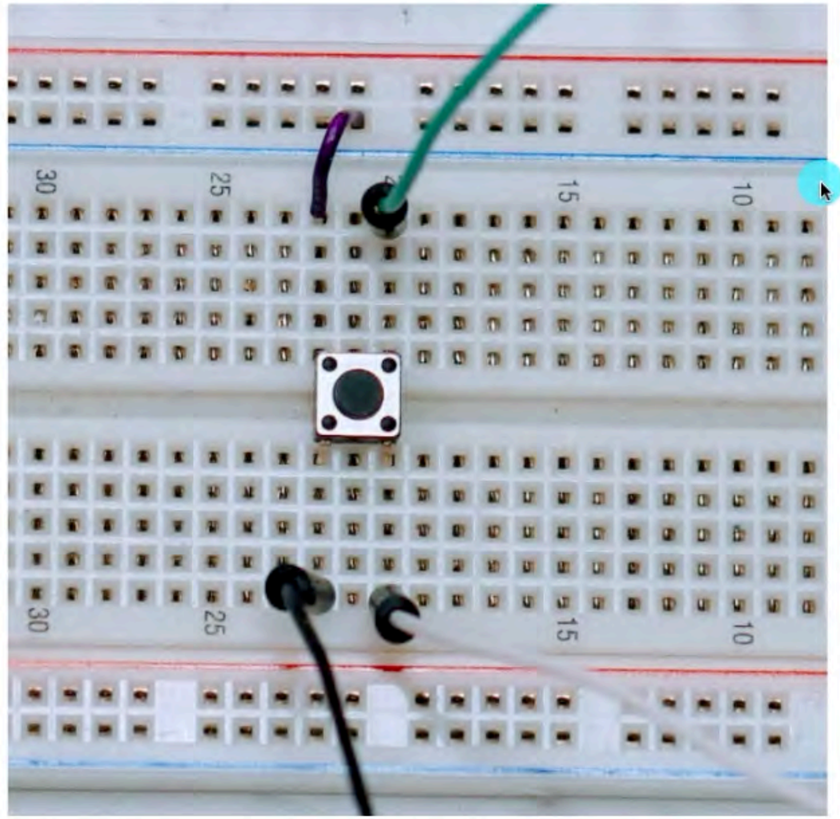
Next

Button Press Check

Measure the voltage across the button using the tester.

Connect the *black wire to GND (ground)* and the *white wire to the Arduino-connected side*.

The voltage should drop as you press the button down - *hold it down for AT LEAST 2 seconds*.

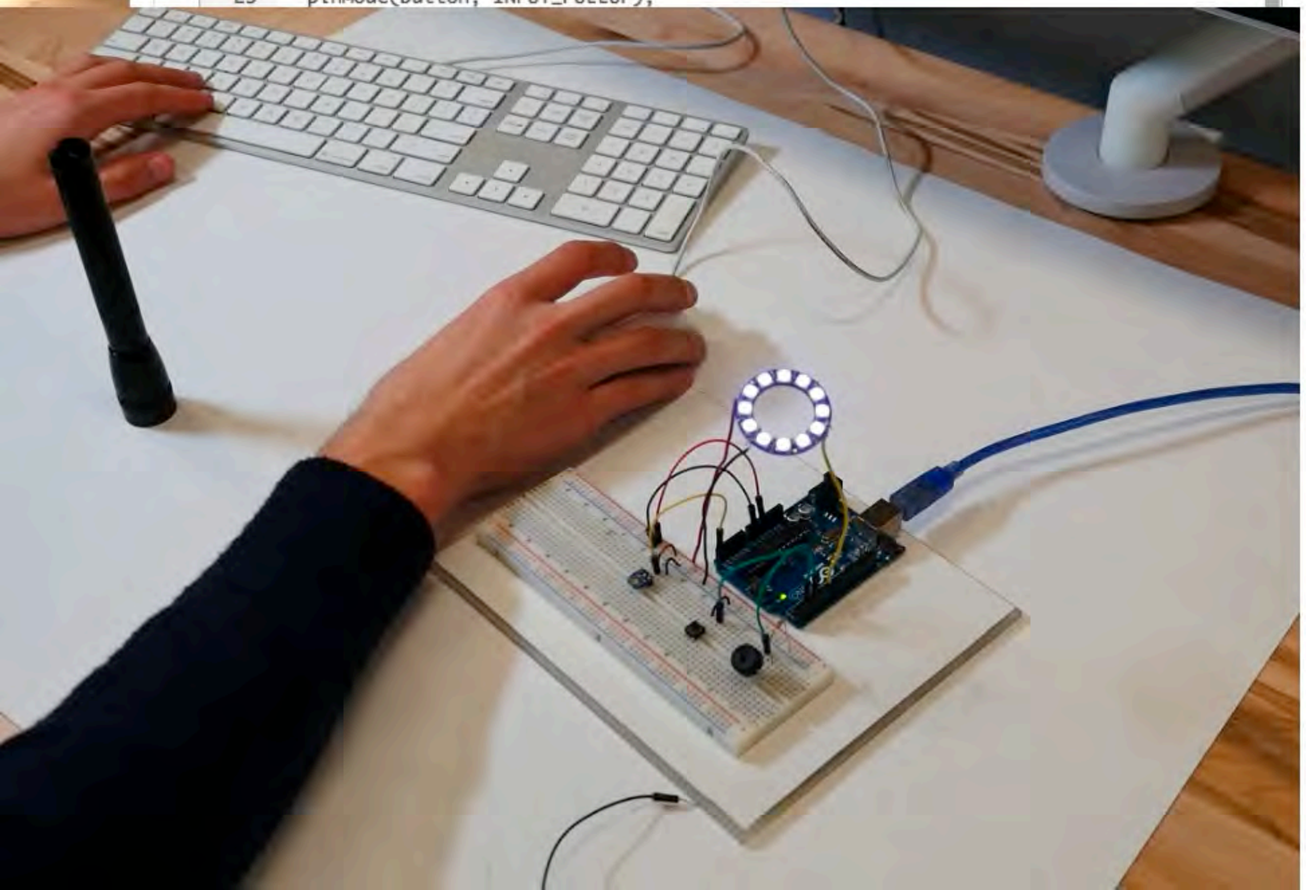


Click to Measure Voltage Signal

Voltage Knowledge Test

runtime code value test

```
#define thresh_lo 100
#define thresh_hi 900

#define button 2
#define outLED 13

#define buzzer 4
#define freq 220

int color = 0;
Adafruit_NeoPixel strip = Adafruit_NeoPixel(PIXELS, PIN, NEO_GRB + NEO_KHZ800);
uint32_t white = strip.Color(16, 16, 16); // dim white color

void setup() {

  pinMode(light, INPUT);
  pinMode(button, INPUT_PULLUP);
```



