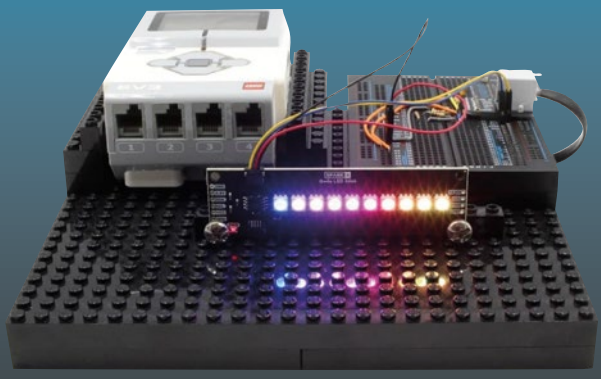
TECHNOLOGY IN ACTION™



The LEGO Arduino Cookbook

Expanding the Realm of MINDSTORMS EV3 Invention

Grady Koch

Apress®

The LEGO Arduino Cookbook

Expanding the Realm of MINDSTORMS EV3 Invention

Grady Koch

Apress®

The LEGO Arduino Cookbook: Expanding the Realm of MINDSTORMS EV3 Invention

Grady Koch
Yorktown, VA, USA

ISBN-13 (pbk): 978-1-4842-6302-0 ISBN-13 (electronic): 978-1-4842-6303-7
https://doi.org/10.1007/978-1-4842-6303-7

Copyright © 2020 by Grady Koch

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

Trademarked names, logos, and images may appear in this book. Rather than use a trademark symbol with every occurrence of a trademarked name, logo, or image we use the names, logos, and images only in an editorial fashion and to the benefit of the trademark owner, with no intention of infringement of the trademark.

The use in this publication of trade names, trademarks, service marks, and similar terms, even if they are not identified as such, is not to be taken as an expression of opinion as to whether or not they are subject to proprietary rights.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Managing Director, Apress Media LLC: Welmoed Spahr
Acquisitions Editor: Aaron Black
Development Editor: James Markham
Coordinating Editor: Jessica Vakili

Distributed to the book trade worldwide by Springer Science+Business Media New York, 1 NY Plaza, New York, NY 10014. Phone 1-800-SPRINGER, fax (201) 348-4505, e-mail orders-ny@springer-sbm.com, or visit www.springeronline.com. Apress Media, LLC is a California LLC and the sole member (owner) is Springer Science + Business Media Finance Inc (SSBM Finance Inc). SSBM Finance Inc is a Delaware corporation.

For information on translations, please e-mail booktranslations@springernature.com; for reprint, paperback, or audio rights, please e-mail bookpermissions@springernature.com.

Apress titles may be purchased in bulk for academic, corporate, or promotional use. eBook versions and licenses are also available for most titles. For more information, reference our Print and eBook Bulk Sales web page at http://www.apress.com/bulk-sales.

Any source code or other supplementary material referenced by the author in this book is available to readers on GitHub via the book's product page, located at www.apress.com/978-1-4842-6302-0. For more detailed information, please visit http://www.apress.com/source-code.

Printed on acid-free paper

Table of Contents

About the Author ix

About the Technical Reviewer xi

Introduction xiii

Chapter 1: The LEGO Arduino Workstation 1

The Arduino 1

Assembling the LEGO Arduino Workstation 4

The Breadboard and Wiring 11

Final Assembly 13

Summary 14

Chapter 2: Programming the EV3 Intelligent Brick 15

Getting Started with the MINDSTORMS EV3 Programming Environment 15

Programming 18

Extra and Aftermarket Device Blocks 20

My Blocks 20

Summary 23

Chapter 3: Programming the Arduino 25

Installing the Arduino Integrated Development Environment (IDE) 25

Navigating the Arduino IDE 26

Running a First Sketch 29

Working with Libraries 32
Working with Functions 34
Summary 35

Chapter 4: Sensors and Electronics 37

MINDSTORMS Sensors and Motors 37
Aftermarket MINDSTORMS-Compatible Sensors 38
Arduino Sensors 39
Pulse-Width Modulation (PWM) 40
Inter-integrated Circuit (I2C) Interface 42
Serial Peripheral Interface (SPI) 42
Electronic Components 43
Resistors 44
Capacitors 47
Summary 48

