

# Cube-in: A Learning Kit For Physical Computing

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## ABSTRACT

We present *Cube-in*, a learning kit designed to teach beginners about fundamental concepts in physical computing. Through play and observation, Cube-in users experience digital and analog signals, inputs and outputs, and mapping between inputs and outputs before they work on electronics and construct circuits. By simplifying interaction methods, Cube-in provides an accessible entry point to key physical computing concepts.

## Categories and Subject Descriptors

H.5.m. Information interfaces and presentation: Miscellaneous.  
K.3.m Computers and Education: Misc.

## General Terms

Design, Human Factors

## Keywords

Tangible Learning, Physical Computing, Digital Craft

## 1. INTRODUCTION

The intersection between ubiquitous computing and today's maker culture is growing. An increasing number of maker events, workshops, and classes call attention to this emerging field of digital craft. Accordingly, many institutions also offer introductory physical computing classes, many of which start with teaching students how to use the Arduino microcontroller [1] with sensors and actuators. Although students use electronic devices every day, in this introductory class many encounter their lack of knowledge of basic electronics. The need to acquire fundamental concepts such as input and output, or power ( $V_{cc}$ ) and ground, can overwhelm students and inhibit more advanced learning.

Cube-in is a learning kit for those beginners, a first steppingstone to understanding basic electronics. By inserting physical component cubes in Cube-in's base cube, a learner can observe and grasp fundamental concepts in physical computing, such as the difference between digital and analog signals, inputs and outputs, and functional mappings between inputs and outputs.

The Cube-in is accessible to any beginners. Through simple tangible interactions, learners build a solid foundation of knowledge before they begin working with microcontrollers and electronics components to build designs.

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Figure 1. A simple interaction with the Cube-in kit.