Next

✔ Code Selection Test - Sensor Reading

Software Trigger Check

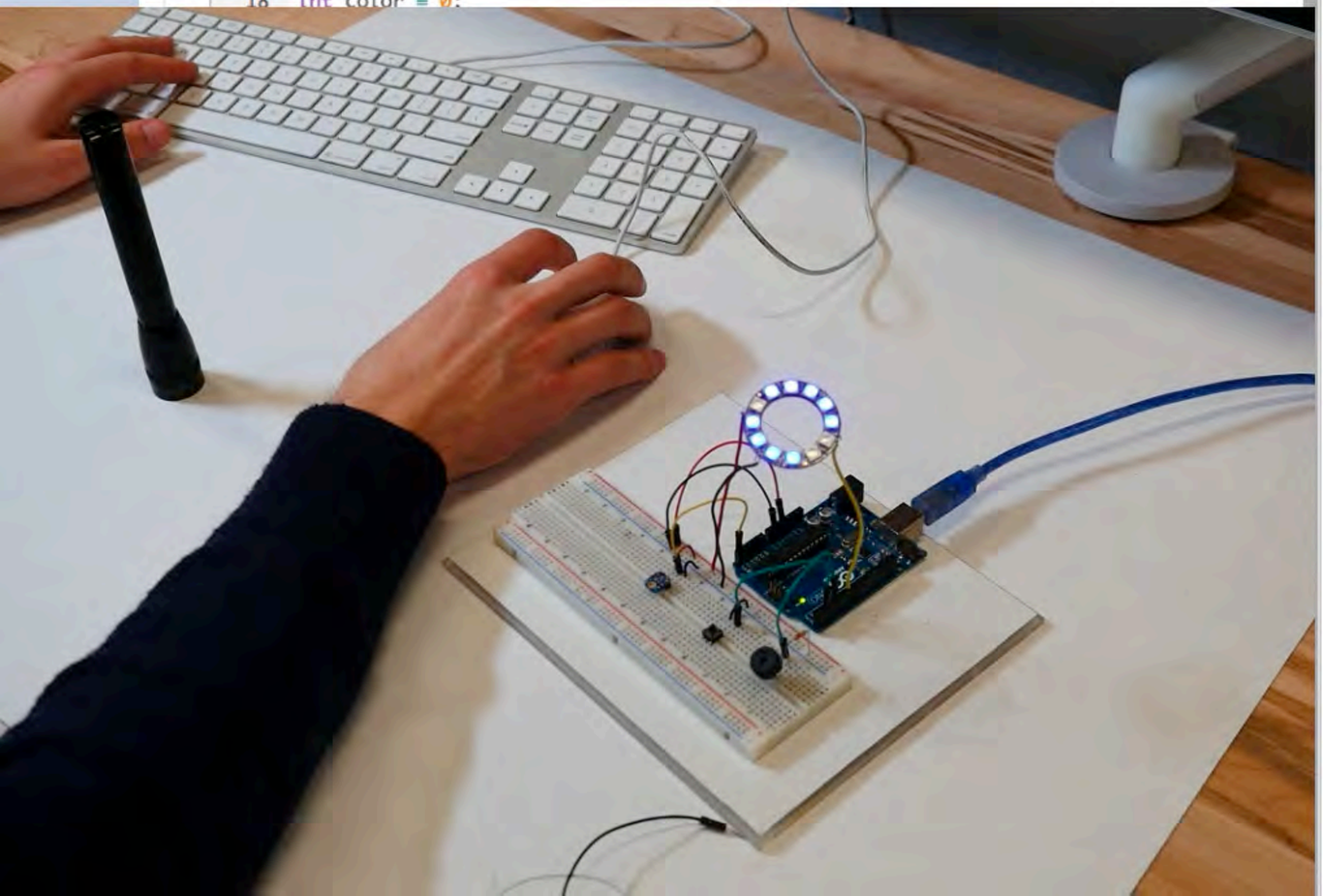
The system will now check to see that you programmed the Arduino board correctly.

Once loaded, shine the light sensor to raise the level above the threshold.

Click to Measure Code Variable

wiring test

```
#define PIXELS 12

#define light  A5
#define thresh_lo 100
#define thresh_hi 900

#define button 2
#define outLED 13

#define buzzer 4
#define freq 220

int color = 0;
```



Unpassed Tests
Pass the tests to continue.

Next

Hardware Configuration Check

Check that the sensor is connected and configured as `INPUT`, not `INPUT_PULLUP`.

We will now check that your hardware is configured corrected.

Try *flashing the light sensor* to turn on the alarm.

Try *pressing the button* to turn off the alarm after it is activated.

Did both of these functions work as expected?

Click to Setup and Begin Test

compilation test

Include this library code for the LED ring *at the VERY top* of the file:

```
#include <Adafruit_NeoPixel.h>
```

Then, define the pin the Neopixel ring's data pin is connected to, and the number of "pixels" in the ring.

```
#define PIN    7
#define PIXELS 12
```

Before the `setup()` function, create the strip of LEDs and a base white color.

```
int color = 0;
Adafruit_NeoPixel strip = Adafruit_NeoPixel(PIXELS, PIN, NEO_GRB + NEO_KHZ800);
uint32_t white = strip.Color(16, 16, 16); // dim white color
```

Initialize the LED strip *just before* the end of `setup()` function.

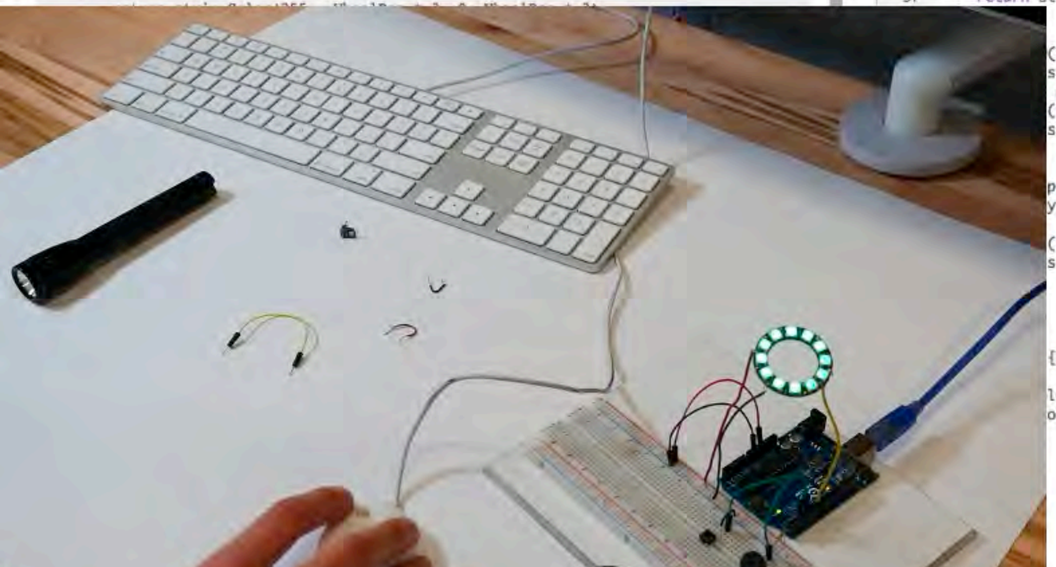
```
  strip.begin(); // This initializes the NeoPixel library.
  strip.setBrightness(16);
```

In between the `setup()` and `loop()` functions, insert these two light helper functions.

The first function, `Wheel`, takes in a number (specifically a byte, an 8-bit number), and returns a color that we can use to set the LED.