Chapter 5: The LEGO Metal Detector—I2C Sensor with EV3 Analog Interface 49

Mounting the Grove Inductive Sensor 50
The Low-Pass Filter 52
Wiring Connections 54
EV3 Code 57
Arduino Sketch 59
Results 63
Alternate Mount 65
Summary 69

Chapter 6: Programmable LEDs—I2C Controller with EV3 Analog Interface 71

Mounting the Qwiic LED Stick 72

Wiring Connections 74

Analog Signals from the EV3 Intelligent Brick 76

Arduino Sketch 82

Results 90

Summary 91

Chapter 7: I2C Communication with the EV3 Intelligent Brick 93

The EV3 I2C Block 93

Bits and Bytes 94

Wiring Connections 96

Reading Bytes into the EV3 Intelligent Brick 97

EV3 Code for Reading 97

Arduino Sketch for Writing 99

Writing Bytes from the EV3 Intelligent Brick 101

EV3 Code for Writing 101

Arduino Sketch for Reading 102

I2C Conflicts 105

Summary 105

Chapter 8: The LEGO Lidar—PWM Sensor with EV3 I2C Interface 107

Mounting the Lidar 108

Wiring Connections 114

EV3 Code: 10-Meter Distance Capability 116

Arduino Sketch: 10-Meter Distance Capability 118

Software Modification for 40-Meter Distance Capability 123
Example Application: Scanning a Scene 125
Example Application: Measuring Trees 129
Adding a Camera: The LEGO Traffic Monitor 132
Summary 137

Chapter 9: The LEGO Weather Station—SPI Sensor with EV3 I2C Interface 139

Mounting the Atmospheric Sensor 140
Building the LEGO Weather Station 141
Wiring Connections 144
EV3 Code 146
Arduino Sketch 149
Example Application: Diurnal Weather Trends 153
Summary 156

Chapter 10: The LEGO Spectrum Analyzer—Arduino Shield with I2C Output to EV3 157

Mounting the Spectrum Shield 158
Building the Spectral Display 160
Wiring Connections 161
EV3 Code 164
Arduino Sketch 169
Results 173
Summary 174

Chapter 11: Favorite Color Machine—Arduino Shield with I2C Output from EV3 175

Mounting the NeoPixel Shield 176

Mounting the LEGO Motors 177

Wiring Connections 180

EV3 Code 181

Arduino Sketch 185

Using the Favorite Color Machine 188

Summary 189

Chapter 12: Connecting MINDSTORMS to a Smartphone 191

Mounting the 1Sheeld+ 192

Building the Tilt Mimic 193

Wiring Connections for the Tilt Mimic 198

EV3 Code for the Tilt Mimic 200

Arduino Sketch for the Tilt Mimic 201

Setting Up the Smartphone for the Tilt Mimic 204

Running the Tilt Mimic 207

Second 1Sheeld+ Project: Intrusion Monitor 208

Building the Intrusion Monitor—Sensor Mount 208

Building the Intrusion Monitor—Smartphone Stand 212

Wiring the Intrusion Monitor 215

EV3 Code for the Intrusion Monitor 216

Arduino Sketch for the Intrusion Monitor 218

Setting Up the Smartphone for the Intrusion Monitor 220
Running the Intrusion Monitor 221
Summary 222

Appendix 223

Index 231

About the Author

Grady Koch emphasizes building things from LEGO that can be applied to practical use in science, engineering, or security. He is the author of *High-Tech LEGO Projects, LEGO Wind Energy*, and *Secrets of Eli's LEGO Collection*. He also writes for and runs www.hightechlego.com, which features various LEGO technology projects. His day job since 1987 has been as a research engineer with NASA Langley Research Center. There, he works with technology for remote sensing atmospheric phenomena. He holds a PhD in Electrical Engineering. And he holds three patents in the field of wind measurements with lidar.

About the Technical Reviewer

Associate Professor **Gene Harding** has a Master of Science in Electrical Engineering from Rose-Hulman Institute of Technology. His experience includes 28 years of combined active and reserve service in the United States Air Force and 3 years in the private industry with Agilent Technologies. He has taught electrical engineering technology at Purdue's South Bend location since the fall of 2003.