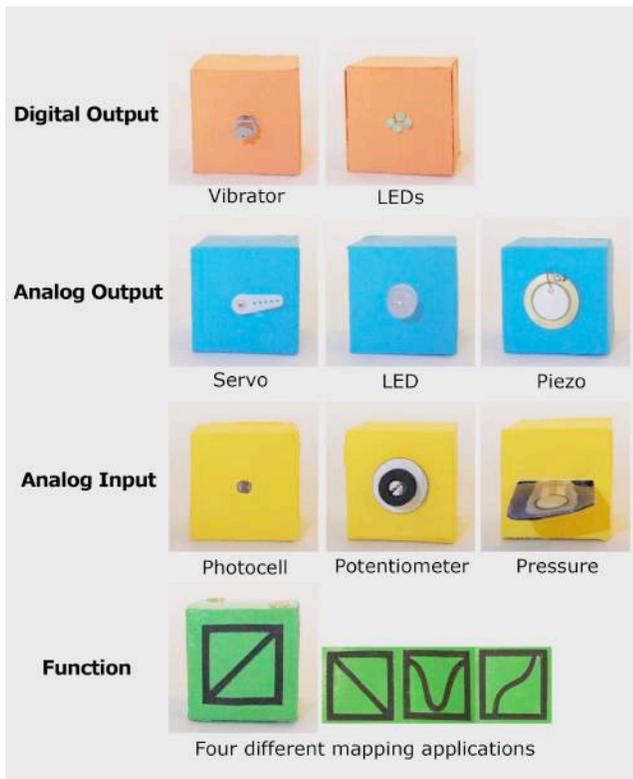
## 2. RELATED WORK

Cube-in is similar in spirit to several previous tangible learning kits. The Topaoko [5] construction kit comprises a microcontroller, sensors, actuator, and hardboard pieces. It allows users to build their own embedded-circuit kit and play with kit components. With roBlocks (now Cubelets) [3], people build robots by assembling sensor, action, and operator blocks, and learn basic robotics. It also engages users to play with each type of block and construct modular creations. Whereas both kits are intended to allow users to construct their design, Cube-in provides a pre-constructed kit in which users play, observe, and learn by simple interactions. The littleBits [2] kit of preassembled circuit boards helps people create electronics prototypes by snapping modules together. It lets users build circuits with the components. LightUp [4] also enables users to design their own circuits, but it includes a mobile app that recognizes the circuit behavior and gives live and interactive graphic feedback using Augmented Reality technology. Those toolkits help users to exploring circuit-building—we want users to explore fundamental concepts underlying such circuits through the Cube-in. The Cubes project [6] presents a set of 20 cubes that each combines an input and an output. Each cube is a complete experience and the transparent material lets people see the mechanics of the sensing and actuation. Whereas the Cubes project allows users only to experience within the limited set of cubes, Cube-in lets users interact with diverse pairs of inputs and outputs to grasp the fundamental concepts.

## 3. CUBE-IN: THE LEARNING KIT

### 3.1 Conveying Concepts

The Cube-in experience is designed to convey three fundamental concepts in physical computing: the difference between digital and analog signals, the difference between input and output, and the functional mapping between inputs and outputs.



**Figure 2. Four types of the nine component cubes.**

### 3.1.1 Difference between digital and analog signals

In order to demonstrate the difference between analog and digital signals, the kit provides two types of output cubes. Digital output cubes are actuated by a binary signal (ON or OFF); analog cubes vary actuation continuously. For example, with the digital output cubes the user can only turn a device (the vibrator motor or LED) on or off. On the other hand, with the analog output cubes the user can continuously vary a servo position, LED brightness or a melody's tempo through a piezo actuator.

Although every analog output can be also driven with a digital signal, we made separate digital and analog cubes in order to unify the interface of all types of component cubes and the base cube. The coherent layout for connecting magnets for ground, power, and signal is essential to make the Cube-in experience simple and accessible. Therefore, instead of adding more connections to make the output cubes applicable to both digital and analog outputs, we separated the two types of output cubes.

### 3.1.2 Relation between (analog) input and output

Another key concept is the relation between inputs and outputs. Connecting the values received by input cubes directly to the output values enables users to see how input signals influence output signals. Various sensors support different interactions to enhance the engagement and support learning concepts within the limited number of component cubes. Specifically, users can control the amount of light reaching the light sensor by shading it with their hands; the potentiometer provides a familiar rotation input using a knob; and the user can squeeze and press on the pressure sensor. While interacting with the input cubes, users observe the connection with the output cubes, and see how values received from different types of sensors (inputs) can be transmitted to various types of actuators (outputs).

### 3.1.3 Changing the input and output mapping

Lastly, the function cube demonstrates mapping. By switching its orientation, the four sides of the function cube enables users to apply one of the four mappings to change the way input values map to output values. The four mappings (depicted on the cubes as a graph) are

'direct' (output  $\leftarrow$  input),

'inverse' (output  $\leftarrow$  (- input)),

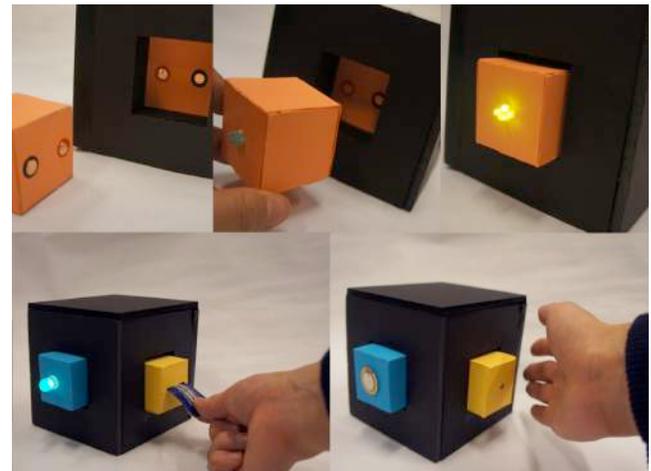
'sine' (output  $\leftarrow$  sine (input) ) and

'tangent' (output  $\leftarrow$  tan (input) ).