The second function, `rainbow`, loops over all of the LEDs in the ring and updates their color, using the `Wheel` function.

```
uint32_t Wheel(byte WheelPos) {
    WheelPos = 255 - WheelPos;
    if (WheelPos < 85) {
```



```
// Starter code - this is a comment.

#include <Adafruit_NeoPixel.h>

#define PIN    7
#define PIXELS 12

#define button 2
#define outLED 13

#define buzzer 4
#define freq 220

void setup() {

int color = 0;
Adafruit_NeoPixel strip = Adafruit_NeoPixel(PIXELS, PIN, NEO_GRB + NEO_KHZ800);
uint32_t white = strip.Color(16, 16, 16); // dim white color

  pinMode(button, INPUT_PULLUP);
  pinMode(outLED, OUTPUT);

  strip.begin(); // This initializes the NeoPixel library.
  strip.setBrightness(16);
}

uint32_t Wheel(byte WheelPos) {
    WheelPos = 255 - WheelPos;
    if (WheelPos < 85) {
        return strip.Color(255 - WheelPos * 3, 0, WheelPos * 3);
    }
    if (WheelPos < 170) {
        WheelPos -= 85;
        return strip.Color(0, WheelPos * 3, 255 - WheelPos * 3);
    }
    WheelPos -= 170;
    return strip.Color(WheelPos * 3, 255 - WheelPos * 3, 0);


(int start, int wait) {
start;
 q = 0; q < 3; q++) {
(int i = 0; i < strip.numPixels(); i = i + 3) {
strip.setPixelColor(i + q, Wheel( (i + j) % 255)); //turn every third
  pixel on

p.show();
y(wait);

(int i = 0; i < strip.numPixels(); i = i + 5) {
strip.setPixelColor(i + q, 0);      //turn every third pixel off



{

lor, 2);
olor+2) % 255;
```

Unpassed Tests

Pass the tests to continue.

Next

✔ Code Selection Test - Library Inclusion

✖ Compilation Check

Test your code to see if there are any errors in it.

```
code: In function 'void setup()':
code:17:5: warning: unused variable 'color' [-Wunused-variable]
int color = 0;
^
code:19:10: warning: unused variable 'white' [-Wunused-variable]
uint32_t white = strip.Color(16, 16, 16); // dim white color
^
code: In function 'uint32_t Wheel(byte)':
code:31:16: error: 'strip' was not declared in this scope
return strip.Color(255 - WheelPos * 3, 0, WheelPos * 3);
^
code:35:16: error: 'strip' was not declared in this scope
return strip.Color(0, WheelPos * 3, 255 - WheelPos * 3);
^
code:38:12: error: 'strip' was not declared in this scope
return strip.Color(WheelPos * 3, 255 - WheelPos * 3, 0);
^
code: In function 'void rainbow(int, int)':
code:44:29: error: 'strip' was not declared in this scope
for (int i = 0; i < strip.numPixels(); i = i + 3) {
^
code:47:9: error: 'strip' was not declared in this scope
strip.show();
^
code: In function 'void loop()':
code:58:11: error: 'color' was not declared in this scope
rainbow(color, 2);
^
code: In function 'uint32_t Wheel(byte)':
code:39:1: warning: control reaches end of non-void function [-Wreturn-type]
}
^
[ERROR] Took 3.83 seconds
[compile] Error 1
```

Click to Attempt Compilation

code selection test

Step 9: Tone Generation Code

To stop the piezo's beeping, press the *Upload* button in the Arduino IDE.

Next, in software, add code to set up the system to buzz whenever the button is pressed.

Add these statements at the top of the file to define the buzzer pin and note frequency.

```
#define buzzer 4
#define freq 220
```

Then, *just before the end* of `loop()` function, set the `tone` to play when the button is pressed:

```
if (press) {
  tone(buzzer, freq, 10);
  delay(10);
}
```

Pass the tests to continue.
Pass the all tests in the right-hand pane to continue.

Back | Next

```
1  // Starter code - this is a comment.
2
3  #define button 2
4  #define outLED 13
5
6  #define buzzer 4
7  #define freq 220
8
9  void setup() {
10
11   pinMode(button, INPUT_PULLUP);
12   pinMode(outLED, OUTPUT);
13
14 }
15
16 void loop() {
17
18   int press = !digitalRead(button);
19   digitalWrite(outLED, press);
20
21 }
22
```

Testing

Step Tests
Click to start tests.

Begin

code selection test

```
1  // Starter code - this is a comment.
2
3  #define button 2
4  #define outLED 13
5
6  #define buzzer 4
7  #define freq 220
8
9  void setup() {
10
11   pinMode(button, INPUT_PULLUP);
12   pinMode(outLED, OUTPUT);
13
14 }
15
16 void loop() {
17
18   int press = !digitalRead(button);
19   digitalWrite(outLED, press);
20
21 }
22
23  if (press) {
24     tone(buzzer, freq, 10);
25     delay(10);
26   }
```

Testing

Unpassed Tests
Pass the tests to continue.

Next

Code Selection Test

Highlight the part of your code which turns on the buzzer.

Make sure to include the buzzer code line as described in the left pane.

```
int press = !digitalRead(button);
```

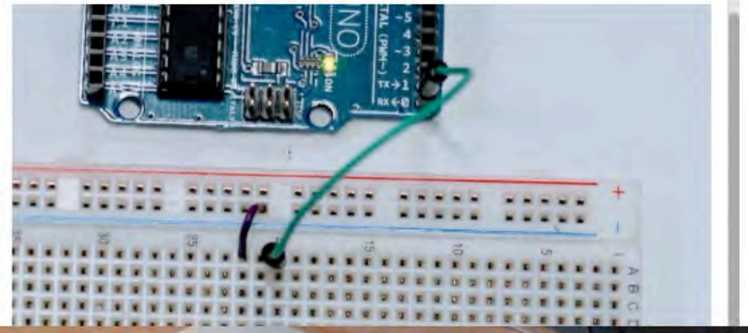
Check Code Selection

knowledge test

Insert the button onto the breadboard, as pictured.

Connect the one side of the button to GND (blue/ground) with a jumper wire.

Connect the other side to digital pin 2 on the Arduino board.



```
3
4  void setup() {
5
6  }
7
8  void loop() {
9
10 }
11
```

Next

Button Press Check

Voltage Knowledge Test

What voltage difference exists between the power (red) and ground (blue) rails?