Introduction

MINDSTORMS EV3 serves as an excellent platform for experimenting with robotics. And with a little push, given in this book, the use of the EV3 Intelligent Brick can be expanded to provide a means for rapid prototyping of all sorts of inventions. There are several single-board host computers for developing inventions, such as the Raspberry Pi, BeagleBone, or LattePanda. There are even hardware adapters to use MINDSTORMS motors on a Raspberry Pi or BeagleBone. But this book keeps LEGO as the foundation, including the MINDSTORMS EV3 Intelligent Brick as a host computer. There are several reasons for this LEGO-centric approach.

First, the mechanical design of inventions is simple by using the vast array of LEGO building bricks that can be attached to the EV3 Intelligent Brick. There's no need to build an enclosure around the computer heart, since the EV3 Intelligent Brick is already powered, hardened, and enclosed. It has built-in batteries, display, control buttons, speaker, and SD card storage. Mounting points on the rear and sides of the EV3 Intelligent Brick provide quick and easy attachment of sensors and motors.

Second, the artistic aspects of LEGO are maintained by using the EV3 Intelligent Brick as the host computer. LEGO constructions have an aesthetic appeal enjoyed by artists and builders, so the EV3 Intelligent Brick is used as the basis in this book. This artistic appeal is in contrast to the alternate approach of building a device from a Raspberry Pi and trying to put a LEGO box around the device, potentially resulting in a clumsy mash-up. In this book, LEGO is the heart of the invention.

Third, the educational foundation of LEGO can be built upon to introduce kids and students to more sophisticated technologies. LEGO adapts to kids' interests as they grow older, culminating with

MINDSTORMS EV3. As mastery of MINDSTORMS is achieved, this knowledge can be built upon to learn and use more complex electronic and software capabilities.

The key to expanding LEGO MINDSTORMS is introducing the wide selection of sensors, actuators, devices, and even smartphones that can be interfaced through an Arduino controller. This book shows how to add this Arduino interface for many applications. No prior knowledge of Arduino is required.

The development of this book's ideas begins in Chapter 1 with introducing the Arduino. Instructions are given on how to select among the many varieties of the Arduino, along with the accessories for attaching it to LEGO bricks and wire connections. Two options are suggested of either an Arduino Uno circuit board with shield accessories or the STEMTera. A design is given for mounting of the Arduino alongside the EV3 Intelligent Brick to create a LEGO workstation for building prototype inventions.

Chapter 2 discusses programming the EV3 Intelligent Brick, preparing to interface it to the Arduino. The MINDSTORMS EV3 programming environment will be used throughout this book, taking advantage of its likely familiarity with many readers. While prior experience working with the robots of the EV3 Home Edition software is helpful, it is not necessary to build the projects in this book with instructions given on how to get started and how to program the projects' EV3 code. Advanced programming blocks are used in some of the projects in this book that readers may not be familiar with, so these blocks are introduced in this chapter.

Chapter 3 sets up the Arduino, specifically in how to program this device and how to interpret the architecture of an Arduino program sketch. Arduinos are programmed with a variant of the C language, which can get complicated. However, programs are largely simplified by using sketches already developed and tested for a particular sensor or actuator. So an approach is taken in this book of using these predeveloped sketches,

with some minor modifications. These modifications are documented throughout this book. All of the sketches found in this book can be downloaded from www.github.com.

Chapter 4 takes a look at the sensors available for projects. While Arduino-based sensors are the primary interest of this book, many of this book's projects combine Arduino sensors with LEGO-made sensors or motors, so an overview is given of MINDSTORMS-based devices. A motivation to consider Arduino sensors is the wide capability they offer, but a drawback of so much variety is trying to figure out which sensor will work. So Arduino sensors are classified in this chapter by how they interface with the Arduino, either by pulse-width modulation (PWM), inter-integrated circuit (I2C), or serial peripheral interface (SPI). Some project designs need electronic components to send signals between sensors, the Arduino, and the EV3 Intelligent Brick. Such connections can involve resistor and/or capacitor circuits, so a guide is presented on understanding and buying these components.

