

From Schematic to Breadboard: A Constrained Visual Interface for Teaching Introductory Electronics to Children

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Abstract

Electronics and breadboarding are fundamental entry points into computing, physical making, and engineering literacy. Yet in many K–6 contexts, the logic of circuit construction remains underexplained: children may encounter electronic modules or pre-packaged kits, but are not always supported in understanding why a circuit works, how current flows, or how a schematic maps onto a physical build. We present the design of a browser-based learning platform that teaches introductory electronics through a constrained, highly visual breadboarding interface. The system guides learners from schematic to physical circuit using linked 2D and 3D views, puzzle-like placement constraints, and stepwise instructional image cascades inspired by the clarity of construction toys. Rather than replacing circuit reasoning with opaque module composition, the platform is intended to preserve the realities of circuit building while making them more approachable, inspectable, and teachable. We outline the motivation, design principles, interface structure, and initial curriculum progression of the system, including modules on components, breadboard basics, LED circuits, switches, and potentiometers. We also discuss how constrained visual construction may support learner exploration, instructor inspection, and productive mistakes around core concepts such as power, batteries, and Ohm’s law.

CCS Concepts

• **Human-centered computing** → **Interaction design for children**; • **Applied computing** → **Interactive learning environments**; *Computers in other domains*.

Keywords

breadboarding, electronics education, K–6 learning, visual programming, constructionist learning, circuit education, educational interfaces

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1 Introduction

Electronics and breadboarding are foundational topics in computing and engineering education, but they are often introduced late,

taught only in specialized physics settings, or reserved for introductory college courses. For younger learners, the “magic” of electronics can remain hidden: components light up, buzz, or respond, yet the underlying circuit logic is not always made explicit.

Many existing platforms successfully reduce friction for beginners, but they can also abstract away the act of circuit building itself. Modular kits and snap-based systems can help children engage with electronic artifacts, yet may leave unexplained why a build works, what role each component plays, and how a symbolic schematic relates to a real breadboarded circuit. This motivates a different design question for child-centered electronics learning: how might we preserve the realities of circuit construction while still making it approachable, visual, and fun?

We present an in-progress platform for teaching introductory electronics through constrained visual circuit building. The system allows children to build circuits from schematics while viewing synchronized 2D and 3D circuit representations. A puzzle-like interface constrains wire lengths and component placements to reduce overwhelming choice without removing core circuit reasoning. The goal is not to turn breadboarding into a black box, but to help learners understand components, schematics, and the mapping between symbolic and physical circuit representations.

This paper contributes:

- a child-centered framing for breadboarding as a teachable visual translation problem between schematic symbols and physical components;
- a constrained interface concept that combines schematic, 2D breadboard, and 3D physical views;
- a curriculum-oriented design structure for introductory modules in electronics; and
- a set of design principles for instructor-readable, inspectable, and mistake-tolerant circuit learning.

2 Motivation and Design Rationale

Our work is motivated by a gap in current introductory electronics experiences for children. Some products expose children to components and playful interaction, but do not explicitly teach circuit construction. In such systems, the reason a build works may remain implicit, and lesson progression can feel like “it just works” rather than “this is why it works.” Other systems support fast assembly, but their component vocabulary may be limited, constraining how far learners can progress toward genuine circuit reasoning.

In contrast, our design aims to foreground the act of building a circuit from a schematic. The system is intentionally visual because the visual layer serves an instructional purpose: it helps map real-life components to schematic parts and back again. By keeping circuits clean, color-coded, and spatially legible, the platform is also

designed to support instructors, who need to inspect student work quickly and compare it against a reference configuration.

We also position expansion modules as extensions rather than the core of learning. The core experience should introduce children to components, schematics, breadboard structure, and basic circuit logic before widening into more advanced modules or accessories.

3 Related Work

3.1 Snap-based electronics kits

A useful point of comparison is the family of snap-based beginner electronics kits typified by Snap Circuits. These systems lower the barrier to entry by providing large, color-coded modules that physically “click” together, making early construction feel approachable and puzzle-like [4]. This physical clarity is a strength: for young learners, the size, color, and tactile feedback of the pieces can make electronics feel less intimidating than loose components and jumper wires. At the same time, such kits are typically bounded by the specific modules included in the set, and classroom activity can drift toward assembling known configurations rather than learning how a schematic maps onto a more open-ended prototyping medium. Our system takes inspiration from the legibility and attractiveness of this style of kit, but aims to retain the transfer value of breadboarding.