- 0 V
- 10 V
- 5 V
- 3.3 V

Submit Choice

Hardware Wiring Check

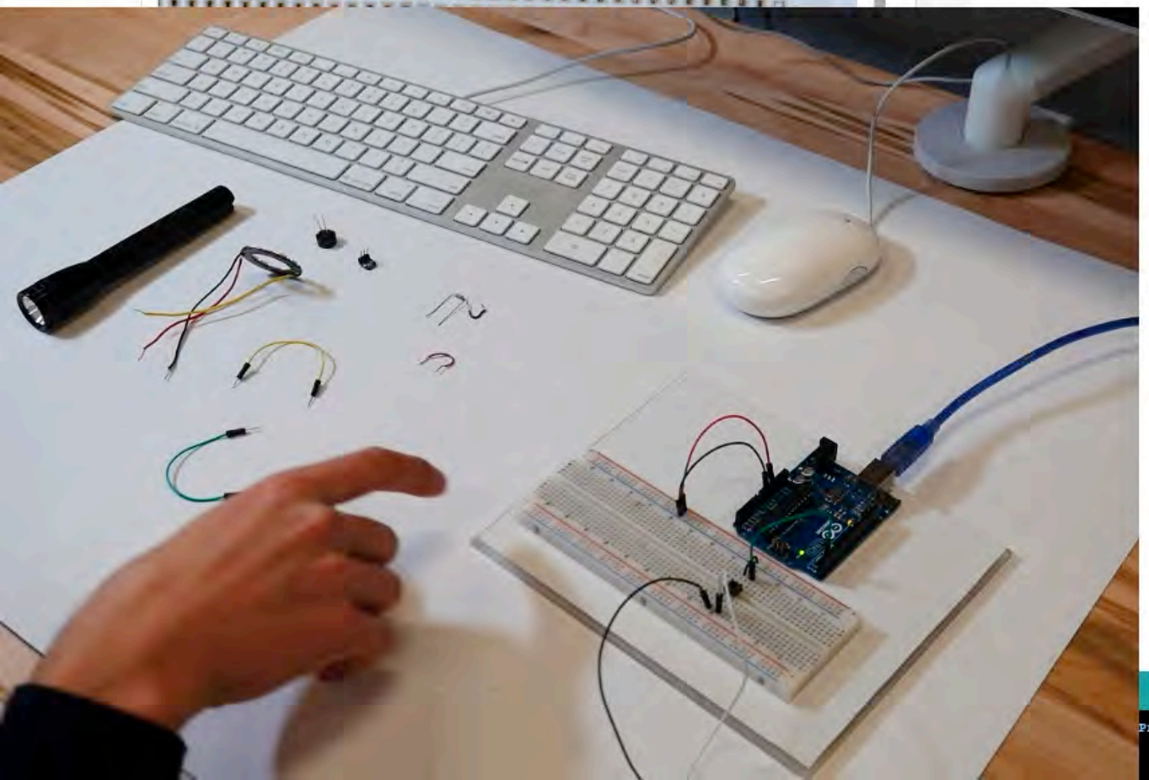
REMOVE THE WHITE AND BLACK PROBES FROM THE CIRCUIT BEFORE DOING THIS TEST

The system will now check to see that you have wired up the board correctly.

Does the Arduino light turn on as you push the button?

Click the button below to begin the test.

Click to Setup and Begin Test



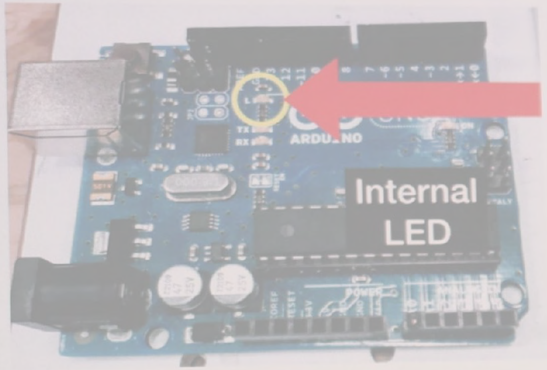
```
Processing uno (platform: atmelavr; board: uno; framework: arduin
```

pinMode(button, INPUT_PULLUP);
pinMode(outLED, OUTPUT);

Last, add this code to the `loop()` function to read the button's value.

```
int press = !digitalRead(button);
digitalWrite(outLED, press);
```

We use a `!` to negate the reading, since when we press the button we pull the pin value to ground (0V). This code will also copy the inverted button state to the onboard Arduino LED, turning it on (high) when we press the button.



Pass the tests to continue.
Pass the all tests in the right-hand pane to continue.

Back

Next

```
}
```

[Thu Apr 5 02:23:41 2018] Processing uno (p
[SUCCESS] Took 4.03 seconds

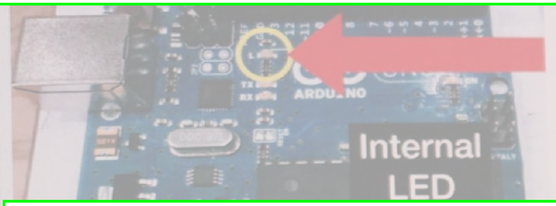
evaluation

evaluation

We were interested in seeing how ElectroTutor would shape participants' ***usage patterns***, ***knowledge retention***, and **subjective experiences** while working with the tutorial.

evaluation

process

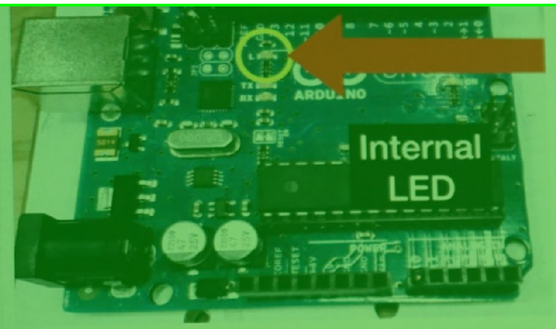


demo

tutorial (45m)

survey/quiz
& interview

evaluation



Last, add this code to the `loop()` function to read the button's value.

Pass the tests to continue.

Pass the all tests in the right-hand pane to continue.

Back

Next

setup

software

hardware

evaluation

conditions

ElectroTutor	tests enabled, pass to progress
Control	no tests, no progress restrictions

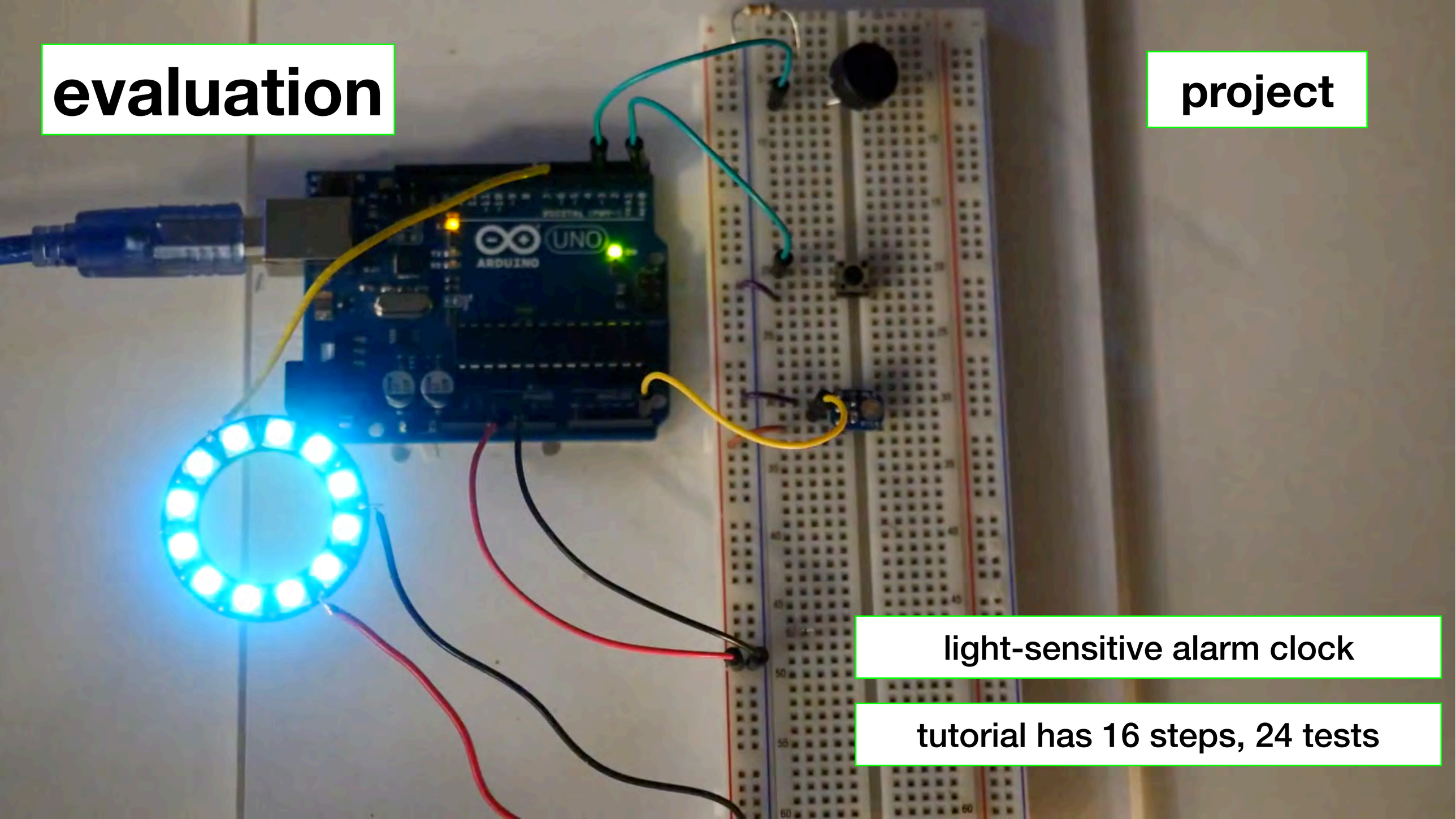
evaluation

participants

participants	12 total (10 male, 2 female, ages 20-54)
study design	between-subjects (6 ElectroTutor, 6 control)
skill	no electronics work, varied software skill

