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TALEMIA

وزارة التعليم
Ministry of Education
2023 - 1445

Name: .... School: ....

Engineering

Second year - Secondary stage - Pathways System

1445 - 2023 Edition

المملكة العربية السعودية

VISION رؤية 2030
المملكة العربية السعودية
KINGDOM OF SAUDI ARABIA

وزارة التعليم
Ministry of Education

Engineering

1445 - 2023 Edition

Second year
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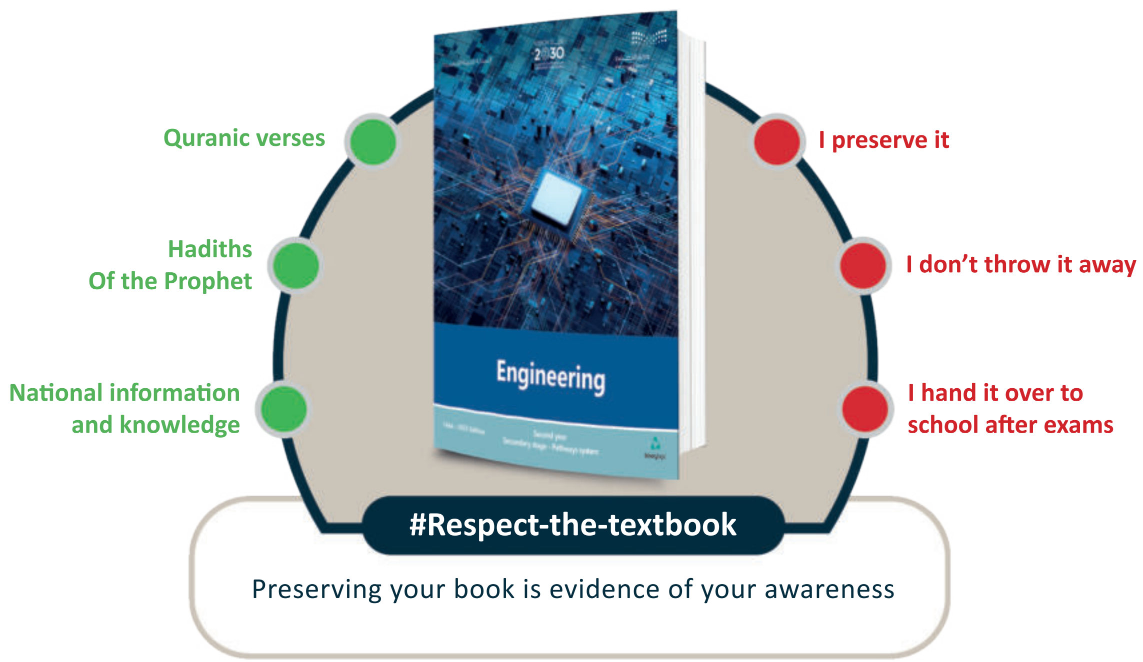
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وزارة التعـليم
Ministry of Education

المملكة العربية السعودية

Engineering

Secondary stage - Pathways system

Second year

وزارة التعـليم
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وزارة التعليم
Ministry of Education
2023 - 1445

Introduction:

The progress and development of countries is measured by the ability to invest in education, and the extent to which their educational system responds to the requirements and changes of the generations. In the interest of the Ministry of Education sustaining the development of its educational systems, and in response to the vision of the Kingdom of Saudi Arabia 2030, the Ministry of education has taken the initiative to adopt the "Secondary Education Pathways" system to bring about an effective and comprehensive change in high school.

The secondary education pathways system provides a distinguished and modern educational model for high school in the Kingdom of Saudi Arabia, which efficiently contributes to:

- Strengthening the values of belonging to our homeland "the Kingdom of Saudi Arabia" and loyalty to its wise leadership "may God protect him" based on a pure belief supported by the tolerant teachings of Islam.
- Strengthening the values of citizenship by focusing on them in school subjects and activities, in line with the demands of sustainable development, and the development plans in the Kingdom of Saudi Arabia that emphasize the consolidation of both values and identity, based on the teachings of Islam and its moderation.
- Qualifying students in line with future specializations in universities or the required jobs; ensuring the consistency of education outputs with the labor market requirements.
- Enabling students to pursue education in their preferred path at early stages, according to their interests and abilities.
- Enabling students to join specific scientific and administrative disciplines related to the labor market and future jobs.
- Participation of students in an enjoyable and encouraging learning environment in school based on a constructive philosophy and applied practices within an active learning environment.
- Delivering students through an integrated educational journey from the primary level to the end of the high school level and facilitating their transition process to post-general education.
- Providing students with technical and personal skills that help them deal with life and respond to the requirements of their level.
- Expanding opportunities for graduate students through various options in addition to universities, such as: obtaining professional certificates, joining applied faculties, and earning job diplomas.

The pathways system consists of nine semesters that are taught over three years, including a common first year in which students receive lessons in various scientific and humanities fields, followed by two specialized years, in which students study a general path and four specialized paths consistent with their interests and abilities, which are: the Rightful path, Business Administration path, Computer Science and Engineering path, Health and Life path, which makes this system the best for students in terms of:

- The existence of new study subjects that match the requirements of the Fourth Industrial Revolution and development plans, and the Kingdom's Vision 2030, which aims to develop higher-order thinking, problem-solving, and research skills.
- Elective field programs that are consistent with the needs of the labor market and students› interests, as they enable students to join a specific elective field according to a specific job skill.
- Scale as it ensures the achievement of students› efficiency and effectiveness, and helps them identify their tendencies and interests, and reveal their strengths, which enhances their chances of success in the future.
- Volunteer work designed specifically for students in line with the philosophy of activities in schools, and is one of the graduation requirements; which helps to promote human values, and build society (its development and cohesion).
- Bridging which enables students to move from one path to another according to specific mechanisms.

- Proficiency classes through which skills are developed and the achievement level improved, by providing enrichment and remedial mastery classes.
- The options of integrated learning and distance learning, which are built in the paths system based on flexibility, convenience, interaction and effectiveness.
- The graduation project that helps students integrate theoretical experiences with applied practices.
- Professional and skill certificates granted to students after completing specific tasks, and certain tests compatible with specialized organizations.

Accordingly, the computer science and engineering path as one of the updated paths at the secondary level contributes to achieving best practices by investing in human capital, and transforming the student into a participating and productive individual for science and knowledge, while providing him with the skills and experience necessary to complete his studies in fields that meet his interests and abilities, or to join the labor market.

Engineering is one of the main subjects in the Computer Science and Engineering path that helps students to learn the basics of engineering, by engaging and participating to discover a wide variety of topics in the field of engineering, starting by providing a historical overview of engineering and introducing various fields of engineering disciplines that help meet human needs and improve quality of life. The course focuses on inspiring and empowering students through an understanding of engineering and its associated career opportunities, as well as creating positive attitudes toward engineering majors in post-secondary education. The different learning steps and creative ideas in different engineering fields will also be reviewed by reviewing some electronic circuits and their basic elements and design criteria, as well as designing and building a microcontroller using a variety of computer applications to find engineering solutions to life problems. The theoretical aspect of this subject is integrated with the requirements that students should know about real problems up to their level of knowledge related to the subject objectives, in addition to finding engineering solutions under the guidance and supervision of the teacher.

The Engineering book is characterized by integrated, homogeneous and motivative theoretical and practical content for an interactive learning environment through exercises, activities and projects that are reflected in concrete life practices. This book also emphasizes important aspects in engineering education and learning, which are:

- Linking the practical side to different life applications.
- Interest in using engineering in a variety of fields.
- Consistent presentation of theoretical content and its practical applications.
- Diversity of content presentation in attractive and interesting ways.
- Use of computer applications in exercises, activities and projects.

To keep with global developments in this field, the Engineering book provides an integrated set of diverse educational materials that consider the individual differences between students, in addition to software, which provides the student with the opportunity to engage in modern technologies and practice-based communication; This confirms its role in the teaching and learning process.

As we present this book to our dear students, we hope that it will catch their interest, meet their requirements, and make their learning of this syllabus more enjoyable and useful.

God grants success

Contents

بسم الله الرحمن الرحيم

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1. Engineering Fundamentals

In this unit, students acquire basic knowledge about engineering. More specifically, they will learn the basics of engineering, its history, its different fields, and its purposes.