3.2 Simulation-first learning environments

Another important line of existing work comes from screen-based simulation tools. PhET has shown how interactive simulations can support conceptual learning by giving students multiple linked representations and opportunities for exploratory manipulation [5]. In electronics specifically, Tinkercad Circuits offers a browser-based environment for building and simulating breadboarded circuits, making it easier for beginners to experiment without the friction of physical setup [1]. These systems are powerful for access, iteration, and conceptual rehearsal. However, they do not fully solve the representational jump between schematic symbols, a planar breadboard layout, and the look and feel of physical components in front of a child. Our approach therefore borrows the accessibility of browser-based simulation while emphasizing tightly linked schematic, 2D breadboard, and 3D physical views, as reflected in the lesson composition shown in Figure 1.

3.3 Manipulatives, color, and tangible learning

Our work is also informed by research on manipulatives and tangible learning. Across mathematics education, a meta-analysis found small-to-moderate benefits for concrete manipulatives compared with instruction using only abstract symbols, while also showing that instructional design matters greatly [3]. Cuisenaire rods are a longstanding example of color-coded tangible materials used to make relational structure visible; in the Cuisenaire–Gattegno tradition, rods of the same size share the same color, and learners coordinate visual, tactile, and symbolic reasoning through direct construction [2]. We do not claim that breadboards should function exactly like mathematics manipulatives, but these lines of work suggest that color, discreteness, and tangible structure can help learners notice relationships rather than merely memorize steps. This is one reason our interface treats wires and components as

constrained, visually distinct pieces rather than as unconstrained placements from the outset.

4 Design Goals

The platform is guided by the following design goals.

4.1 Build from schematic, not just from imitation

The central goal is to help children build a circuit from its schematic rather than only copying an arrangement of parts. The interface therefore keeps the schematic visible and links it to the breadboard representation.

4.2 Support linked 2D and 3D understanding

The system includes both a 2D breadboard view and a 3D view. The 2D view emphasizes correctness, connectivity, and placement. The 3D view helps learners recognize real-world components and understand how a physical build should look.

4.3 Use constraints as pedagogical scaffolds

The interface constrains actions in a puzzle-like manner, similar to construction systems that use discrete pieces. For example, wire lengths and placements can be limited to a manageable set of valid options. These constraints are intended to reduce unnecessary complexity while preserving authentic circuit structure. Figure 4 highlights the real-world component vocabulary and bounded wire set that motivate this design choice.

4.4 Make instruction visually progressive

An instructional image cascade is a key part of the system. Stepwise visual progression can show learners exactly what changes between steps and can support lesson pacing in a way that is easy to follow in classrooms.

4.5 Make circuits easy to inspect

Clean wiring, clear colors, and consistent placement should help instructors rapidly compare student work to a reference build. This is especially important in classrooms, camps, and workshops where instructors must assess many builds quickly.

4.6 Preserve room for productive mistakes

The platform should not eliminate errors; instead, it should make them learnable. Allowing students to make and inspect mistakes may create opportunities to learn concepts such as power flow, batteries, short circuits, and Ohm’s law.

5 System Overview

6 System Design

The platform runs in the browser and links three views of the same circuit state: a symbolic schematic, a 2D breadboard build view, and a 3D physical rendering. Children follow guided lesson steps while placing wires and components into the breadboard view, with constrained interaction used to reduce overwhelming choice rather than remove circuit reasoning.