evaluation

project



light-sensitive alarm clock

tutorial has 16 steps, 24 tests

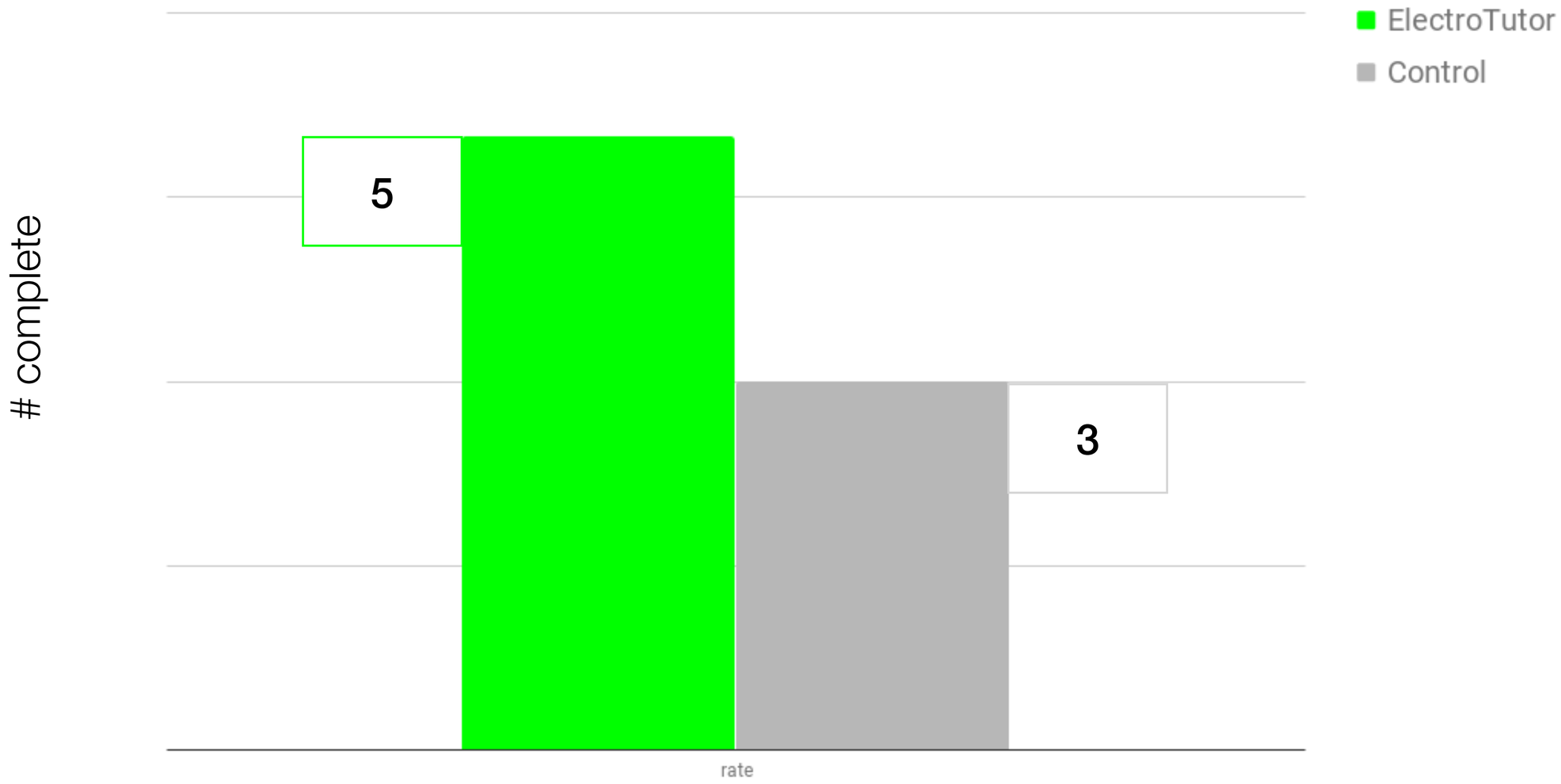
results

completion	completion rate
timing	time to completion
knowledge	post-tutorial quiz
back steps	progression patterns