Finally, students will learn the importance of engineering, how engineering can be used to improve quality of life, and the differences between a computer engineer and a software engineer.

Learning Objectives

In this unit, you will learn to:

> Define what engineering is.
> Describe the fundamentals of engineering.
> Recall the history of engineering.
> Understand the different fields of engineering.
> Identify career opportunities in engineering.
> Understand future challenges for engineers.
> State the purposes of engineering.
> Understand the improvement in quality of life through engineering.
> Recognize the importance of jobs related to computing.
> Classify the differences between a computer engineer and a software engineer.

Python programming prerequisite

The Data Science and Engineering curricula in the pathways system require knowledge of Python programming basics. You can scan the QR code on the right to access Python introductory content. To find out what topics are available and for quick access to each unit, you can see pages 230-231.

Lesson 1
Introduction to Engineering

Link to digital lesson
www.ien.edu.sa

The Fundamentals of Engineering

The fundamental principle of engineering is the use of mathematics, science and creative thinking, in diverse professional settings, to solve complex multidisciplinary problems to benefit people and society.

Almost all engineers need to have a good grasp of mathematics and physics. Depending on the engineering field, they may also need to have more specialized knowledge of chemistry, biology and medicine, electricity and magnetism, or computer science and Information Technology.

Apart from technical knowledge, engineers need to have good oral and written skills. A great amount of their time is spent explaining and promoting their ideas to their colleagues and superiors. Some of the greatest engineers in history have also been great communicators with excellent social skills.

Engineering

The application of science and math to solve problems.

The history of Engineering

Engineering, which is the process of using our thinking brain to solve problems in our environment, has been a part of human life since the invention of agriculture. Until that time, humans lived in nomadic tribes of hunter-gatherers. Their problems included inventing new ways to hunt, clothe, and protect themselves from hazardous environments and violent wildlife. When humans started gathering and growing crops, many new problems were created. They needed to prepare the soil, provide water through irrigation, use livestock for more efficient work, harvest the grown crops and store them in a secure site where they were safe from the weather and thieves. These new problems created a new dimension in how people think and interact in their environment. Figure 1.1 reviews the history and eras of engineering.

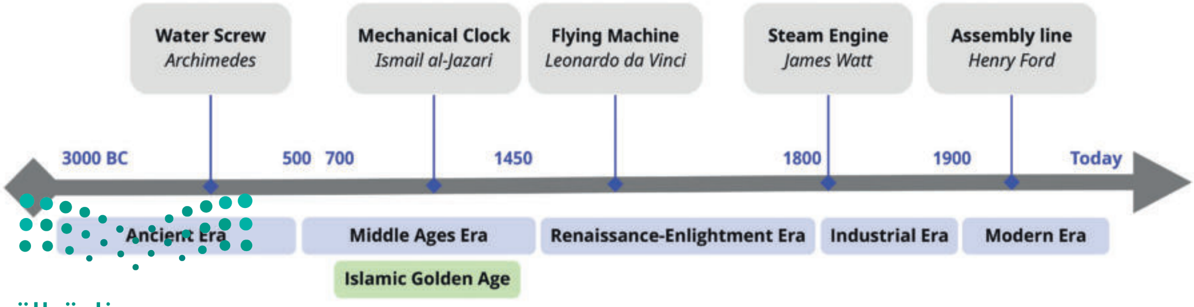

Figure 1.1: The history of Engineering

The Ancient Era

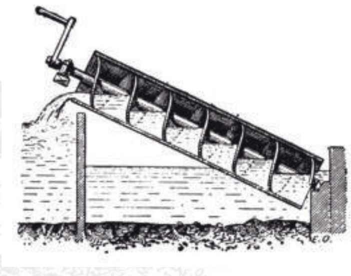

Figure 1.2: Archimedes' water screw

The great turning point was when people started using written language and arithmetic. Some of the earliest writings that have been found are records and ledgers of supplies and provisions for towns and cities. People then started developing mathematics to better describe and process the new information created. After that, people wanted to visualize the problems they faced and the solutions they were designing. Hence geometry was born, ushering in a new golden era of innovation in the Mediterranean and the Middle East. In 300 BC, in the region which is now modern Greece, Euclid wrote his book Elements, which is considered one of the most influential scientific textbooks of all time.

Figure 1.3: Al-Jazari's famous elephant clock

The Middle Ages - Islamic Golden Age

In the European region, until the fall of the Roman Empire, engineering as a scientific methodology was further developed, and was used to advance all aspects of life, from city planning to warfare.

At the start of the medieval period, most of Europe was declining into the Dark Ages. However, the situation in the Middle East was completely different.

Arab and Muslim scientists and engineers made significant advances in math, physics, chemistry and biology. As a result, a myriad of new devices and solutions to the most prominent problems of the time were invented by pioneering Muslim and Arab engineers. Great feats of architecture and urban planning were made by pioneering Arab Islamic engineers, which can still be found and admired to this day. The period between the 8th and 14th centuries is known as the Islamic Golden Age.

The Arabic mathematician and engineer Ismail al-Jazari (1136-1206), best known for his mechanical devices, is considered the "father of robotics". He designed and built automated machines, clocks, and water-raising machines, in which the camshaft was used for the first time.

The Renaissance - Enlightment Era

Figure 1.4: Da Vinci's flying machine

While all this was happening in North Africa and the Middle East, engineers in the Far East and the Chinese kingdoms were also producing inventions which were slowly brought west along the Silk Road. The most important of these are often called The Four Great Inventions: the compass, papermaking, printing, and the invention of gunpowder, which would forever alter history when brought to the West.

With gunpowder, warfare was completely changed, and the compass and printing increased the movements of people and ideas across the globe. This ushered in the Renaissance Age, where engineering and art were brought again to the forefront of human endeavor. The needs of war and trade pushed engineers of the time to invent new weapons and design better protection for cities, which led to significant advances in building architecture. One of the most prominent figures of the time was Leonardo da Vinci. While best known as an artist, he was a brilliant engineer who designed many inventions and complex machines.

He made a prototype for a helicopter, which testing has shown would be capable of flight if manufactured with modern materials. During the same period, invasions carried out by the Mongol and Timurid empires blocked the Silk Road, so it could no longer bring goods and materials from India and China.

The Industrial Era

European engineers had to advance naval travel and navigation to find new routes to India and China to solve this problem. Great ships designed for long journeys were built, and expeditionary forces were sent searching for new trade routes. However, alas, something else happened. In 1492, Christopher Columbus discovered the American continent and so dawned the Colonial and Imperialist ages. Gold and silver mined from the American continent, fueled the advance of even more engineering feats in Europe, which had its engineers create even more efficient weapons, giving European kingdoms a technological edge over the rest of the world. With this power, these kingdoms colonized most of the world, and another revolution soon began.

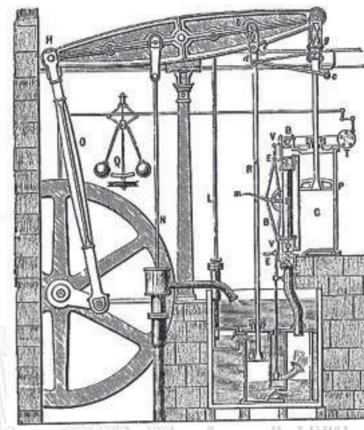

Figure 1.5: A drawing of the steam engine by Boulton & Watt

In 1776, James Watt invented the Watt steam engine, a machine which had the greatest capacity to produce motion through energy. This invention started what is now called the Industrial Revolution. Factories started being built, which created a new set of problems to solve. There were constant innovations in mechanical engineering, chemical engineering, and biomedical engineering. Goods and medicine that only 100 years before were only used by royalty were put in the hands of the common people. Industrialization started a chain reaction of technological and societal changes occuring faster than ever before.

The Modern Era

The 20th century, although an era of global conflicts, brought advances in manufacturing, chemistry and most important of all, the advent of computing and nuclear engineering. Although Henry Ford didn't invent the automobile, he changed the manufacturing process forever by introducing the moving assembly line in 1913. The Space Race after World War II brought together scientists and engineers to build nuclear weapons and rockets to venture out into space. During these years, engineers laid the foundations for almost all the modern technologies that we use today. In the 90s, globalization started taking shape, and a new era of global cooperation between engineers began to reshape almost all aspects of life. Every decade the quality of our lives in almost every part of the world has improved exponentially.