Chapter 5 describes the first project—a metal detector built from an electromagnetic inductive sensor. The EV3 Intelligent Brick sounds and flashes an alarm when a metal is nearby, with an indication also given of how far away the metal is from the sensor. This project is first built on the LEGO Arduino Workstation of Chapter 1 and then is built in an alternate form of a handheld metal detector. The sensor in this project communicates with the Arduino by I2C and then with an analog signal to the EV3 Intelligent Brick.

Chapter 6 reverses the direction of data flow of Chapter 5, by now having the EV3 Intelligent Brick generate an analog signal that is read by the Arduino. The Arduino then sends I2C commands to the external device of a linear array of color-programmable light-emitting diodes (LEDs). Various LED color patterns can be displayed, useful for adding lighting effects to LEGO models.

Chapter 7 delves more deeply into I2C communication, a powerful tool for sending and receiving data to or from the EV3 Intelligent Brick. The

I2C passes data in 7-bit words, so a description is given on how decimal numbers are represented in this digital format. I2C communication, facilitated by a programming block developed by Dexter Industries, works within the EV3 programming environment to keep programs simple. The software interface for the Arduino end of I2C is also developed and explained in this chapter.

The I2C capability built in the previous chapter is exploited in Chapter 8 to combine a lidar with LEGO inventions. The lidar can measure target distance up to 40 m, reporting results to the EV3 Intelligent Brick for a variety of possible uses. Example applications are shown in a scanning lidar for profiling an outdoor area, as well as measuring the height and canopy thickness of a tree. Scanning is accomplished by mounting the lidar on a LEGO EV3 Large Motor. Further capability is added by combining a camera with the scanning lidar, with an example project of monitoring roadway traffic. The data communication link between the Arduino and the lidar is by PWM.

Chapter 9 explores the use of sensors that communicate by SPI, in this case a weather sensor of temperature, barometric pressure, and humidity. Another environmental measurement is added by use of a LEGO EV3 Color Sensor to record the ambient light level. The EV3 Intelligent Brick logs these four meteorological parameters over the course of many hours. An example project is shown of how weather parameters vary over the course of a few days.

Chapter 10 introduces working with Arduino shields, which offer more sophisticated functionality than the discrete sensors used in earlier chapters. The shield used in this chapter is a spectrum analyzer that separates audio or music signals into several frequency bands. This spectral data is read by the EV3 Intelligent Brick in an example project to visually and mechanically represent the frequency content of music. The seven spectral bands are displayed in a bar graph format on an LED array. Also, three of the spectral bands are used to drive three different LEGO mechanisms that dance in time with music.

Whereas the previous chapter has the EV3 Intelligent Brick receiving data from an Arduino shield, Chapter 11 has the EV3 Intelligent Brick sending data to an Arduino shield. The shield used in this chapter is a vibrant two-dimensional LED display with a color adjustable by the user to contemplate their favorite color. Color adjustment is made by LEGO EV3 motors adapted to serve as control knobs for setting the levels of red, green, and blue constituent colors that get mixed together.

Chapter 12 features an Arduino shield that interfaces with a smartphone for a wide range of applications. The communications, imaging, and sensing capabilities of a smartphone can be incorporated into LEGO inventions. Two example projects are described. First, a smartphone's orientation sensor provides data to the EV3 Intelligent Brick, which in turn orients the tilt of a LEGO liftarm to match the smartphone's angle. The second project is a security monitor that uses an EV3 Ultrasonic Sensor to trigger the smartphone to take a picture and send email notification that an intruder has been detected.

Each project in this book is described with step-by-step instructions for the building aspects involved: LEGO part assembly, electronics, wiring, EV3 code, and Arduino sketch. All the parts used in a chapter are summarized in an appendix, along with suggested sources for purchasing electronic components. LEGO parts are also identified in each chapter with a graphical parts diagram that also gives the part's name and number so it can be found on LEGO part supply sources such as Bricklink (www.bricklink.com).