results

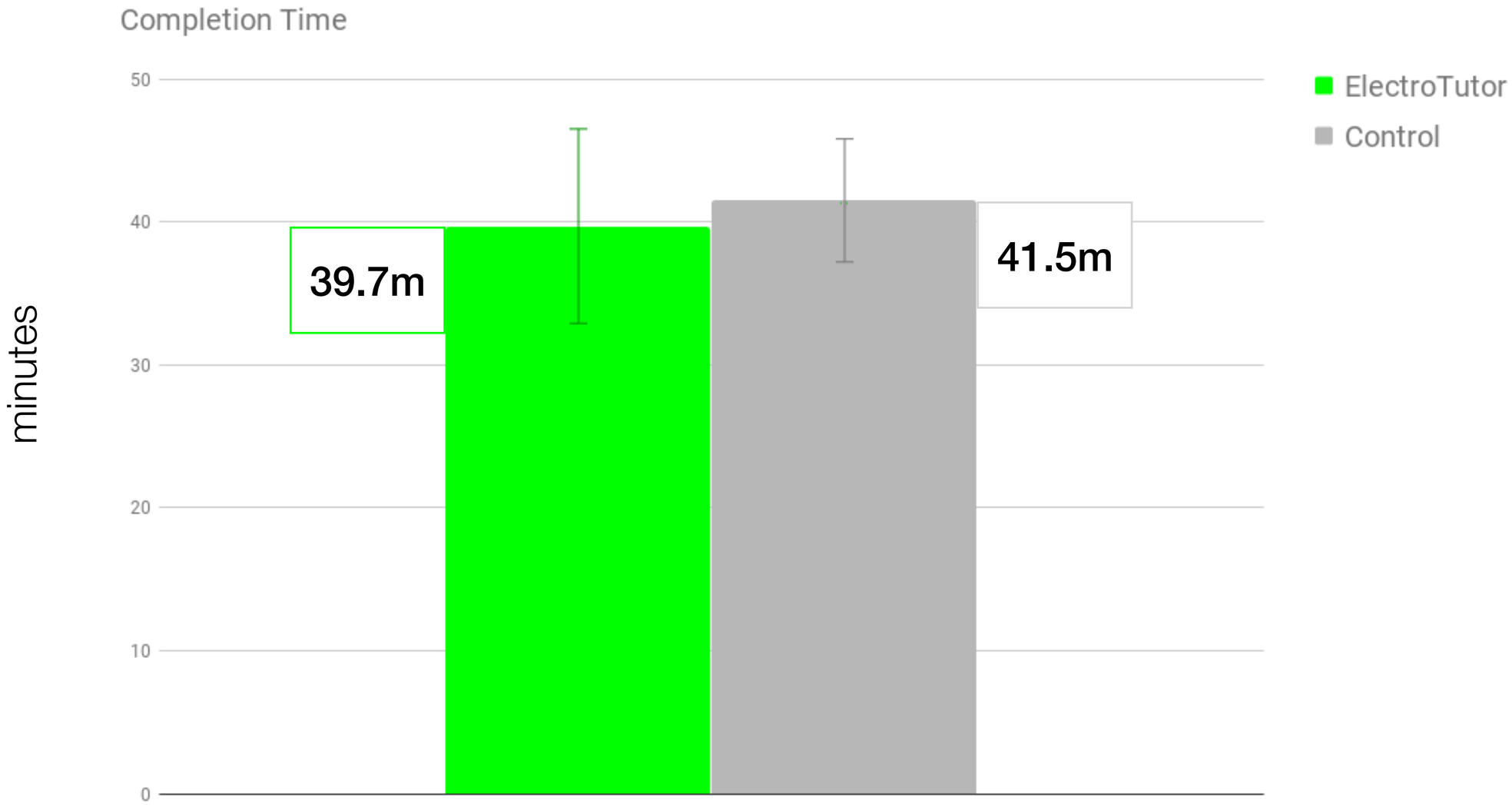
max = 6

completion



results

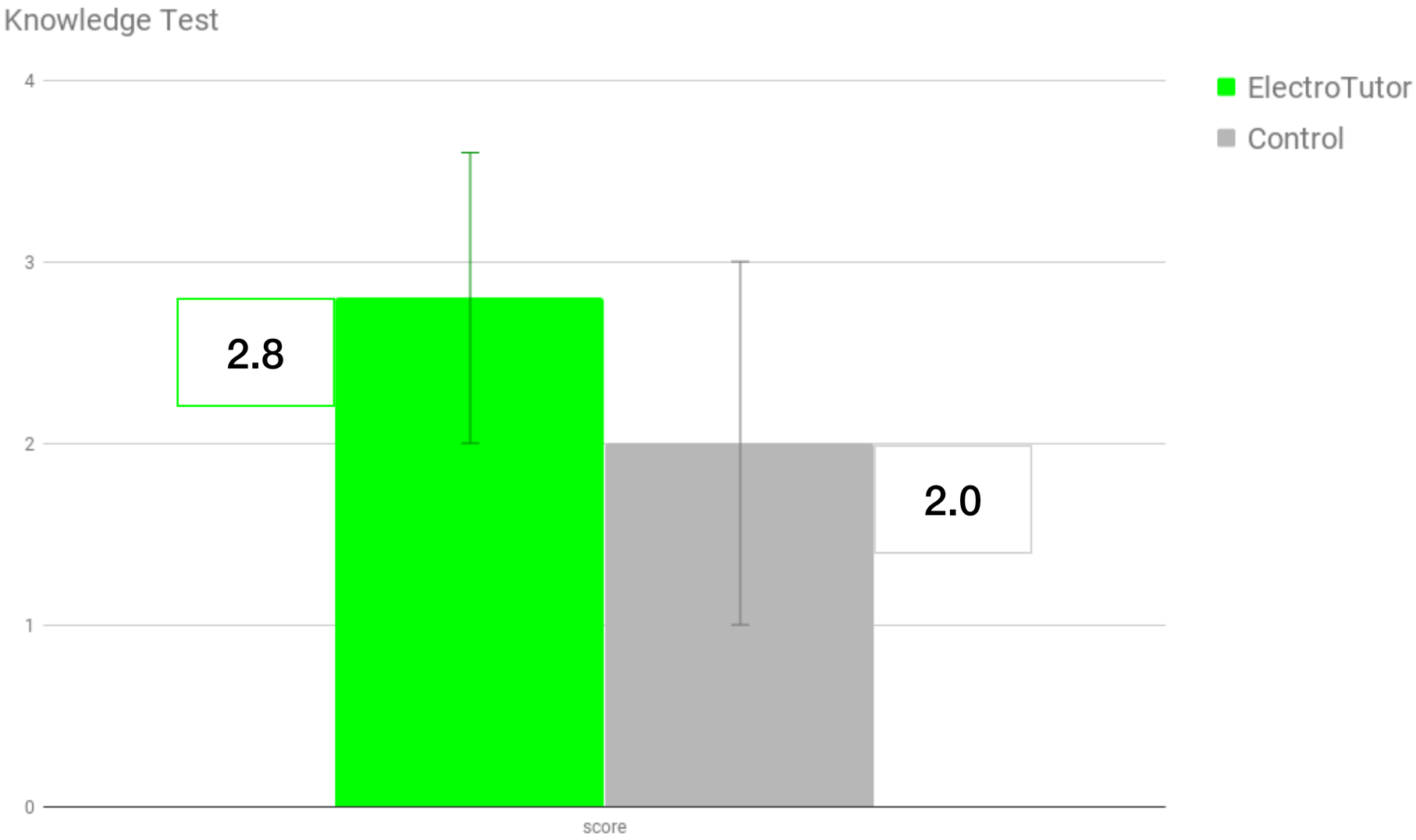
timing



results

max score = 4

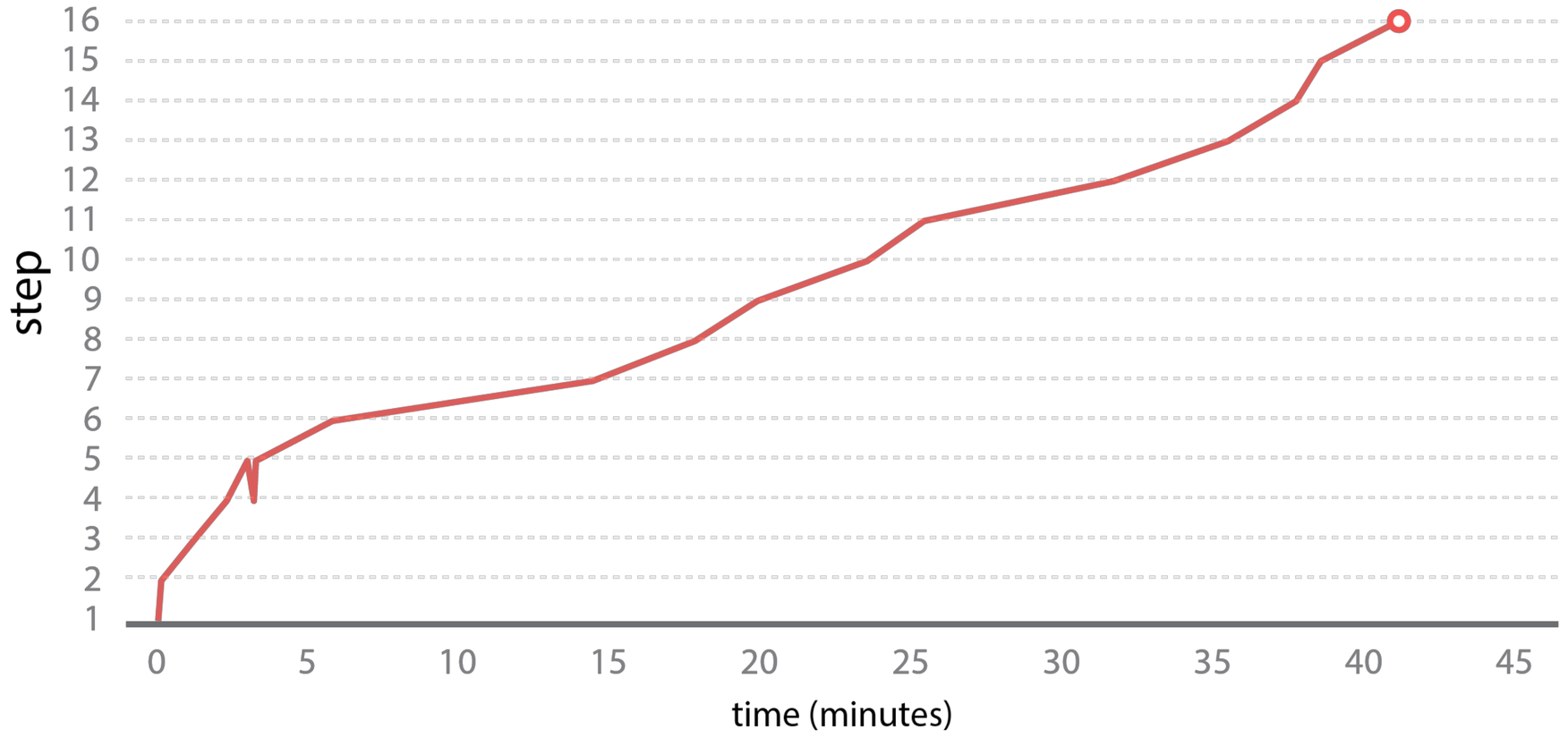
knowledge



results

back steps

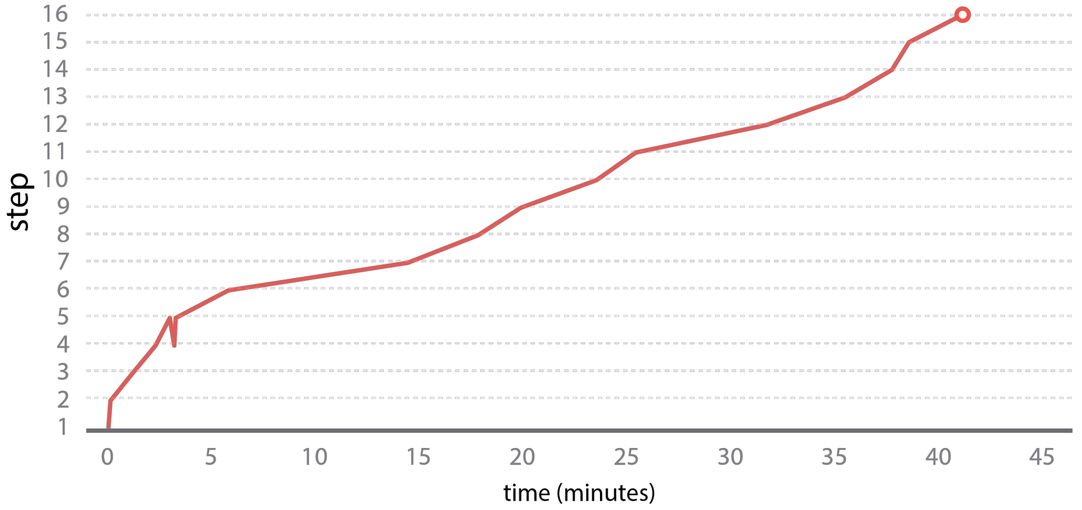
progress

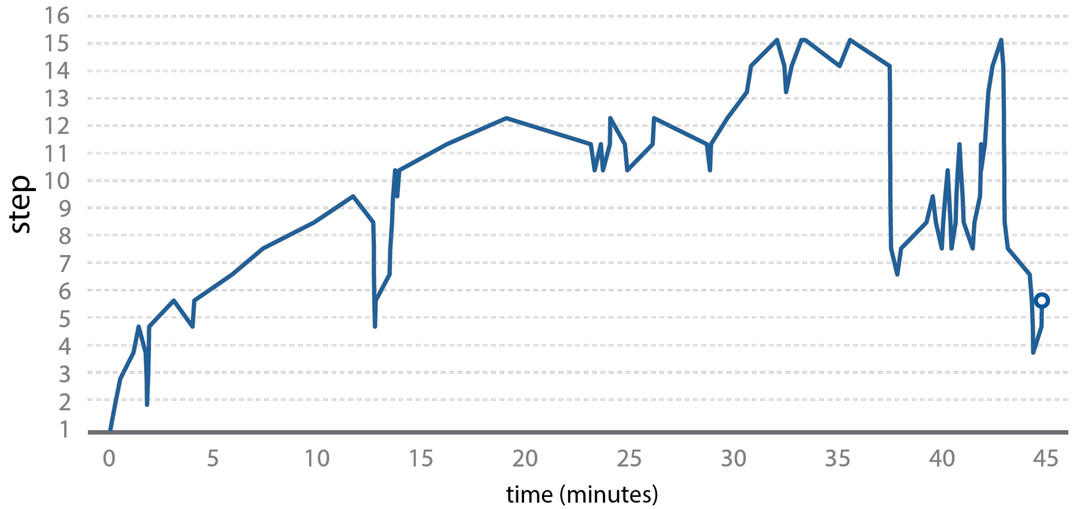


time

results

back steps



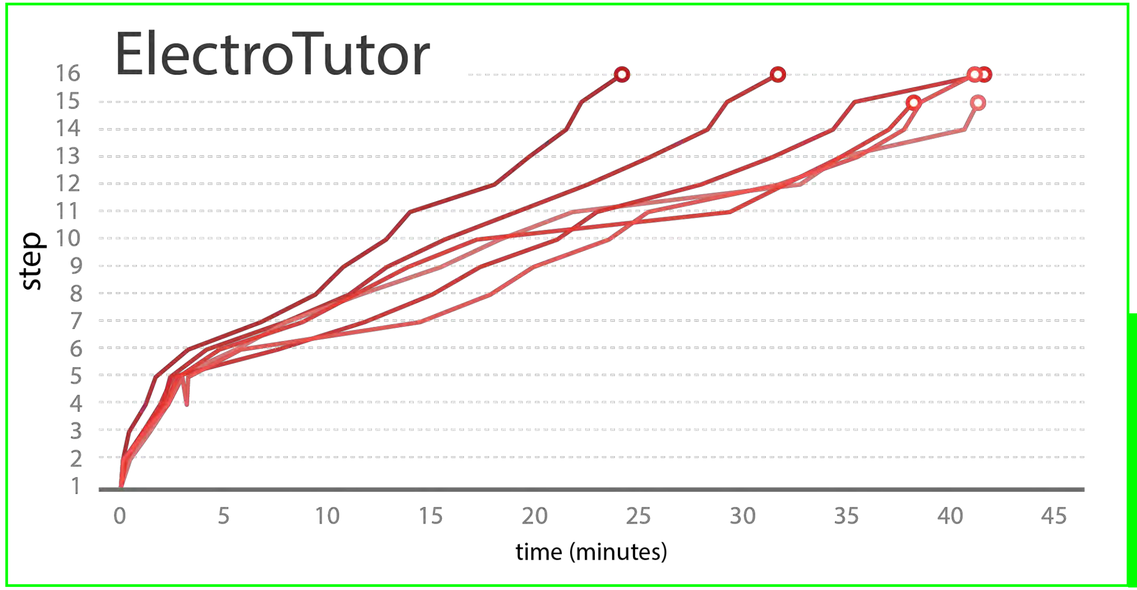


progress

time

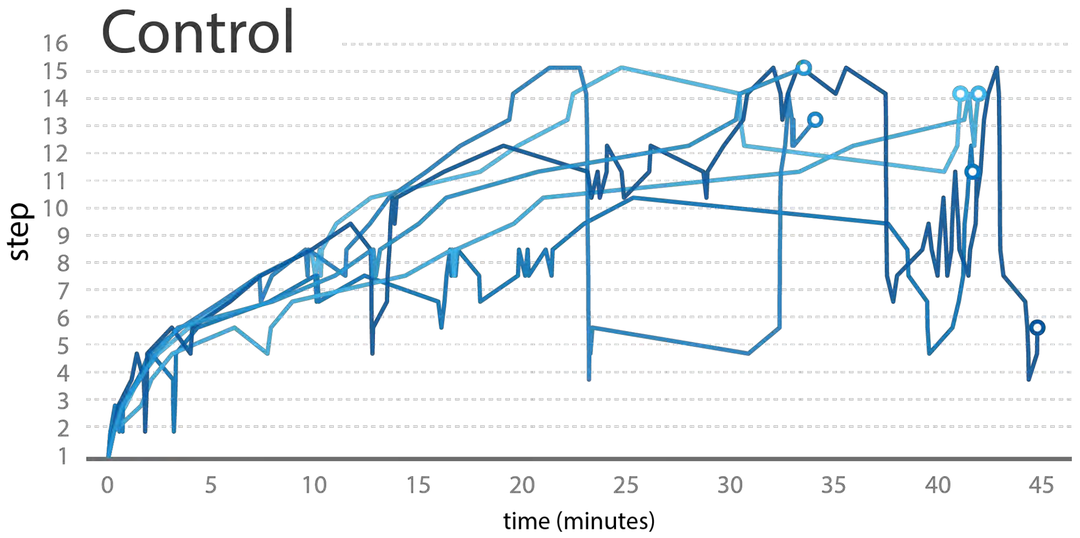
results

back steps



less back steps

0.2 steps average



18.8 steps average

progress

time

feedback

ElectroTutor	tests enabled, pass to progress

It’s fun making things happen. I was never good at electronics in university, so… it’s fun and breaks it down really nicely to make sure that ***you feel very comfortable where you are before you go onto the next thing***.