Figure 1.6: Ford Motor Company assembly line

We now live in the Information Age. Artificial intelligence is processing big data to aid engineers in most fields. However, they will need all the help they can get because, despite all the advances, the next generations face some of the greatest challenges to date, namely climate change and the energy crisis brought forth by the depletion of natural resources. As it has always been throughout history, these modern problems require innovative solutions. It is a recurring cycle, with scientists and engineers right at the forefront, helping humanity confront new challenges.

Engineering Fields

Chemical Engineering

1. Biochemical Engineering

Biochemical engineers work in the pharmaceutical, energy, and food and drink industries. They work to develop new drugs and treatments for pharmaceutical companies, they invent new methods to produce and preserve food and drinks, and they design new ways for fossil fuels to be refined into purer, cleaner and more efficient gasoline to help reduce emission of pollutants.

2. Environmental Engineering

Environmental engineering is an extremely relevant field nowadays, because climate change has started taking its toll on the global population and natural resources are being depleted worldwide.

Environmental engineers specialize in finding optimal solutions to problems while minimizing their negative impact on the environment. Many companies and governments have started new projects with sustainable development in mind. This is where environmental engineers come in.

3. Nuclear Engineering

Nuclear engineers are tasked with developing safe and efficient means of producing electricity through nuclear energy.

Now that fossil fuels are becoming ever more expensive, nuclear energy can be a clean and powerful alternative. However, nuclear energy has been catastrophic when used for military purposes.

The new generation of nuclear power plants will be safer, generate less dangerous waste and cannot be used to produce weapons.

4. Process Engineering

Process engineers are specialized in designing and optimizing the processes that take raw materials and energy and convert them into other materials and other forms of energy. The transmutation of materials and energy sources into suitable forms is one of the most fundamental elements of every engineering solution.

Figure 1.7: A petrochemical plant in Saudi Arabia

Civil Engineering

1. Construction Engineering

Construction engineers have responsibility for managing the construction of a building or a building complex, which could be anything, from a simple warehouse to an international airport. They coordinate and manage large teams of other construction engineers, electrical engineers, and materials engineers. Through well-developed project management skills, they communicate information with clarity to their superiors and pass down the necessary information to their co-workers.

2. Geotechnical Engineering

Geotechnical or geological engineers are responsible for analyzing construction projects and ensuring that they are developed safely and securely. They analyze and prepare the soil and rock surfaces where the main structures will be constructed. One example is deciding where to place the columns of a bridge so that it is as stable as possible in the event of an earthquake. They work closely with construction engineers to ensure that all operations run according to plan.

3. Municipal Engineering

Municipal engineers are responsible for urban and city planning. They analyze the geographic locations and the needs of the citizens, companies, and organizations, and decide where to place a city's resources and services. For example, municipal engineers need to consider energy and water supply and waste disposal, as well as the distinction between residential, commercial and industrial areas, all the while following government policies and standards.

4. Transportation Engineering

Transportation engineers need to make sure that the inhabitants small towns and major metropolitan areas are able to get to their destinations safely and quickly. They are the people who design road networks, bus routes and underground metro systems. They are constantly analyzing traffic flow and trying to optimize it, because less traffic means fewer emissions and less money spent on fuel. They work closely with municipal and geotechnical engineers to coordinate their projects and figure out how their solutions fit into the overall picture.

5. Architectural Engineering

Architectural engineers apply engineering principles and creativity to design buildings that are resilient, sustainable, safe and functional. They work alongside architects, who are responsible mainly for the visual elements of the construction.

Figure 1.8: Metro construction in Riyadh

Electrical and Computer Engineering

1. Power Engineering

Power engineering is a very specialized field tasked with optimizing how generated power is transmitted and distributed. Power engineers need to find ways to convert all kinds of energies, whether from renewable sources or fossil fuels, into electricity that is ready to use through power distribution grids. Engineers are now developing smart grids, a promising technology that will save energy and money for households and industry.

2. Electronics Engineering

Electronics engineers research, design, develop, and test electronic components and systems for commercial or scientific applications. They create electronic circuits and components for telecommunications, aerospace guidance, acoustics, and instruments and controls.

3. Instrumentation Engineering

Instrumentation engineers have one of the most important jobs in manufacturing production. They plan, design and monitor the automation systems in a manufacturing environment. This career involves working with metering devices, instrumentation systems and process control software.

4. Telecommunications Engineering

With the ever-growing adoption of IoT technologies, telecommunications engineers now at the forefront of technological progress. Telecommunications engineers design solutions that allow devices and systems to communicate and work together. Nowadays, with the advent of 5G networks, Edge AI and neuromorphic chips, telecommunications engineers are faced with many challenges and opportunities to change our lives.

5. Computer Engineering

Computer engineering combines electrical engineering, electronics and computer science. Computer engineers are responsible for a wide range of computer technology like microchips and servers or even experimental technologies like quantum computers. They also work with almost everyindustry, from healthcare to manufacturing and transportation.

6. Software Engineering

Software engineers provide the solutions to real-world challenges through software development. Behind the functionality of every digital device or network, mission critical software is operating in the background. Today, software engineering is a crucial field.

Figure 1.9: A telecommunications engineer

Mechanical Engineering

1. Mechanical Engineering

Mechanical engineers apply engineering principles and problem-solving techniques from design to manufacturing for any object. They use the principles of motion, energy, and force to find solutions to a problem, ensuring that their designs are efficient, reliable and cost-effective.

2. Manufacturing Engineering

Manufacturing engineers focus on the processes that create the products in a manufacturing unit. They aim to optimize cost, quality, and production capacity to create environmentally sustainable and commercially competitive products.

3. Industrial Engineering

Industrial engineers are tasked with designing and optimizing complex industrial environments while considering ergonomics guidelines and manufacturing capacity. They must balance a wide variety of interconnected social, economic, and manufacturing variables to achieve optimal results.

4. Materials Engineering

Materials engineering is one of the most important engineering professions. Materials engineers are responsible for designing and producing new materials with properties not normally found in nature.
New materials mean new environments for experiments and devices that would not have been possible under normal circumstances.
Their research concerns materials and components like metals, plastics, ceramics, and nanomaterials.

5. Automotive Engineering

Automotive engineering is the field that specializes in the design and production of vehicles. Through innovative research on smart roads and autonomous driving technologies, automotive engineers develop safer and more efficient vehicles. With renewable fuels and the rise of smart cities, transportation will be an integral part of city infrastructure modernization. Currently, automotive engineers are working on designing future transportation methods with sustainable development in mind.

6. Acoustical Engineering

Acoustical engineers work in the arts industry, and they are responsible for handling sound equipment designing the most efficients theaters, auditoriums and concert halls to ensure the clearest possible sound can be heard by everyone present.

7. Aerospace Engineering

Aerospace engineers are involved in building aircraft for sky and space missions. It is a profession that is in high demand nowadays, mainly because aviation companies are investing in hypersonic flight and low-consumption planes.

Figure 1.10: Drone engineer

Engineering Career Opportunities

Engineering provides an array of career opportunities. Engineers that work in the same field and specialty can have different job roles and daily activities. Below are the most common positions that you can pursue.

Research and Development

When working in the research and development (R&D) department, you must take an idea and figure out how to make it into a tangible product. To accomplish this, you research potential new materials, improve existing processes, invent new ones, and make sure that the product is built and sold at competitive prices. Your finished product must be intuitive and appropriate for its purpose.

Design

As an engineer, you are tasked with taking the information derived from the R&D department and designing a product that serves its function and is financially sustainable, and commercially competitive. You will produce schematics and prototype models made with Computer-Aided Design (CAD) and simulation tools.

Planning

Planning is the final step before the manufacturing of the product begins. You will be responsible for defining the materials and manufacturing equipment required, and you will plan all the steps needed to build a reliable and cost-effective product.

Production

As a production engineer, you utilize the work of your colleagues in R&D, design and planning, to implement the production stage. You need to ensure that the correct materials are provided, the schematics are correct, the appropriate tooling equipment is acquired, and that the product can be manufactured within the financial and time constraints.