CHAPTER 1

The LEGO Arduino Workstation

A wide new range of LEGO inventions can be realized by combining MINDSTORMS with an Arduino. Arduino is a single-board host controller for many types of sensors, motors, displays, actuators, and interfaces. It has become the most common host controller for electronics developers due to its low cost and ease of use. The Arduino is meant for nonexpert electronics builders to be able to build their own inventions. In this chapter, the hardware for connecting MINDSTORMS EV3 with an Arduino will be developed. This LEGO Arduino Workstation serves as a platform for building the projects found in this book.

The Arduino

The Arduino controller comes in many versions that can be confusing to distinguish from one another. This book uses the basic workhorse version known as the Arduino Uno, shown in Figure 1-1. The LEGO Arduino has many connection points for power and signal input and output that will be used throughout this book. Most of the connection points are by the rows of pins, called *headers*, on top of the device. Labels on the circuit board and on the side of the headers indicate, in abbreviated form, what these pins do. Other connections on the circuit board are for power input and a micro-USB connector for programming the Arduino Uno. These connections will be discussed in the following chapters.

© Grady Koch 2020
G. Koch, *The LEGO Arduino Cookbook*, https://doi.org/10.1007/978-1-4842-6303-7_1

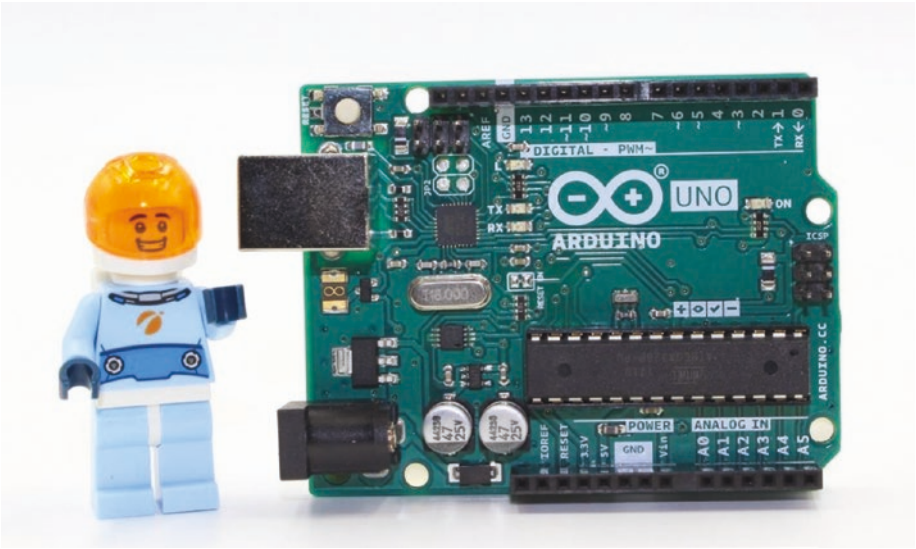


Figure 1-1. *The Arduino Uno is a programmable board for hosting sensors and controllers*

In this chapter, the mechanical mounting and interface of the Arduino Uno to LEGO are built. Standing alone, as in Figure 1-1, the Arduino Uno is inconvenient to connect to LEGO. So a mechanical mounting plate can be purchased from the 3D printing marketplace that fits in the four mounting holes of the Arduino Uno. Such a plate is shown in Figure 1-2, purchased from www.shapeways.com.