The tests were definitely helpful. I especially liked the fact that tests were done in a granular manner at each step along the tutorial, so that ***I felt confident throughout the tutorial.***

feedback

Control	tests disabled, no restrictions

I struggled with the hardware part, I was not that familiar with it. It's kind of like, I am following the instructions but ***I am just not sure if I am doing it the right way.***

Did a good job of guiding me to successful completion, but ***did not really educate me on what I was doing***.

future work

1. tutorial authorship interfaces
2. activity review dashboards
3. skill-aware dynamic tutorials
4. supporting formal learning

acknowledgments

Thanks to my collaborators, the Autodesk User Interface Research Group, and David Mellis.

AUTODESK. RESEARCH

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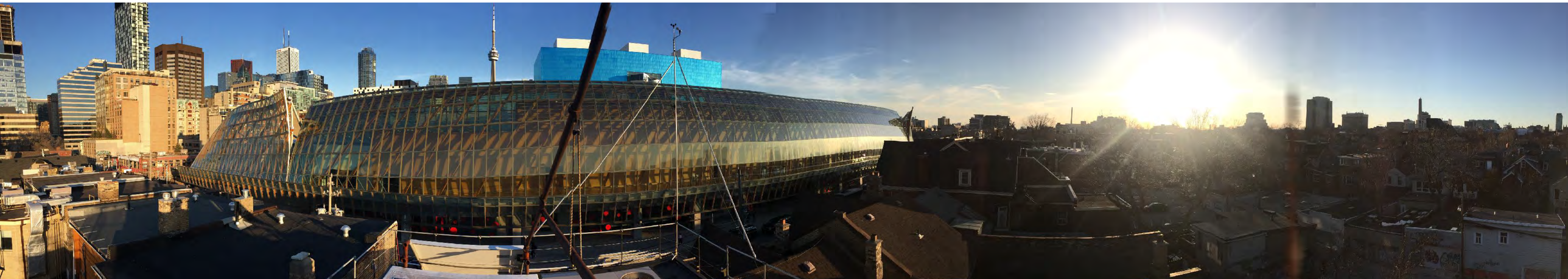
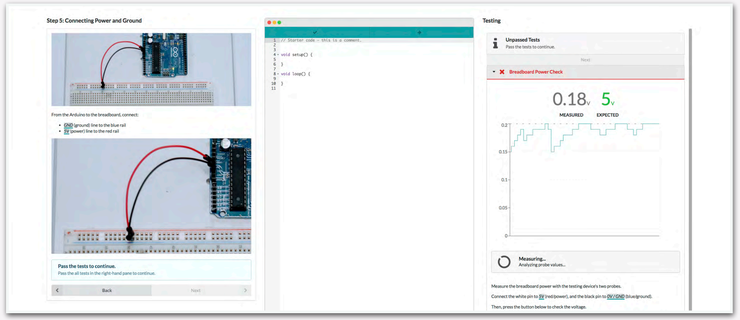
UNIVERSITY OF TORONTO



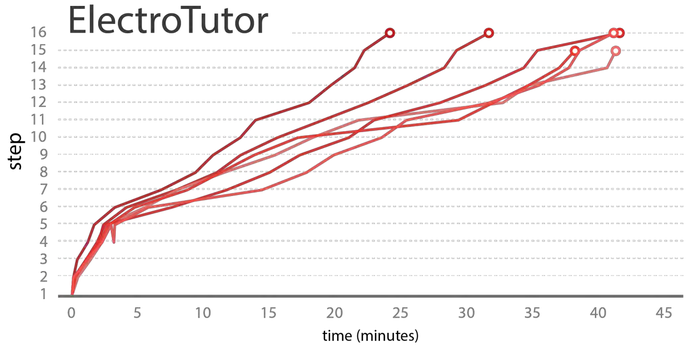
ElectroTutor:

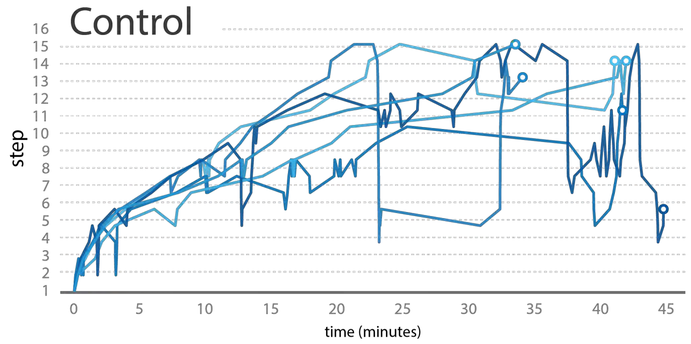
Test-Driven Physical Computing Tutorials



ElectroTutor is a novel system that *integrates tests into physical computing tutorials*. Novices can benefit from incremental tests in physical computing tutorials.

Incremental tests aid novices in problem scoping, and preliminary work points towards the potential for *improved tutorial completion rates*.





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Ben Lafreniere
George Fitzmaurice
Tovi Grossman

Thanks!

`http://bit.ly/electrotutor`

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