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Using Machine Learning to Assess Breadboardia: a Technical Storybook

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Abstract

This paper documents the continuation of a long-term study on the use of storytelling to deliver technical electronics content. Stories have the ability to capture our attention and improve our retention. A particularly dry technical topic becomes engaging when introduced with a personal story. Lessons become more obvious, understood more fully, and retained for longer when delivered in the narrative form. A storybook was developed to introduce first-year engineering students to breadboards. The right-hand pages contain a narrative story about bringing light to a town, and the left-hand pages contain the corresponding technical information instructing students to build a simple LED circuit. The previous study found that a storybook is as effective as a lecture at delivering technical content, and participants who were exposed to the storybook were able to complete the activity faster than those who received the lecture. This paper proposes a revised instrument and protocol that employs machine learning for data analysis to assess technical learning objectives, retention of the material, and anxiety levels related to technology.

Introduction

Just as STEM (Science, Technology, Engineering and Math) has evolved to STEAM (Science, Technology, Engineering, Arts, and Math) in K–12 education with the addition of 'Arts', more artistic forms of learning can be found in traditionally STEM disciplines at the university level. Utilizing a visual medium such as picture books and graphic novels can make scientific concepts more accessible and memorable [1]. One example of this is the use of storytelling in nursing programs [2,3], utilizing a method that mirrors the way the nursing students will receive information from future patients. In a science course, Crocetti and Barr examine the use of storytelling and graphic novels to deliver science literacy concepts [4]. In the engineering field, digital storytelling has become a tool to use the digital medium to convey technical information in a more accessible way to non-technical audiences [5], to learn technical information in a civil engineering laboratory setting [6], and to develop engineering process skills [7]. Lastly, storytelling has been recommended for innovators to find ways to engage decision makers in buying into their idea [8]. Thus, the use of storytelling as a pedagogical practice spans disciplines.

Attempting to make fundamental electronics concepts more interesting, particularly the functionality of a breadboard, a storybook was created to use narrative to teach technical engineering concepts [9]. By supplementing technical content with a narrative, students can remember information in a story better than if it were listed sequentially [10,11], and provide a more accessible and engaging learning experience [12]. However, using storytelling to convey technical topics has the potential to spread "faulty science" if analogies are not clearly conveyed [13], and the experience can be interpreted as patronizing [14]. To reduce the potential for these adverse effects, the storybook was created with both the technical and the whimsical content displayed side-by-side. The storybook entitled *Breadboardia* presents a narrative about bringing light to a town on the right pages, shown in Figure 1, with rough, hand-drawn images to make the technical content feel more accessible. The corresponding left pages present technical content to show how to connect a simple LED circuit.