Installation

In cases where the equipment or the system is very complex, as an installation engineer your work will be focused on its proper installation and setup. Machinery needs to be carefully integrated into an industrial or construction environment.You will manage this process and test and maintain the product's installation.

Quality Control

Quality control or quality assurance is a critical part of a product or system lifecycle. At every stage of product development, several tests are run. As a quality control engineer, you will inspect materials, check that dimensions and measurements are precise, and perform stress tests to record the product's behavior under unfavorable or extreme conditions. Furthermore, monitoring helps you analyze usage data and predict faults even after the product is sold. Quality control is a costly and time-consuming process, but it is financially beneficial because it saves the organization money and time spent on repairs.

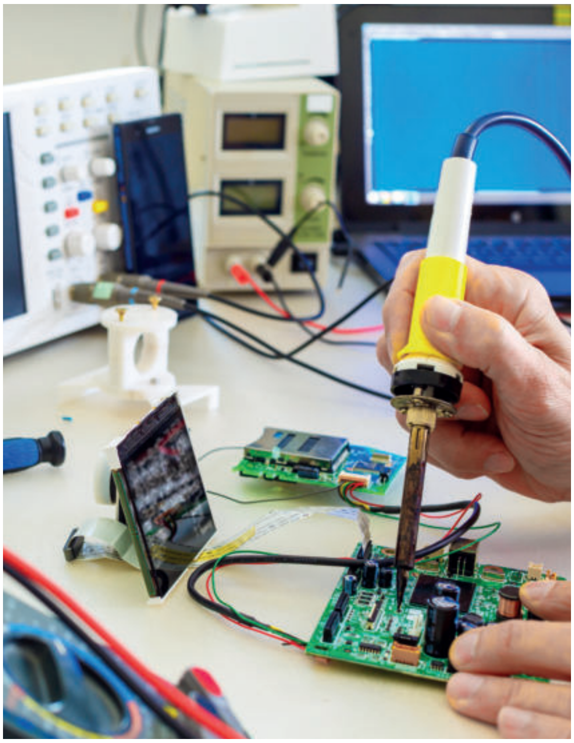

Figure 1.11: Electronics R&D workbench

Marketing and Sales

Whether the organization has an internal marketing department or marketing is outsourced, communication with the engineering department is paramount for an effective marketing and sales campaign. You will be tasked with explaining the product's qualities and the competitive advantages for potential customers to the marketing professionals.

Customer Service and Support

During the use of a product or system, damage and malfunctions may occur. Many products are complex machines that need to undergo maintenance operations at specific time intervals. Customers will need support to diagnose and fix issues. As an engineer who has an in-depth knowledge of the product or system, you will need to plan appropriate maintenance procedures and work with the technicians involved in this process.

Figure 1.12: An electrical engineer working on renewable energy

Future Challenges

The main challenges that engineers will face in the coming years are multidisciplinary problems requiring innovative thinking and cooperation, as shown in Table 1.1.

Table 1.1: Future challenges

Climate change has started affecting the Earth in the recent decades.	Rising temperatures and sea levels are endangering coastal cities and threatening transportation networks. Engineers will need to work on solutions that halt the rate at which these problems are advancing and provide society with the necessary tools to adapt to changing conditions.
Natural resources are not infinite.	The use of renewable energy resources has proven to be effective, and some countries have achieved the target of covering energy consumption through renewable energy sources. Engineers need to invent energy-efficient systems and extend renewable energy infrastructures. The solutions to these problems also reduce emissions which may slow down climate change.
Modern globalized society is vulnerable to pandemics that may affect all aspects of life.	Suitable medical units must be deployed rapidly, and laboratory devices must support innovative vaccine development. In both hospital and laboratory, engineers will have to create solutions.
Securing cyberspace and protecting privacy.	Modern IT applications are interconnected and form systems that exchange critical and confidential data. Computer, network and software engineers need to ensure that these systems are secure and not vulnerable to cybercriminals.
Food shortages occur due to overpopulation.	The global population is increasing at a steady rate, which creates a need to provide huge amounts of food at affordable costs. Chemical engineers need to contribute to improving food production and processing and ensure adequate food supply to all people.
Healthcare needs to be accessible to everyone.	While average life expectancy is rising, treatments for many illnesses and diseases are becoming more expensive, which may cause a divide in access to healthcare treatments. Engineers are tasked with inventing and developing medical equipment and treatments to provide accessible healthcare to people of all socioeconomic statuses.

The Importance of Engineering

Problem Solving with Engineering

We live in challenging times, where environmental and societal changes are taking place faster than ever before. Engineering professions cover a wide spectrum of specialties, and engineers need to work together to find optimal solutions to complex problems. Throughout history, the greatest problems and challenges have led to advances in science and technology, and it was engineering that provided the solutions. Becoming an engineer is one of the best ways to positively impact communities, countries, and the whole of global society.

Improving Quality of Life with Engineering

People's life has improved since we first started using engineering to solve small and large problems. However, the rate of progress has varied accross the ages.

The advent of the Internet in the last 30 years, global cooperation among scientists and engineers and widespread knowledge have enabled the rapid creation of even more inventions.

A person living 100 years ago could never imagine the average person's quality of life today. Modern transportation has allowed the movement of people all around the world. A trip that used to take weeks or months is now completed in hours.

People can now live in countries with harsh winters or hot summers, with unfavorable conditions mitigated by temperature controlling devices. People can communicate with one another from anywhere in the world through chat or video calls. Many work remotely through advanced video conferencing applications, bringing an evolution to the work environment.

Hunger, one of humanity's most prominent problems, has been almost eradicated, with biotechnologies bringing an abundance of food.

Modern-day medical devices and telemedicine save lives. With the latest and upcoming advances in technology, our quality of life will only improve from now on.

Figure 1.13: Electric minibus

The Importance of Jobs Related to Computing

Technological advances in computing have created numerous jobs in engineering roles related to computers and computer networks. As computers are literally everywhere in our lives, the importance of these roles is significant. Some of the most common computer-related engineering jobs are:

> *Telecommunications engineer*
> *Software engineer*
> *IoT engineer*
> *Cybersecurity engineer*
> *Systems architect*
> *Database administrator*
> *Systems engineer*
> *Technical support engineer*

Some of these roles refer to hardware and some to software, but all of them require the skills and mindset of an engineer.

Computer Engineer versus Software Engineer

There is an assumption that computer and software engineers do the same thing. Their studies may have a common basis in the key concepts of Computer Science, but their roles are different in practice.

Figure 1.14: Software engineer

Computer engineer

Computer engineers are mainly focused on designing hardware and planning computer infrastructure and communication processes.

Software engineer

Software engineers are tasked with the development and implementation of software applications and platforms.

Exercises

1

Read the sentences and tick ✓ True or False.	True	False
1. Engineering is the application of science to solve problems.		
2. The basic principle of engineering is the use of mathematics, science, and creative thinking to solve complex multidisciplinary problems.		
3. Engineering has been a part of human life since agriculture was invented.		
4. The four great inventions are: the compass, papermaking, printing, and the computer.		
5. The next generations face some of the most significant challenges, namely climate change, the energy crisis, and vulnerability to pandemics.		
6. Materials engineering is a field of mechanical engineering.		
7. Power engineering is a field of electrical engineering.		
8. An engineer in a design position has to produce schematics and prototype models made with Computer-Aided Design (CAD) and simulation tools.		
9. Quality control is a time-consuming and costly process, but it is financially beneficial because it saves money and time spent on repairs.		
10. Database administration is a computer-related engineering profession.		

2 Explain your understanding of the term "Engineering".

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3 Describe and compare the fields of electrical engineering.

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4. Create a table with the main challenges that engineers will face in the coming years.

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5. What influence do you think the Islamic Golden Age had on the evolution of engineering? Search the Internet for information on the invention of horizontal plane windmills associated with this period.

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6. From what you have learned, name three occupations that are in danger of disappearing in the next few years, and three professions that you think are more important than those.

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7. Which future challenge do you think is most urgent and which engineering profession do you think can overcome it? Research online and find universities that offer this engineering field specialization and related information for graduate and postgraduate studies.

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8. Describe the role of the Kingdom of Saudi Arabia's Vision 2030 in solving global challenges? How do you think Saudi engineers can help make things better for society?