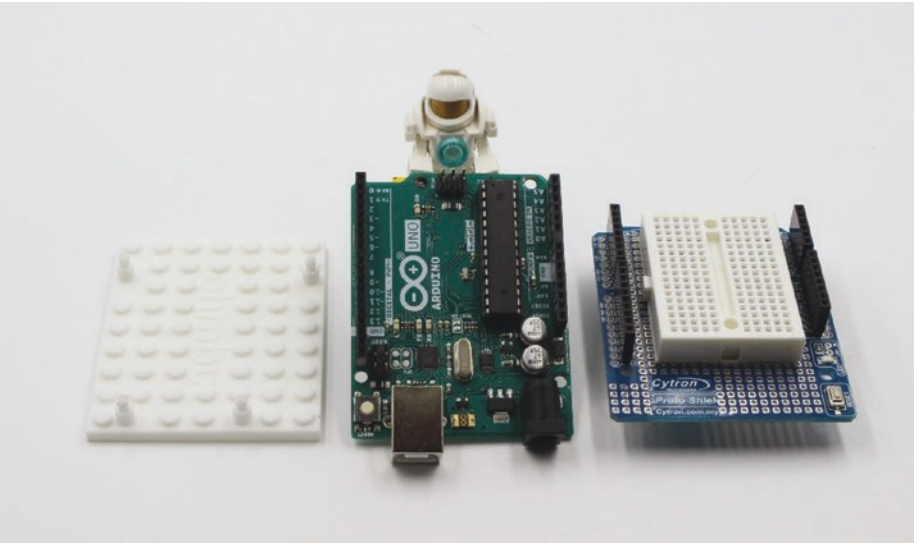


Figure 1-2. *Connecting the Arduino Uno to LEGO involves a baseplate for a mechanical interface (at the left) and an electrical interface (at the right)*

In addition to a baseplate for the mechanical interface of the Arduino to LEGO, an electrical interface is needed to connect power and signals between the Arduino and the EV3 Intelligent Brick. This electrical interface is conveniently implemented with a breadboard, a device used for building prototype electronic circuits. Wires and the leads of electronic components slide into the holes of the breadboard to connect circuits. An Arduino-connected breadboard is available in the form of the Proto Shield, such as the one pictured in Figure 1-2. The Proto Shield has pins on the bottom that match the headers on the Arduino, and the connection between the two is made by pressing the Proto Shield into the Arduino's headers. The assembled three components of baseplate/Arduino/Proto Shield are shown in Figure 1-3. Also shown in Figure 1-3 is an alternative Arduino implementation, known as a STEMTera. The STEMTera is a combined breadboard and Arduino Uno—the Arduino is encased in the base of

the breadboard. In addition, the STEMTera has a LEGO-compatible mechanical mounting on the bottom of the device, so it can simply be pressed together with LEGO parts. Throughout this book, the STEMTera version is used for two reasons: (1) the STEMTera costs less than the baseplate/Arduino/Proto Shield approach, and (2) the STEMTera is more rugged and more attractive.

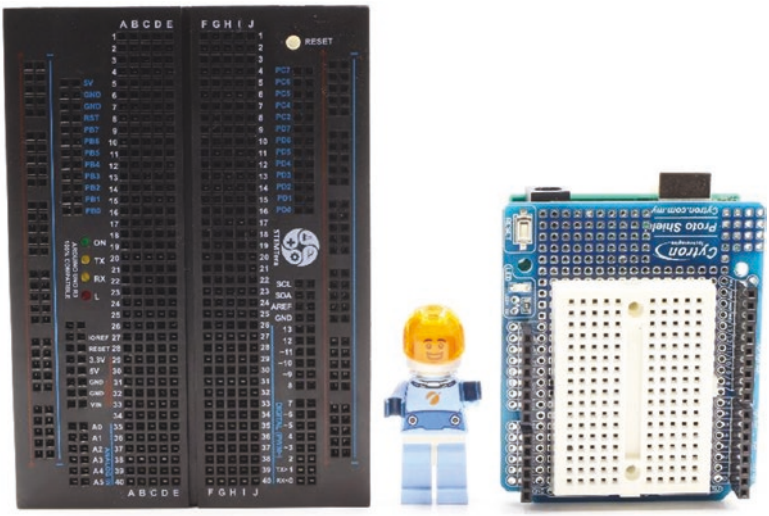


Figure 1-3. *Two possible Arduino implementations are the STEMTera (at the left) and a stack of a 3D printed adapter, Arduino Uno, and Proto Shield*

Assembling the LEGO Arduino Workstation

A LEGO platform can be built to hold the EV3 Intelligent Brick, Arduino, and various prototype setups. Such a platform is shown in Figure 1-4, based on 12×24 bricks. Building instructions follow Figure 1-4.