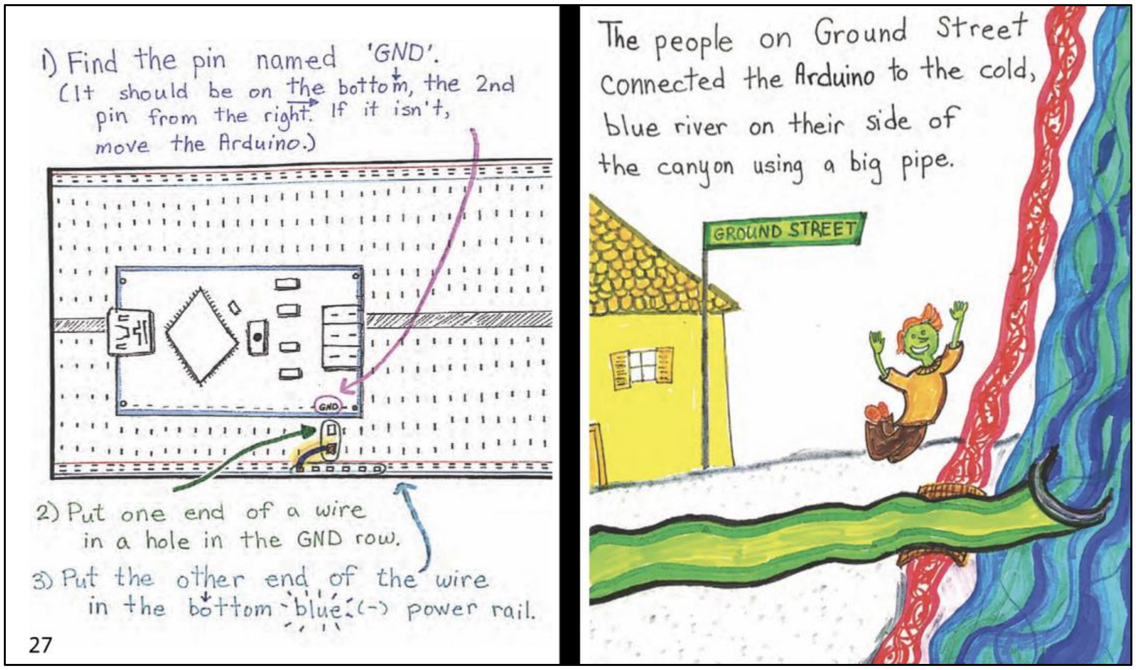


Figure 1. Sample pages from *Breadboardia*: with technical content on the left page detailing how to ground the Arduino and a corresponding narrative on the right.

An instrument assessing the effectivity of the storytelling method showed that the storybook was as effective as a lecture for first-year engineering students [9]. After two rounds of collecting data, lessons learned were developed and a revised instrument was requested to expand the assessment to include retention of the technical content and anxiety levels related to technology. Studies have shown that teachers' anxiety of a topic, particularly a STEM topic can directly affect students' confidence with the subject [15–17]. A storybook has the potential to lower STEM anxiety, particularly through the less-threatening medium of a children's story.

In addition to changing what is being assessed, how the assessment is being performed could also be improved. The traditional step after gathering experimental data is to analyze it with statistical tools and models which infer the relationship between variables to test hypotheses. Then, the scientific method ends with the communication of these results to support informed decision-making. An alternate analytical method is machine learning, which was defined in 1959 as the computer's ability to learn without being explicitly programed to perform a task [18]. While traditional statistical methods draw inferences from a sample, the algorithms in machine learning predict patterns. Adding machine learning analysis techniques to the scientific method allows for insights to surface quickly, extracting knowledge from the data to guide the course of action with optimized algorithms. Machine learning is a branch of Artificial Intelligence (AI) that learns through experience, however, the learning component is dependent on the type of data to be analyzed. Supervised machine learning uses labeled dataset to predict outcomes accurately, while unsupervised machine learning uses unlabeled datasets to discover unknown patterns, without intervention [19–22]. Moving away from a static method of data analysis wherein a hypothesis is statistically confirmed and relationships are inferred, the use of machine learning algorithms will provide this study with accurate predictions generating knowledge about how participants learn, how much information is retained, and how anxiety may interfere with their learning process.

This paper presents the proposed instrument, protocol, and an adaptive assessment technique, incorporating lessons learned from the previous study. This paper is structured in two parts, presenting the findings from two years of data collection and the revised study. It is hoped that the dissemination of this novel pedagogical tool and analytical approach will provide opportunities for discussions and refinement before implementation in the Fall of 2023, as well as inspire educators to adopt similar narrative approaches.

Previous *Breadboardia* Study

Method

Intending to measure whether the storybook can convey the technical content as well as a lecture, students in two sections of a first-year engineering design course were given the option to participate in the study (reviewed by the university research ethics board). One section of students ($n = 28$) was exposed to a 10-minute lecture with engaging slides and an enthusiastic delivery, followed by a hands-on activity to replicate an image of a circuit to light one LED, then three LEDs. The time to complete the two-part activity was recorded for each participant, and then participants completed a survey to assess their technical knowledge of the functionality of breadboards and whether they enjoyed the activity. The second section ($n = 41$) read the storybook, then completed the same timed activity, and concluded with the same survey.

The instrument had two qualitative items (What is a breadboard? What is the red rail generally used for?), a mixed-methods question with three items determining whether participants understood which holes are connected in a breadboard, and three quantitative items self-reporting gender identity, experience, and enjoyment. Gender data were recorded to document whether the purposive sample was inclusive, and previous experience with breadboards and Arduinos were collected for use as a moderating effect. The composition of the groups were similar in regards to gender and previous experience.

The data were analyzed using t-tests comparing time and knowledge variables between the two groups of participants who had no experience with breadboards (novices). Also, two-way ANOVA was employed to compare time and knowledge variables controlling for participant experience and instruction method. These results were published in a conference paper and an expanded journal article [9,23]. The study was repeated the following year in a first-year engineering design course using the same protocol, with 31 students in each of the two sections.