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Project

1 ***Let us*** *say you need to decide on an engineering field specialization that you have learnt about. Do some research and look for information that describes the history of that specialty and why it is still useful to us today.*

2 ***More specifically,*** *you have to answer questions like:*

*- **What** event or recent innovation prompted you to choose this engineering field?*

*- **How** can this engineering field evolve?*

3 ***Using Microsoft*** *PowerPoint, create a presentation using the information you found to introduce the engineering field that you have chosen.*

Wrap up

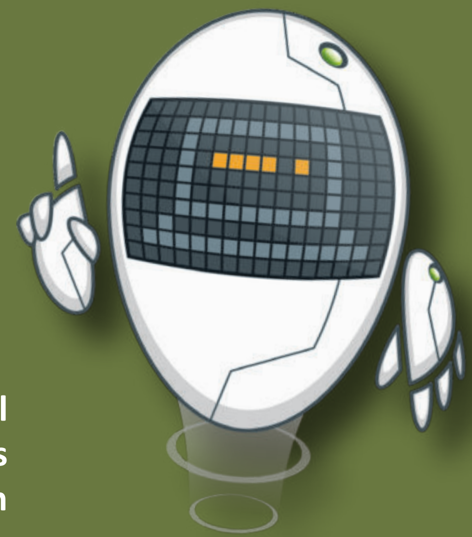
Now you have learned:

- > What is engineering?
- > What are the fundamentals, history and different fields of engineering?
- > What are the opportunities, purposes and challenges of engineering?
- > The improvement of life and the importance of jobs related to computers.
- > What are the differences between a computer engineer and a software engineer?

KEY TERMS

Acoustical Engineering	Electrical Engineering	Municipal Engineering
Aerospace Engineering	Electronics Engineering	Nuclear Engineering
Architectural Engineering	Environmental Engineering	Power Engineering
Automotive Engineering	Geotechnical Engineering	Process Engineering
Biochemical Engineering	Industrial Engineering	Software Engineering
Chemical Engineering	Instrumentation Engineering	Telecommunications Engineering
Civil Engineering	Manufacturing Engineering	Transportation Engineering
Computer Engineering	Materials Engineering	
Construction Engineering	Mechanical Engineering	

2. Electrical Engineering



In this unit, we will learn the basics of electrical circuits. We will also learn about the different types of electrical circuits. Finally, we will use a simulation program to understand how circuits operate.

Learning Objectives

In this unit, you will learn to:

> Describe the basic properties of electrical circuits and electrical quantities.
> Distinguish between DC and AC electric currents.
> Understand how Ohm's law is applied to electrical circuits.
> Demonstrate how to connect resistors in an electric circuit.
> Design electrical circuits.
> Simulate electrical circuits using Multisim Live.

Tools

> Multisim Live

Lesson 1

The Electrical Circuit

Link to digital lesson

www.ien.edu.sa

The basics of Electricity

In this lesson, we will examine some basic concepts that are used in the design of electrical circuits. We will also demonstrate the means by which we study their functions.

Current

The electric current in metallic conductors consists of **electrons** (e^-), which are very small particles that carry the elementary **negative** (-) electric charge and the current moves at very high speeds.

Amperes

To quantify the motion of electrons, André-Marie Ampère created the concept of how many electrons pass through a point in the circuit in one unit of time. He called this electric current, or intensity of current (I), which is measured in amperes (A).

$$1\text{A} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

Volt

In order for an electric current to move in a circuit, we must create a **potential difference**, also called a **voltage (V)**. This shows us how much energy is used in moving one coulomb of electric charge inside the circuit.

$$1\text{V} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

SMART TIP

The volt is the unit of electric voltage, and 1 volt is denoted as 1V and is the measure of the potential difference when an electric current of 1 ampere (A) flows through an element of 1 ohm (Ω) resistance.

Table 2.1: Electrical quantities table

Electrical quantity	Unit of measurement
Electrical Energy	Joule (J)
Electric charge	Coulomb (C)
Electric Current	Ampere (A)
Voltage	Volt (V)
Resistance	Ohm (Ω)
Electric power	Watt (W)

The components of an electrical circuit are built from materials that facilitate the movement of electrons, which means electrical current can flow through them. These materials are called conductors. For example, metals are conductors.

Core Hardware Components of an Electrical Circuit

Power Source

We create a voltage between two points on the electrical circuit with a **power source**. The source works to transfer electrons from one point in the circuit to another. Two poles are created, one with an electron deficit (+) and the other with a surplus (-).

The balance in the quantities of electrons needs to be restored. To achieve this, electrons are drawn from the negative pole (-) to the positive pole (+). This movement generates electricity.

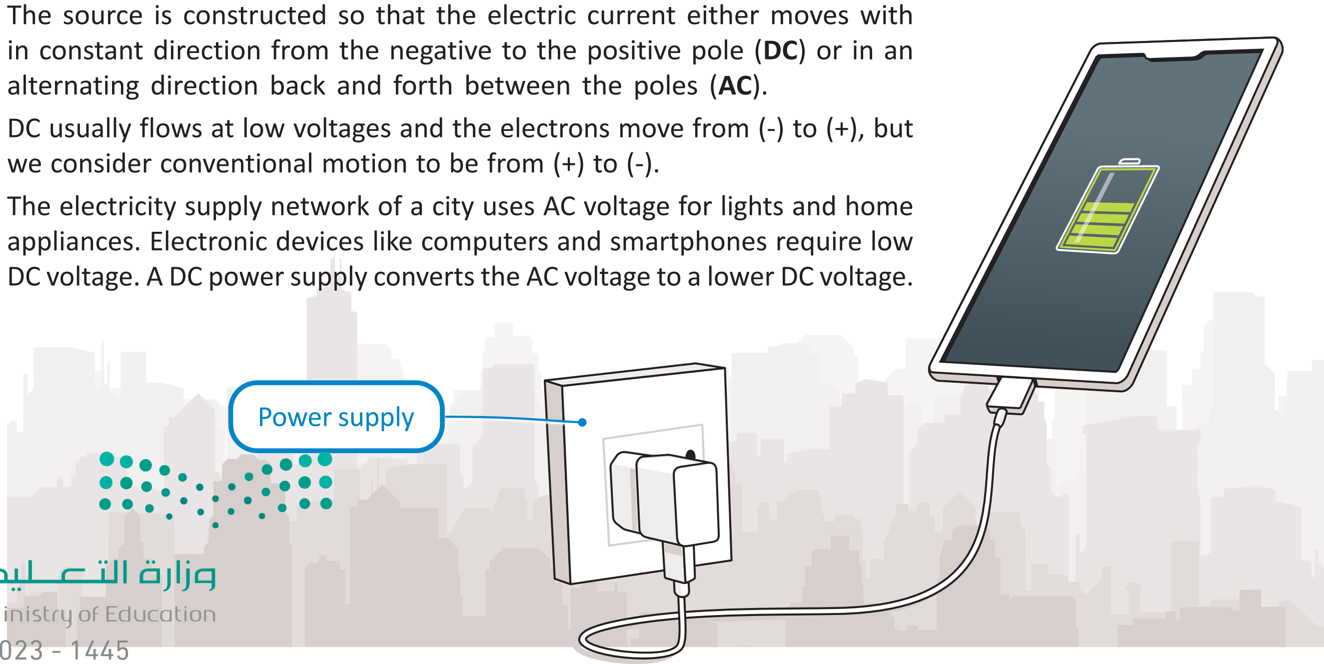
The power source can be a battery or a generator.

Alternating Current (AC) and Direct Current (DC)

The source is constructed so that the electric current either moves with in constant direction from the negative to the positive pole (**DC**) or in an alternating direction back and forth between the poles (**AC**).

DC usually flows at low voltages and the electrons move from (-) to (+), but we consider conventional motion to be from (+) to (-).

The electricity supply network of a city uses AC voltage for lights and home appliances. Electronic devices like computers and smartphones require low DC voltage. A DC power supply converts the AC voltage to a lower DC voltage.



Resistor

As mentioned before, electrical current is the movement of electrons through an electrical wire. Resistors (R), as their name suggests, resist this movement. They do not stop it, they merely slow the movement down. The faster the electrons move, the greater the electrical energy of the system.

The energy carried by the electrons is converted into heat by resistors.