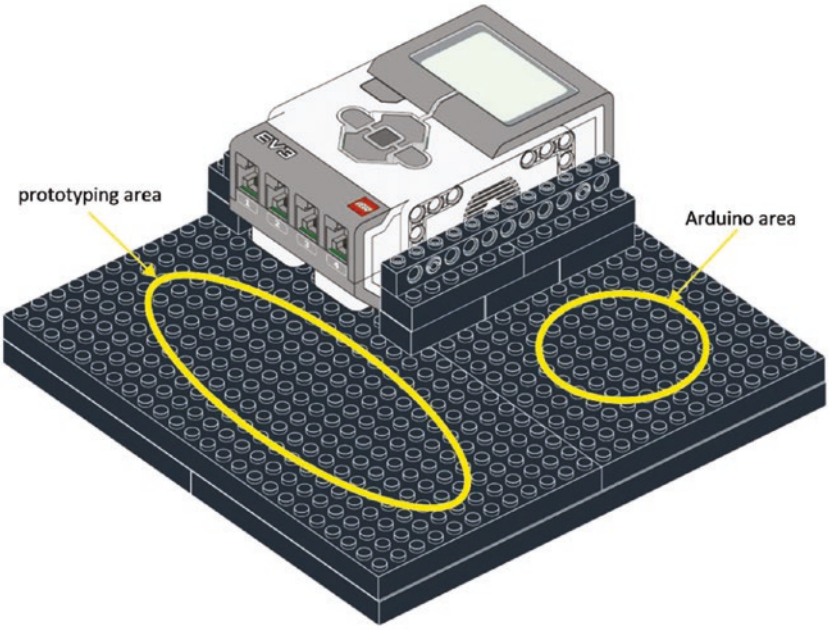
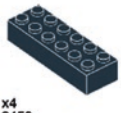


Figure 1-4. *The LEGO Arduino Workstation includes the EV3 Intelligent Brick, Arduino, and area for attachment of experimental prototypes*

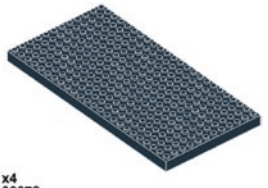
x4
2780
Technic Pin with Friction Ridges