Results

For the first year of study data, novice participants who learned with the storybook connected the circuit with one LED 10 minutes faster than novice participants who received a lecture ($p < .001$), and 12 minutes faster to complete the circuit with three LEDs ($p<.001$) [9]. The novice storybook group performed 6% better on survey than the novice lecture group, though results were not significant. When comparing the four participant groups of novices and experienced participants who received either a storybook or a lecture, the participants with experience performed an average of 7 minutes faster in the activity and 7.3% better in the assessment than novices of either learning method ($p<.001$). There were no significant differences based on gender. The results from the second year of study data confirmed the initial findings that the storybook was as effective as a lecture, allowing the study to progress to the next phase with non-technical participants.

A limitation of this study could be that in addition to the effect of the narrative, the step-by-step instructions in the storybook had an effect on the efficacy of the storybook (as the lecture group were provided with two images of the desired circuits to replicate). However, this first study compared more traditional teaching methods (which do not necessitate step-by-step instructions) to the total benefits of a *storybook* (which include step-by-step instructions), not a *story*. If the study were examining the efficacy of narrative, then the effect of instructions would need to be isolated. However, the study examined the efficacy of the storybook as a whole, which inherently includes instructions.

Recommended Changes to Instrument and Protocol

Observations recorded during the activity and data analysis yielded recommended changes to the instrument and protocol. Anecdotally, the activity for the lecture groups was chaotic, with participants asking numerous questions and requesting support (interventions). However because the storybook provided step-by-step instructions, it was quiet during the storybook group with very few interventions. The recommended protocol should include measuring the number of questions.

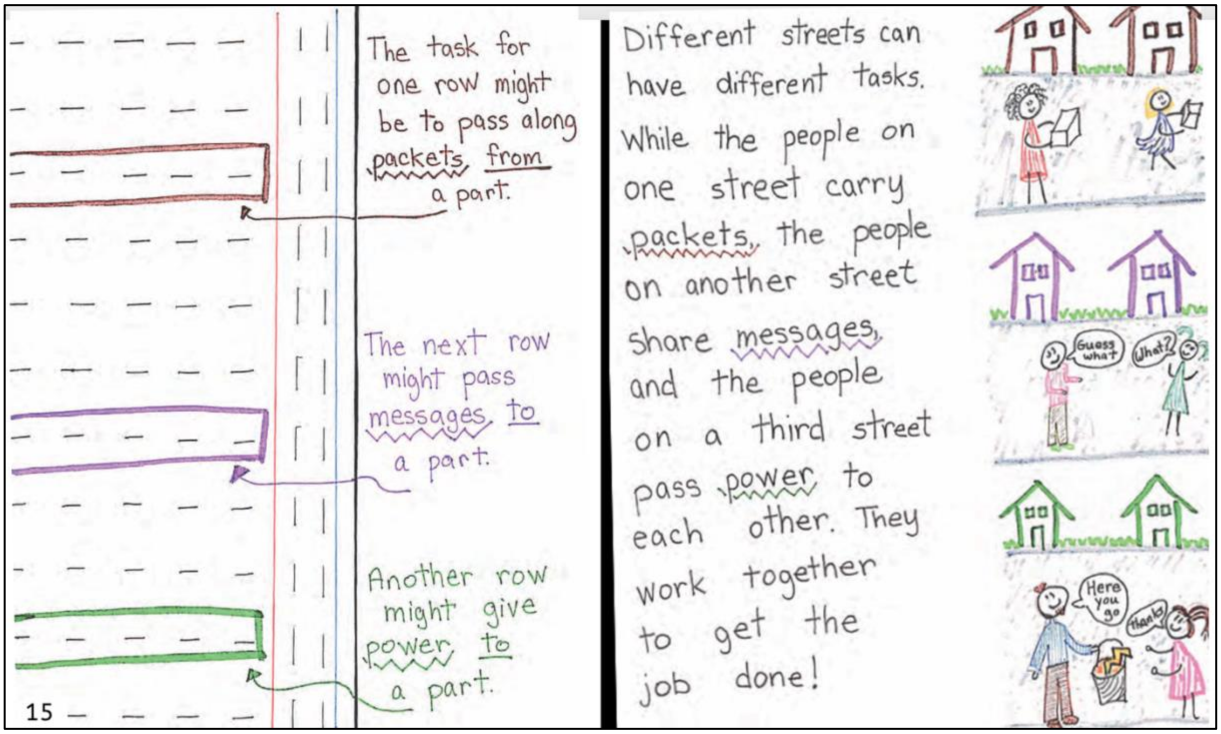
Additionally, once the storybook was shown to be an effective delivery method, *Breadboardia* workshops were offered in grades 5–8, broadening the experience to a non-technical audience. Feedback from teachers refined the storybook protocol. The story (right pages) should be read aloud together at the beginning to ensure participants don't jump to the activity before reading the narrative, and pauses are built in to reinforce important concepts.