Figure 2.1: Photo of resistors

Resistance, measured in ohms, is defined in terms of the ratio of voltage to current. If a current of 1A flows through a resistor when a voltage of 1V is applied to it, its resistance is 1 ohm.

$$1 \text{ ohm} = \frac{1 \text{ V}}{1 \text{ A}}$$

If we have two or more resistors then we give them names, such as R_1, R_2, R_3...

Switch

A switch (or circuit breaker) must be used in each circuit to control whether or not electricity flows through the circuit.

This is a circuit breaker.

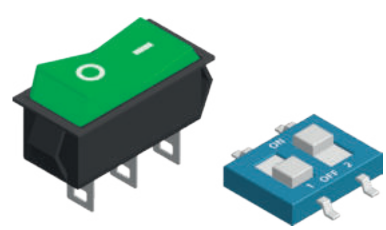


Figure 2.2: Different types of switches and circuit breakers

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Ministry of Education
2023 - 1445

INFORMATION

Resistance is denoted by the Greek letter omega in capitals: Ω (ohm).

Instruments for Measuring Electrical Quantities

Various instruments have been invented for measuring the different electrical quantities. These include::

The **voltmeter**, which is connected in parallel with a conductor and measures the voltage across its ends.

The **ammeter**, which is connected in series with the conductor and measures the intensity of the current flowing through the conductor.

The **ohmmeter**, which measures the resistance of a conductor.

The **multimeter, which** is an instrument that can measure voltage, current and resistance.

Figure 2.3: Multimeter

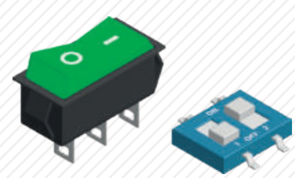
A multimeter is a tool that can measure the values of current, voltage, and resistance across various parts of an electrical circuit.
It is mainly used for troubleshooting.

A lamp behaves like a resistor.

Electrical Circuit Components

Before creating our first electrical circuit, let's look at the basic components we will need:

Electrical Components



Source | Switch | Resistor

Circuit Symbols

What the Colors on a Resistor Mean

Fixed resistors use standard color-coding rules to visually represent the basic properties of a resistor. The number of colored bands on a resistor show whether it is a standard or high precision resistor.

4 bands means a standard-precision resistor, whereas 5 bands means a high-precision resistor and 6 bands is essentially a 5 band resistor but with an extra ring that denotes the temperature coefficient.

How to decode bands on a standard-precision resistor:

> The 1st, 2nd, 3rd and 4rd bands denote the resistor’s value.

> The 5th band denotes the resistor’s tolerance with a standard measurement error of within 5% to 10% of the real tolerance value of the resistor.

Let's take a look at resistor color codes:

COLOR	1st DIGIT	2ndDIGIT	3rd DIGIT	MULTIPLIER	TOLERANCE	TEMPERATURE COEFFICIENT
BLACK	0	0	0	1 Ω		250 ppm/K
BROWN	1	1	1	10 Ω	± 1%	100 ppm/K
RED	2	2	2	100 Ω	± 2%	50 ppm/K
ORANGE	3	3	3	1 kΩ		15 ppm/K
YELLOW	4	4	4	10 kΩ		25 ppm/K
GREEN	5	5	5	100 kΩ	0.5% ±	20 ppm/K
BLUE	6	6	6	1 MΩ	0.25% ±	10 ppm/K
VIOLET	7	7	7		0.1% ±	5 ppm/K
GREY	8	8	8			1 ppm/K
WHITE	9	9	9			
GOLD				0.1 Ω	5% ±	
SILVER				0.01 Ω	10% ±	

Figure 2.4: Resistor color coding

INFORMATION

Not all resistors exert the same amount of resistance on the flow of electrons. The main rule is that the greater the resistance, the more the intensity of the electrical current is diminished.

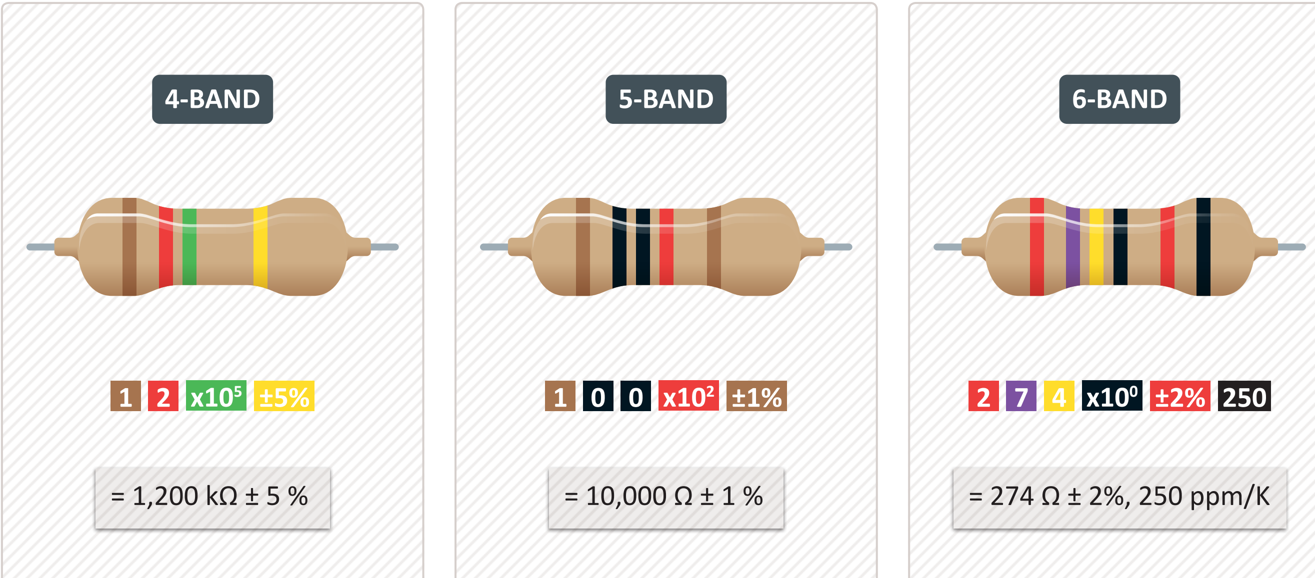
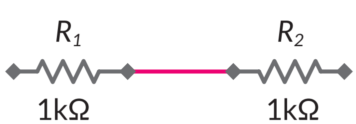
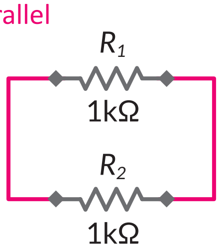


Figure 2.5: Examples of resistor calculation using color codes

Resistor Connections in Electrical Circuits

In an electrical circuit the resistors are connected as follows:

Resistor connections	Description	Total resistance
In series 	Resistors R_1 and R_2 have one common end, the same current I flows through them and have voltages V_1 and V_2 across their ends. Where $V_1 + V_2 = V_T$.	$R_T = R_1 + R_2$
In parallel 	Resistors R_1 and R_2 have two common ends, have the same voltage V across their ends and 2 different currents flow through them, I_1 and I_2. Where $I_1 + I_2 = I_T$.	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$

Total resistance is the resistance generated by all the resistors in a circuit.

Table 2.2: Prefixes of Units of Measurement

Name	nano	micro	milli	kilo	mega	giga
Symbol	n	μ	m	k	M	G
Factor	10^{-9}	10^{-6}	10^{-3}	10^{3}	10^{6}	10^{9}

Electrical Circuit Connections

All components of a circuit offer some resistance to current depending on their use.

In the following circuit we have:

- A lamp denoted by X, operating normally at 12V voltage.
- A switch denoted by S.
- A 12V power source.