x6
3001
2 x 4 Brick

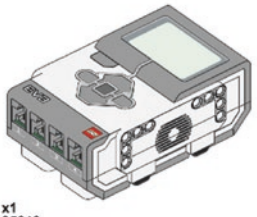


x4
2456
2 x 6 Brick

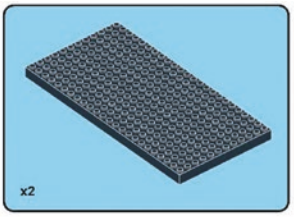
x2
3895
1 x 12 Technic Brick with Holes



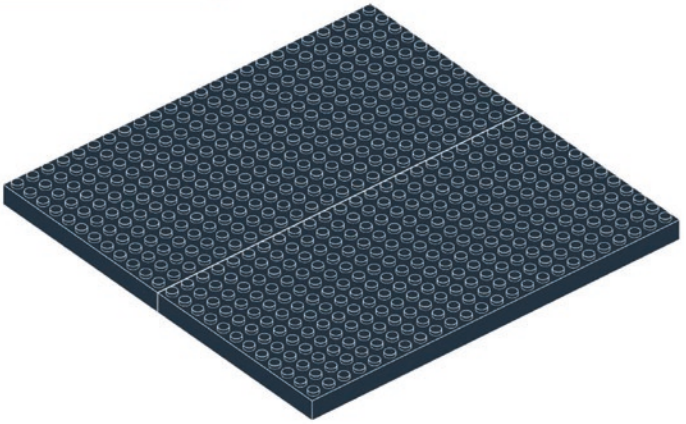
x4
30072
12 x 24 Brick

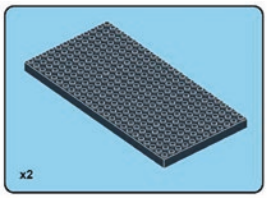


x1
95646
EV3 Intelligent Brick

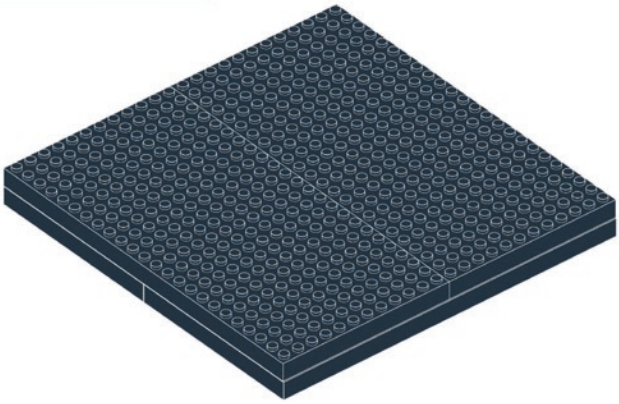


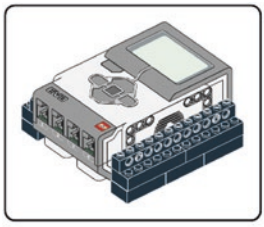
1

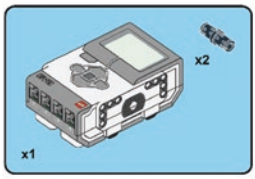




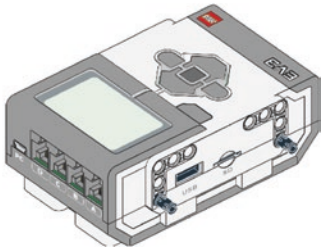
2

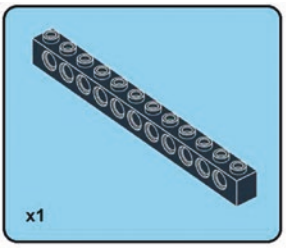




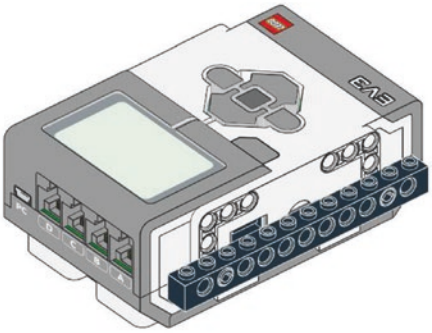


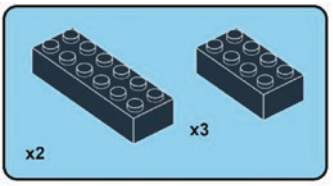
3



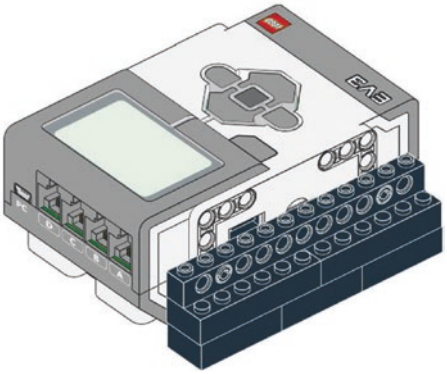


4

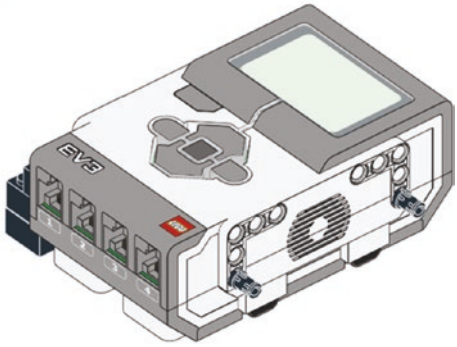


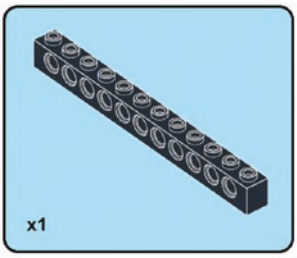
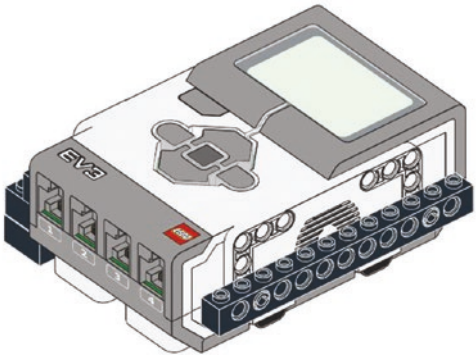


5



6





7