For the instrument, qualitative items were used, which required coding by multiple researchers. A quantitative instrument could reduce the bias and analysis time. Also, there were only three technical learning objectives measured in the first instrument, and this number should be expanded to measure more electronics concepts, as well as abstract objectives such as retention and STEM anxiety. In order to measure these abstract effects, a non-technical participant group is needed, such as K–12 teachers and students in grades 5 – 12 who have not used electronics. Engineering students would not be good candidates to measure retention or anxiety, both because they are regularly exposed to circuits, so it would be difficult to isolate the effect of the storybook for retention, and because being in a STEM field, they are less likely to have STEM anxiety.

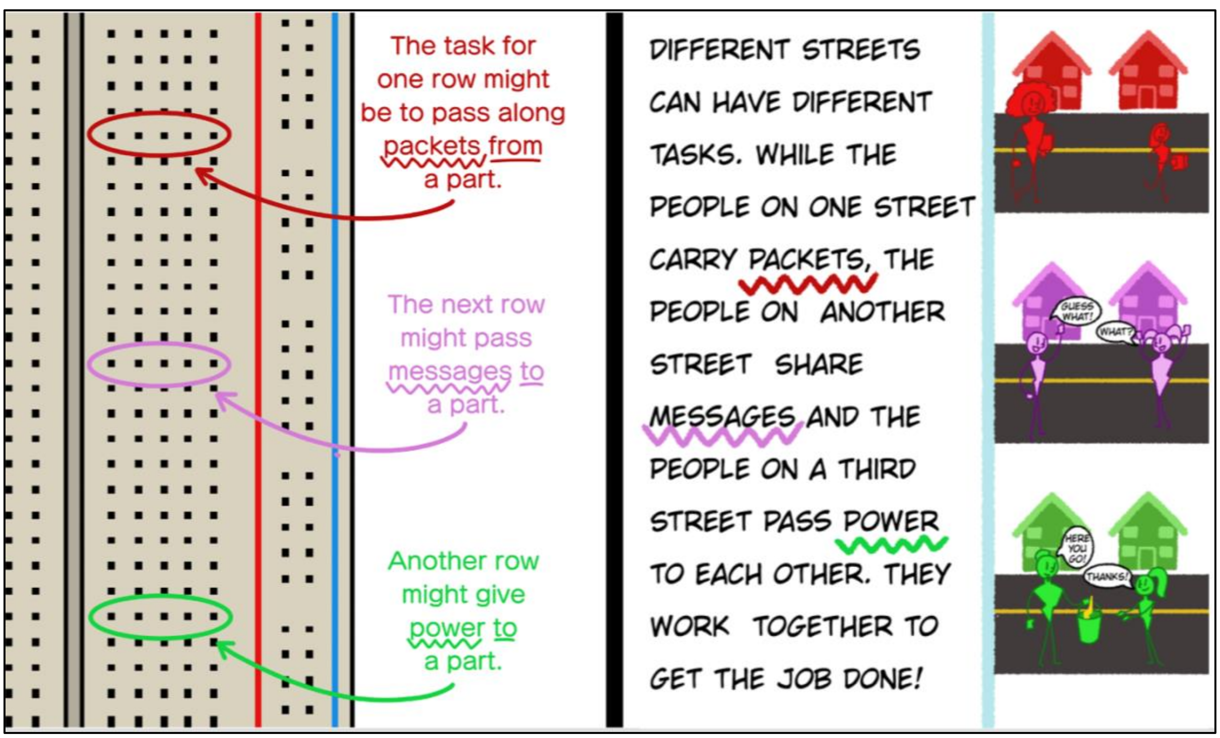
Lastly, the storybook itself was drafted as a template for an artist to produce a more professional version at a later date. A second edition of the storybook should be digitized to clean up the content, while still retaining the accessibility and playfulness of the first edition. Also, a particularly confusing page introducing jumper wires is the source of many questions, and it should be revised to convey the content more clearly.

Revised Storybook and Study

As shown in Figure 2, the digitization of *Breadboardia* has begun and is expected to be completed by April 2023. One of the authors of the paper is a gifted digital artist and engineering student, and he was introduced to breadboards by the storybook during his first year.