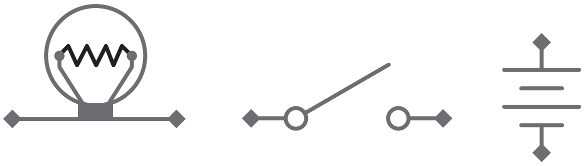
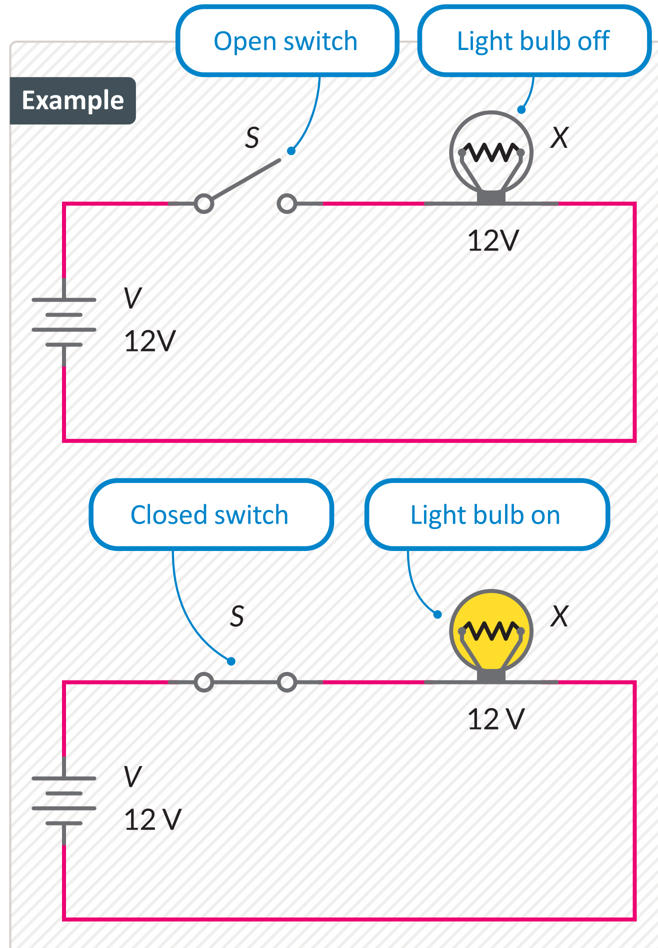


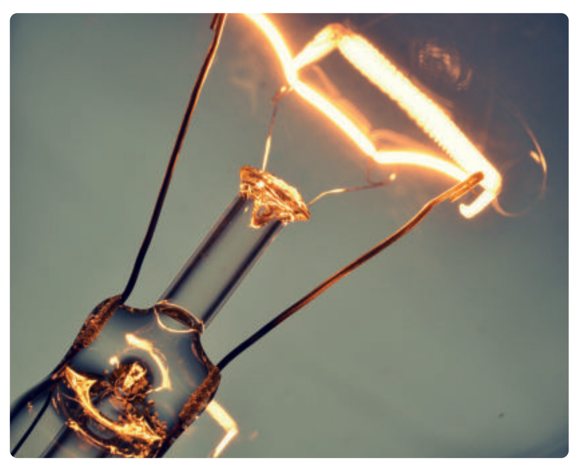
Figure 2.6: Schematic symbols for electrical circuits



Each device offers some resistance. For example, the wire in a light bulb resists electron flow. The result of this is the conversion of electricity into heat and light.

The internal resistance of switches and power sources is negligible, so they aren't counted in the total resistance of the circuit.

The 12V label on a light bulb is the value of the voltage that must be applied to its ends for it to function properly.



The light emitted and the intensity of the electric current flowing through the lamp are in relation to the rated voltage of the connected battery. Low voltage results in light that is dimmed or even barely visible. Very high voltage may damage the lamp.

INFORMATION

Generally, DC sources are much safer than AC sources.

Ohm's Law

In electrical circuits, it is important to know the relationship between the electric current flowing through a resistor and the voltage across its ends. The German physicist Georg Simon Ohm first explored this relationship in 1827.

He defined that a conductor which has a constant resistance R and a voltage V at its ends, allows an electric current of intensity I to flow through the conductor. He observed that the current I is proportional to the potential difference V. In mathematical notation this relation is written as:

$$I = \frac{V}{R}$$

This law can also be applied to a circuit with more than one. Essentially, we view the complete electrical circuit as one resistor itself, by determining the total resistance of the entire circuit.

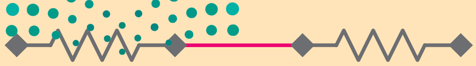
When studying electrical circuits and calculating the values of V, I and R for each component of the circuit, we continuously apply Ohm's law.

Series and Parallel Circuit Connections

Series and Parallel connections of resistors are shown below:

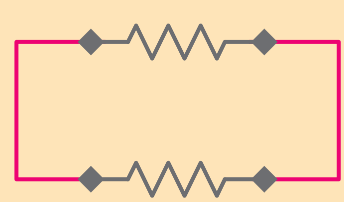
What is a Series Connection?

All components in a series circuit are connected end to end, forming a single path for current to flow along , and there is no branching of the electric current.



What is a Parallel Connection?

Components in a parallel circuit are connected so that there are two or more possible paths for the current, forming two sets of electrically common points, and there is a branching of the electric current.



Series Connections

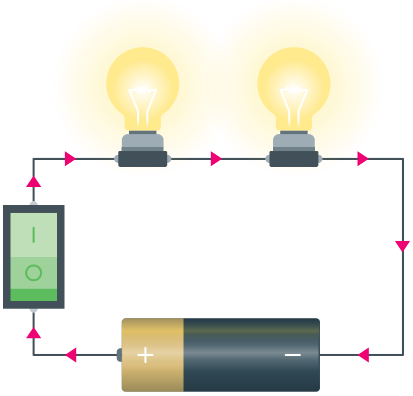
Let's start with the series circuit.

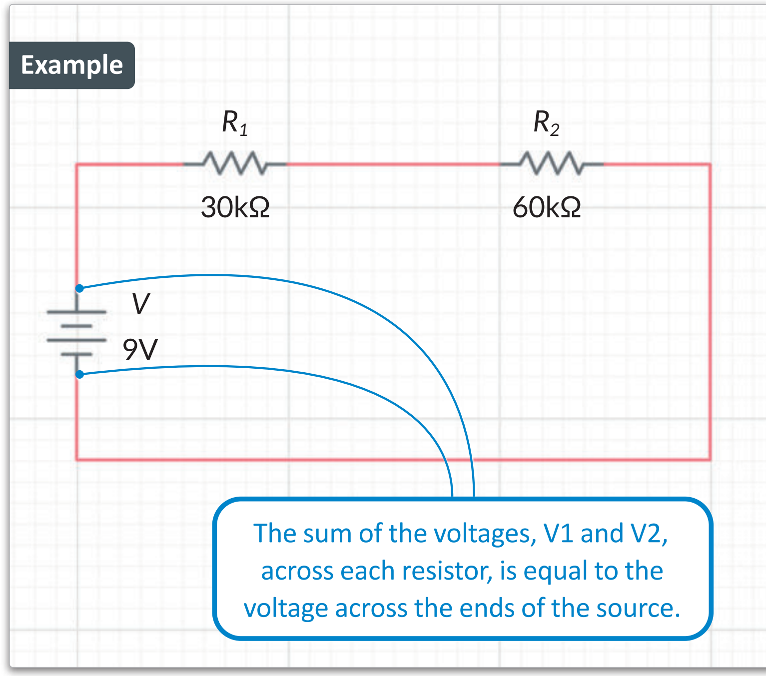
You have the following values:

> R_1 = 30kΩ

> R_2 = 60kΩ

> Voltage V = 9V supplied by the battery.





We will first calculate the total resistance R of the circuit: $R_T = R_1 + R_2 = 90k\Omega$

Next we will calculate the current I flowing through the circuit: $I = \frac{V}{R_T} = \frac{9}{90k\Omega} = 0.1mA$

Finally, we will calculate the voltages V at the ends of each resistor:

$$V_1 = I \times R_1 \Rightarrow 0.1mA \times 30k\Omega = (0.1 \times 10^{-3}) \times (30 \times 10^3) = 3V$$

$$V_2 = I \times R_2 \Rightarrow 0.1mA \times 60k\Omega = (0.1 \times 10^{-3}) \times (60 \times 10^3) = 6V$$

In a wire or cable, the resistance R depends on:

> **the length:** Longer wire means greater resistance.

> **the thickness:** Thicker wire means lesser resistance.

> **the material** that the cable is made from. For example, copper wires have lower resistance.