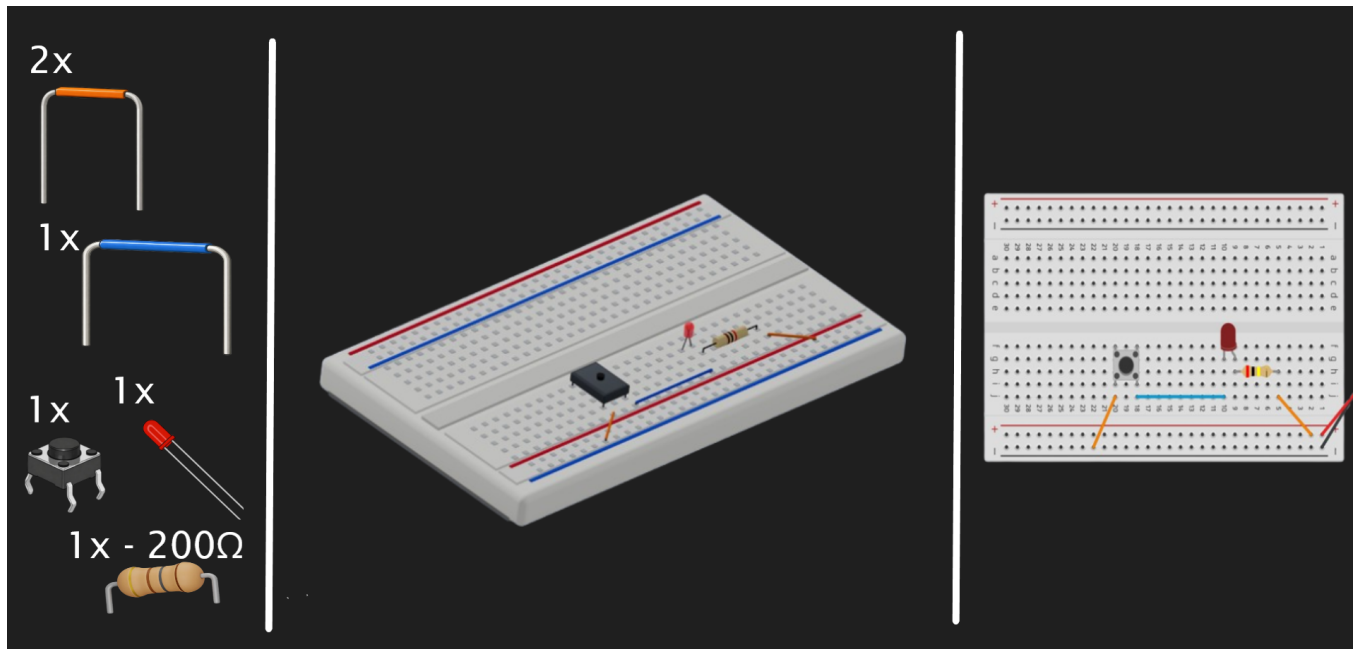


Figure 1: Example lesson composition view showing the relationship between required parts, a 3D physical rendering, and a 2D breadboard target layout. This is the central representational bridge of the system: learners can see what pieces are needed, what the assembled circuit should look like physically, and where those pieces should be placed on the breadboard.

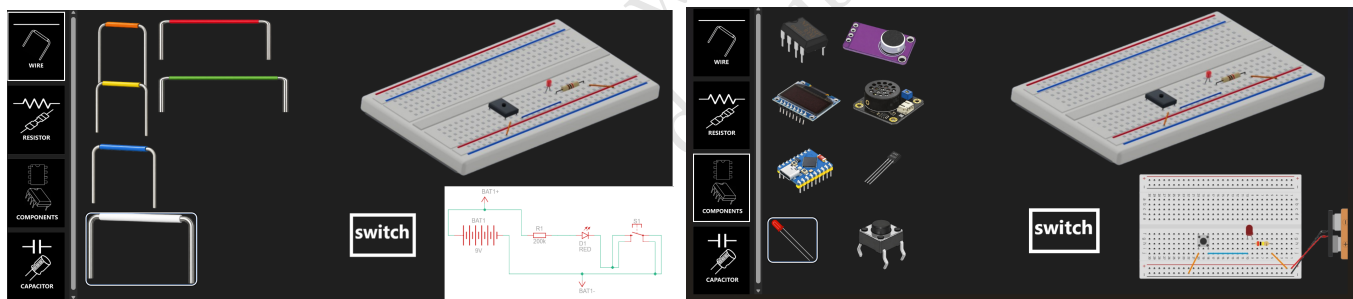


Figure 2: Interface views for constrained selection and placement. Left: a wire-focused palette presenting a small number of discrete jumper lengths and colors alongside the current lesson target. Right: a component-focused palette that surfaces additional parts while maintaining the linked 3D and 2D reference views. Together, these interfaces illustrate how the platform narrows available actions without hiding the underlying circuit structure.

The 3D view mirrors the build so learners can connect symbolic, planar, and physical representations. Figure 3 shows the small starter set of real materials used in early lessons, while Figure 1 shows how a lesson step coordinates required parts, a 3D assembly preview, and the target 2D breadboard layout.

7 Interface Structure

7.1 Schematic-to-breadboard mapping

A major function of the visual interface is to map real-life components to their schematic counterparts. Instead of treating the schematic as an advanced representation introduced later, the system treats it as a live instructional companion to the build process.

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7.2 Puzzle-like placement constraints

Rather than allowing arbitrary placement from the outset, the interface offers a constrained set of wire pieces and components that behave like discrete building primitives. In particular, jumper wires are restricted to a small vocabulary of fixed lengths, each mapped to a color and pin span. This is intended to make early circuit construction feel more like assembling with recognizable pieces than routing unconstrained wires, while still preserving authentic breadboard structure. The wire and component palettes in Figure 2 demonstrate how the system exposes only a bounded set of choices at each stage, and Table 1 summarizes the standardized wire set used in the system.