(a) Hand-Drawn Pages from First Edition, Drawn by Libby Osgood.



(b) Digitized Pages from Second Edition, Drawn by Aiden McBurney.

Figure 2. Sample digitized pages from *Breadboardia*: (a) with first edition hand-drawn pages on the top and (b) second edition digitized content on the bottom.

His edition of *Breadboardia* retains of the elements of the first edition, but he has created unique characters for the narrative and can represent the breadboard more accurately on the technical pages. He was motivated to work on *Breadboardia* because it is a melding of his passion for art with his schooling and potential career path. Additionally, *Breadboardia* could open new career options for him down the road in fields that use his talents as an engineer and as an artist. His goals with the new edition are to provide an open-source education tool to teach young children the basics of circuit construction using a Breadboard and Arduino in a fun and colorful format. He believes this storybook can help get children invested in STEM/STEAM through a fun and engaging story, easy-to-follow instructions, and hands-on experience with tangible results (lighting up an LED). It has the potential to foster a love of Arduino by making it seem fun, approachable, and easily modifiable, showing children that they can experiment with it to create their own circuits.

Employing the second edition of the storybook, the research questions for the proposed follow-on study are: (1) how well a storybook can convey technical content to non-technical audiences, (2) how technical knowledge learned through a storybook is retained over time, and (3) whether storytelling reduces STEM anxiety. The instrument has been revised to measure five more technical learning objectives and three more abstract objectives. Of the 30 technical, abstract, and functional objectives for the book (published in [9]), Table 1 shows the objectives which are being measured in the two revisions of the instruments.

Table 1. Objectives Assessed in First and Second Instrument.

Objective	In First Instrument	In Second Instrument
Technical learning objectives for readers 1a Explain what a breadboard is & why it is used	x	x
1b Identify which holes on a breadboard are connected	x	x
1c Differentiate positive & negative power rails	x	x
1d Explain how each row can have only 1 purpose		x
1e Complete a circuit to light 3 LEDs	x	x
Abstract objectives of the storybook 2a Translate electronic concepts in an engaging and memorable way		x
2b Empower the reader to feel comfortable using electronics		x
2h Engage curiosity of the reader to problem-solve in their world		x
Complementary technical learning objectives for readers 4a List types of components		x
4b Define the following components & why they are used: Arduino, resistor, LED & jumper wire		x
4c Identify functions of pins on Arduino		x
4e Understand the role of a battery in a circuit		x

In order to measure retention of technical content, data will be collected at three different points.

1) STEM anxiety will be assessed by adapting the Abbreviated Math Anxiety Scale (AMAS) [24] for all STEM elements, similar to how the Science Anxiety Scale is an adaptation of AMAS [25], but using both positively and worded items on a 4-point Likert scale. Demographic data will also be collected at the same time as this STEM Anxiety Scale.

2) Using the previous storybook protocol, the narrative (right pages) of *Breadboardia* will be read aloud together, followed by time to independently complete the activity using the left-hand pages to connect three LEDs in a circuit. The duration will be measured to light one LED and three LEDs, and the number of interventions/questions will be recorded for each participant. Then, participants will complete the instrument to measure understanding of the technical objectives, rate whether they enjoyed the activity, and repeat the STEM Anxiety Scale. They will have access to *Breadboardia* during the entire assessment.

3) Two weeks later, participants will be provided with an image of the completed circuit (from the book) to replicate. The number of questions they ask and the time to light one LED and three LEDs will be recorded. The instrument with the same items that have been reordered will be completed, including the STEM Anxiety Scale. In any remaining time, they will be provided with additional components for experimentation to measure engagement and understanding of concepts.

The instrument is presented in the Appendix and contains the STEM Anxiety Scale. For items within the instrument, offering two choices to select from has been shown to be an effective measure for memory [26]. Multiple choice also allows for faster quantitative analysis. In addition to standard statistical techniques, the quantitative and coded qualitative items will be analyzed using unsupervised machine learning exploring different clustering algorithms, such as K-means clustering, Density-based spatial clustering (DBSCAN), Gaussian Mixture Model, Mean-Shift clustering, and Ordering Points to Identify the Clustering Structure (OPTICS).

Limitations

A potential limitation of this research approach is that there is no control to compare against. In the first study, it was difficult for the researcher to provide a lecture when the same learning results were possible with a more engaging method (the storybook). Participants who were in the lecture group later expressed frustration that they did not learn with the storybook. Since the revised study is being deployed in non-technical settings, there could be long-term effects potentially resulting in STEM avoidance, particularly with a didactic lecture. Because the previous study documented the effectivity of the storybook compared to a more didactic teaching method, there is no lecture control group required.