It reinforces the idea of the input-output relation described above and adds a layer to the user's understanding of the how one quantity can be mapped to another.

## 3.2 System Configuration

The Cube-in hardware consists of one base cube (4.5in) and four types of nine component cubes (1.5in). Each type of component cubes is matched to the four faces of the base cube, which houses the programmed Arduino and its batteries. While the Arduino uses one connection to receive signals from the input cubes, it uses independent connections for each analog output cube. The ways to transmit signals between the Arduino and the output cubes, and the scope of possible values to control the output components vary according to the type of actuators and sensors used. In addition, the function cube includes magnets for the top and the bottom edges, so that the four possible different orientations trigger different reed switches to apply different mappings.



**Figure 3. The Cube-in play: by inserting component cubes in its base cube, users can turn the device on (top). Simple interactions with input cubes such as squeezing the pressure sensor or shading the light sensor show how input signals influence output signals (bottom).**

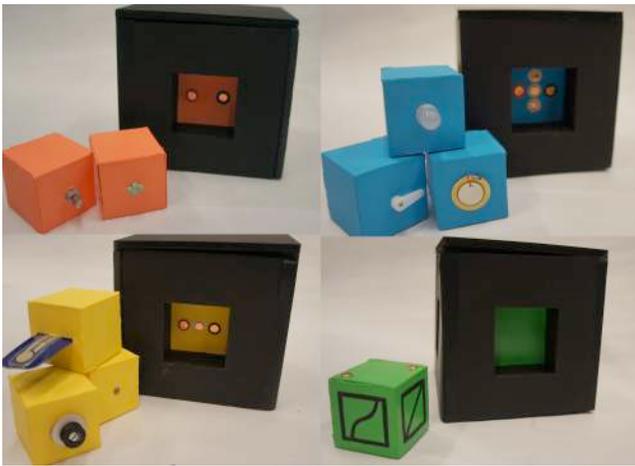


Figure 4. Four faces of the body cube with component cubes.



Figure 5. Supplies and materials to build the Cube-in.

### 3.3 Design Consideration

All component cubes connect to the base cube through ¼” neodymium magnets. People playing with magnets tend to experiment attaching one to another and trying other directions to experience magnetic force. We applied opposite polarity magnets to Vcc and ground, and the opposing polarity prevents the user from connecting the cubes the wrong way round and damaging the electronics. Wires from the sensors or the Arduino are attached to the magnets with conductive (copper foil) tape. When component cubes are attached to the base cube, the current flows. Along with the use of the polarity enforcement and physical connection through magnets, we used craft materials to build the Cube-in. Figure 5 shows the materials and supplies we used. They are commonly available inexpensive craft materials and do not require a great deal of expertise. We want to leave room for those who want to build their own Cube-in kit to teach themselves.

In order to visually highlight the different functionality of the various Cube-in components, we applied colors of different saturations and hues. Pastel colors (pink, light blue, light yellow, and light green) differentiate each type of component cubes and vivid colors (red, white, and black) encircle the connecting magnets on all component cubes and the base cube. By doing so,

we intend to encourage users to play with the Cube-in simply matching the colors without further instructions. (see Figure 4)

## 4. FUTURE WORK

We plan to extend Cube-in’s functional flexibility. The current Cube-in has two types of output cubes; by refining the framework of interface design, we plan to make output cubes that accept both digital and analog signals. Similarly, we are interested in exploring the relation and potential feedback loop between input and output. For example, a photocell sensor as input can be used to control LED brightness as output. However, the LED brightness can again influence the input value received by the photocell sensor. Then, the LED becomes the input for the photocell sensor, a reversal of the original arrangement. By adding another base cube module, we expect to enable users to place input and output cubes freely to see how they affect each other. This greater functional flexibility will let users grasp a broader view of fundamental concepts—digital and analog, inputs, outputs, and mappings—than the current prototype.

## 5. ACKNOWLEDGMENTS

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