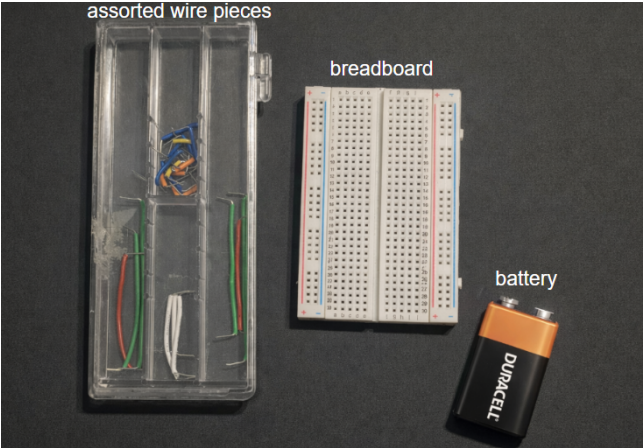


Figure 3: Core physical materials used in the early lessons: a standard breadboard, a 9V battery, and a small set of pre-cut jumper wires. This framing reflects the system’s emphasis on approachable starter materials before introducing more complex circuit assemblies.

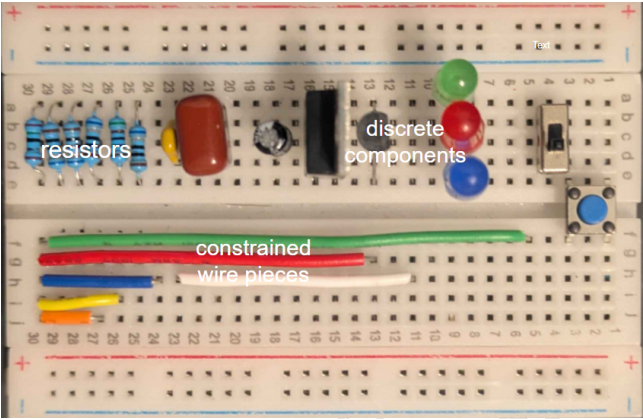


Figure 4: Annotated example of the component vocabulary foregrounded by the platform, including resistors, discrete components, and constrained wire pieces. The use of a bounded, visually distinct parts set supports the platform’s puzzle-like scaffolding strategy.

7.3 Instructional image cascade

The interface emphasizes a cascade of instructional images or steps, where each stage clearly communicates what is added or changed. This supports both self-guided learners and classroom facilitation. Figure 1 illustrates this progression-oriented structure.

7.4 Clean visual language for classroom readability

Color, spacing, and neat routing are intentionally emphasized. These choices are not merely aesthetic; they make it easier for instructors to inspect circuits and for students to compare their work to a reference state.

Illustration	Color	Pin span	Length (mm)
	Orange	3 pins	6
	Yellow	5 pins	10
	Blue	7 pins	13
	White	12 pins	28
	Red	17 pins	41
	Green	25 pins	58

Table 1: Constrained jumper-wire set used by the interface. Each wire acts as a discrete building piece with a fixed color, pin span, and physical length, allowing circuits to be composed from a small, standardized vocabulary rather than arbitrary wire routing.

7.5 Instructional image cascade

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8 Curriculum Scope

The curriculum begins with fundamentals before expanding outward. The core focus is conceptual fluency with components, schematics, and breadboard logic.

Our initial module sequence includes: (1) intro to electronics, (2) basic components, (3) breadboard basics, (4) a first LED circuit, (5) an LED circuit with a switch, and (6) an LED circuit with a potentiometer. Together, these modules introduce component identity, breadboard structure, and the logic of simple circuits.

9 Learning Opportunities Through Mistakes

A core premise of the platform is that students should be able to make mistakes in ways that remain legible and instructive. Because the system is visual and structurally constrained, errors can still occur, but they can be surfaced in interpretable forms. This opens opportunities for learning around topics such as:

- Ohm’s law,

- power and polarity,
- batteries and supply rails,
- component function, and
- basic circuit structure.

Rather than framing mistakes as failure states to be fully prevented, we view them as moments for feedback, inspection, and discussion.

10 Discussion

This project argues for a middle ground between open-ended breadboarding and opaque educational electronics kits. Too much openness can overwhelm novices, while too much simplification can hide the very circuit logic learners should understand. Our proposed system uses visual scaffolding and constraint not to replace electronics reasoning, but to stage it.

An important open question is how much constraint best supports learning without reducing agency. Another concerns how children move from constrained building toward freer circuit design. These questions motivate future classroom deployment and iterative refinement.

11 Conclusion

We presented a design skeleton for a child-centered breadboarding platform that teaches introductory electronics through constrained visual circuit construction. By linking schematic, 2D, and 3D views, emphasizing inspectable and clean builds, and supporting productive mistakes, the system aims to make electronics more understandable rather than merely more accessible. We see this as a step toward bringing authentic circuit reasoning into earlier learning environments in ways that are approachable, visual, and classroom-ready.

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