Also, while the current delivery method incorporates kinesthetic and visual learning for the technical content on the left-hand pages, only the story on the right-hand pages are delivered auditorily. A future protocol could incorporate reading the left-hand pages or an audio file for students who request it to use auditory learning for the technical steps on the left-hand pages.

Conclusion

This paper describes a novel analysis technique of a revised instrument to measure the retention, anxiety, and effectivity of using a newly digitized storybook to convey technical content. Building upon the previous study, the instrument will measure an expanded set of fundamental electronics concepts as well as three of the abstract objectives driving the development of the storybook. *Breadboardia* has been revised from a hand-drawn first edition to a digitized second edition, clarifying a step that students have had the most trouble with. The participant group will be expanded to a non-technical audience, to see if the storybook can be an effective, nonthreatening way to encourage participation in STEM. The analysis techniques will utilize machine learning in order to generate knowledge about the mechanisms of learning, enabling these results to be use in personalizing learning methodology to enhance the academic pathway of the learner. This paper is submitted to get feedback on this approach as well as to encourage educators to incorporate narrative and novel forms of learning to convey technical content. With the prevalence of graphic novels, how might the ancient practice of storytelling be welcomed into technical learning spaces?

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Appendix: Proposed Instrument

1. Demographic data (only on pre-instrument):

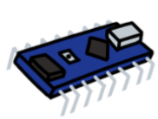
a) Gender Identity: Female Male Non-binary In my own words
b) Grade (for students): or Number of years teaching (for teachers):
c) Rate the amount of experience you have with Arduinos and Breadboards:
   i. None A little Some A lot Expert

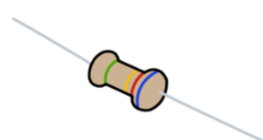
2. STEM Anxiety, Preference, and Engagement Likert Items

	Strongly Agree	Agree	Disagree	Strongly Disagree
STEM Anxiety Scale* (also on pre-instrument) I feel comfortable starting a new topic in science.				
I like to learn new math concepts.				
Trying out new technology is fun.				
I like to design things.				
Problem solving is hard.				
Science class is boring.				
I am not good at math.				
When I come across a new technology, I am scared I might break it.				
Preference / Enjoyment / Real-world connection: This activity was fun.				
This was easy.				
I don't want to use circuits ever again.				
The storybook made it easier to learn.				
The story didn't help me learn electronics.				
I want to solve problems like this to help people.				
I can think of ways to help people using technology.				

3. A breadboard:
a) is a chip that can be programmed to perform different functions
b) is only used once to
c) allows you to move components around to make different circuits

4. Match the name to each component.
a) Resistor
b) Arduino chip
c) LED
d) Jumper wire






5. A resistor:
a) Reduces the power flow to protect the LEDs.
b) Increases the power flow to protect the LEDs.
c) Stops all power from flowing.

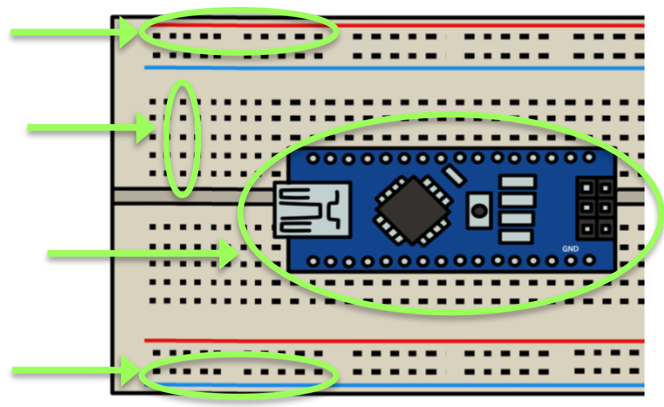
6. Match the power rail with the descriptions.

a) Positive
b) Negative

Connects to power in (Vin) on the Arduino to supply/provide power.
Connects to ground (GND) on the Arduino to return power to the battery.
Connects to power in (Vin) on the Arduino to return power to the battery.
Connects to ground (GND) on the Arduino to supply/provide power.

7. Label the different parts of the breadboard.

a) Positive power rail
b) Negative power rail
c) Row
d) Arduino



8. Which of the following correctly connects different parts of the breadboard? (Check all that apply)