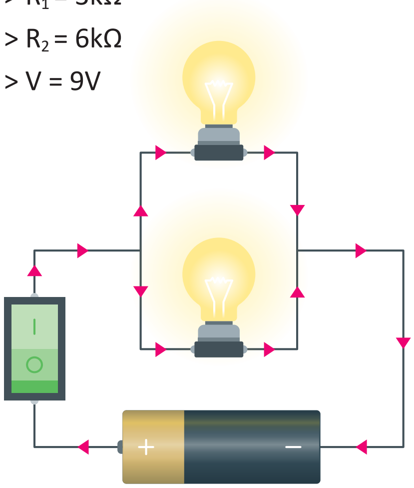
SMART TIP

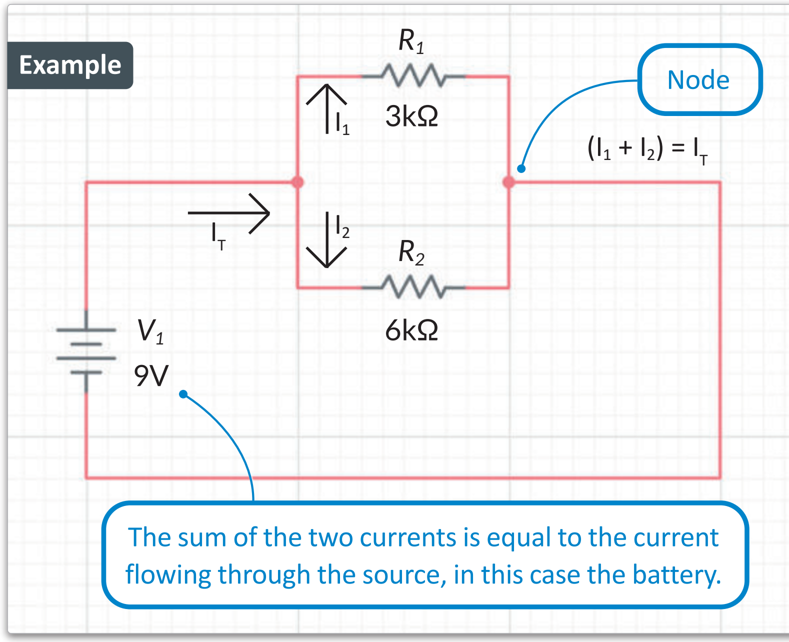
The lower the resistance of a conductor, the higher the intensity of the current flowing through it , for a given voltage.

Parallel Connections

Now we will see a circuit whose resistors are connected in parallel.

> $R_1 = 3k\Omega$
> $R_2 = 6k\Omega$
> $V = 9V$





We will first calculate the total resistance of the circuit:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow R_T = \frac{R_1 \times R_2}{(R_1 + R_2)} \Rightarrow R_T = \frac{18k\Omega}{9k\Omega} = 2k\Omega$$

Next we will calculate the flow of current of R_1:

$$I_1 = \frac{V_1}{R_1} \Rightarrow I_1 = \frac{9V}{3k\Omega} = \frac{9}{3 \times 10^3} = 3 \times 10^{-3} = 3mA$$

Next we will calculate the flow of current of R_2:

$$I_2 = \frac{V_2}{R_2} \Rightarrow I_2 = \frac{9V}{6k\Omega} = \frac{9}{6 \times 10^3} = 1.5 \times 10^{-3} = 1.5mA$$

Next we will calculate the flow of current in the circuit:

$$I_T = I_1 + I_2 \Rightarrow I_T = 3mA + 1.5mA = 4.5mA$$

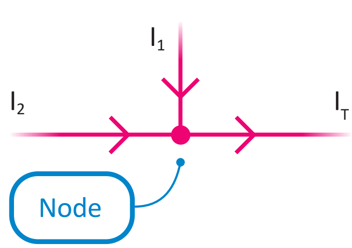
We can find the same result for I_T by applying Ohm's law:

$$I_T = \frac{V}{R_T} \Rightarrow I = \frac{9V}{2k\Omega} = \frac{9}{2 \times 10^3} = 4.5 \times 10^{-3} = 4.5mA$$

Node

A node is a point in a circuit where 2 or more conductors meet.

A circuit loop is a part of the circuit that starts at one point and ends at the same point following the path of current flow.

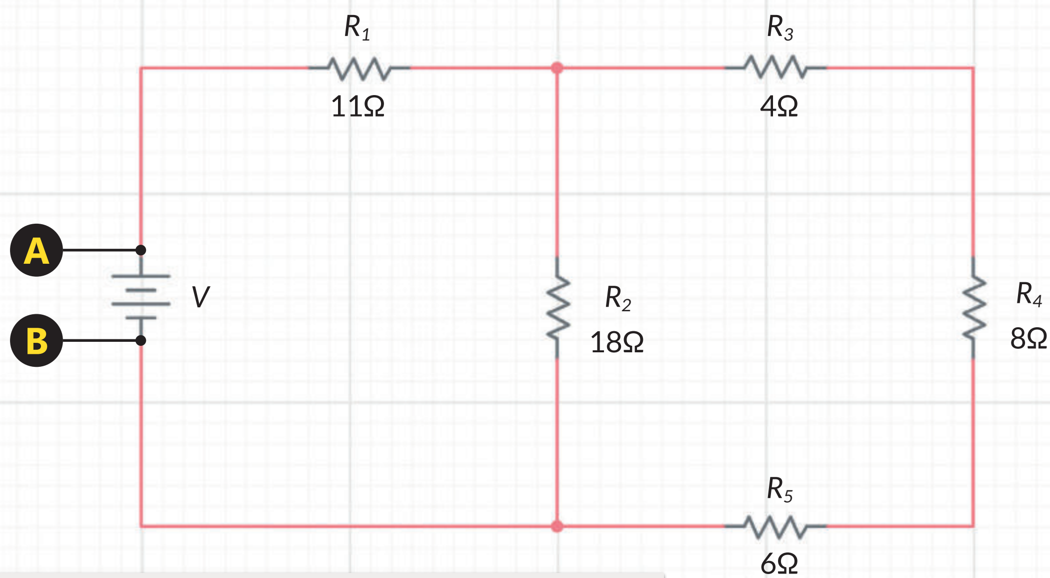


Ohm's law cannot be applied to devices in which the ohmic resistance does not remain constant. Examples include diodes, transistors, etc.

Ohm's Law: Example Problem

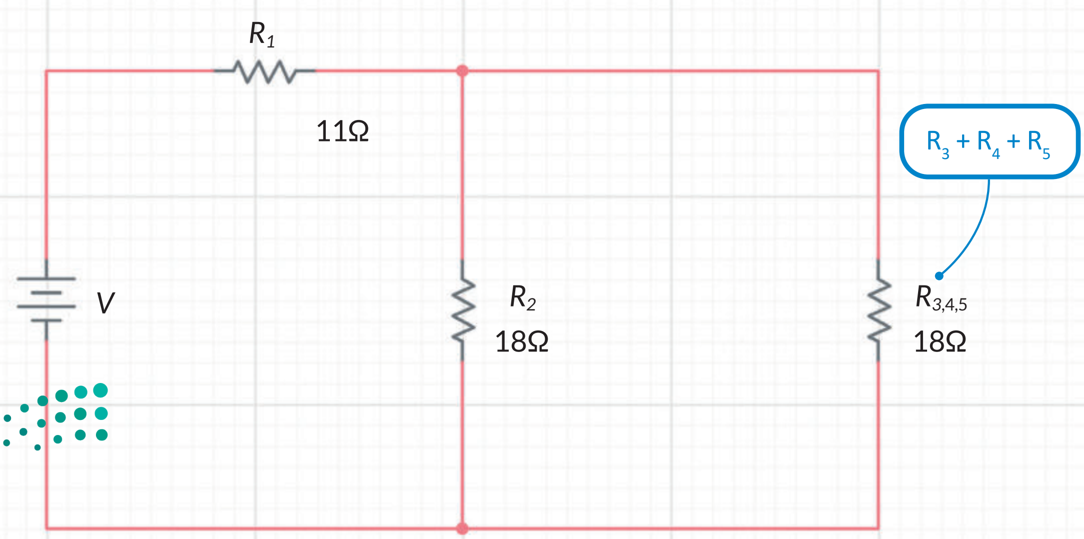
In this example, we want to find the potential difference, or voltage, between points A and B.

You can find the total resistance of the circuit between points A and B:

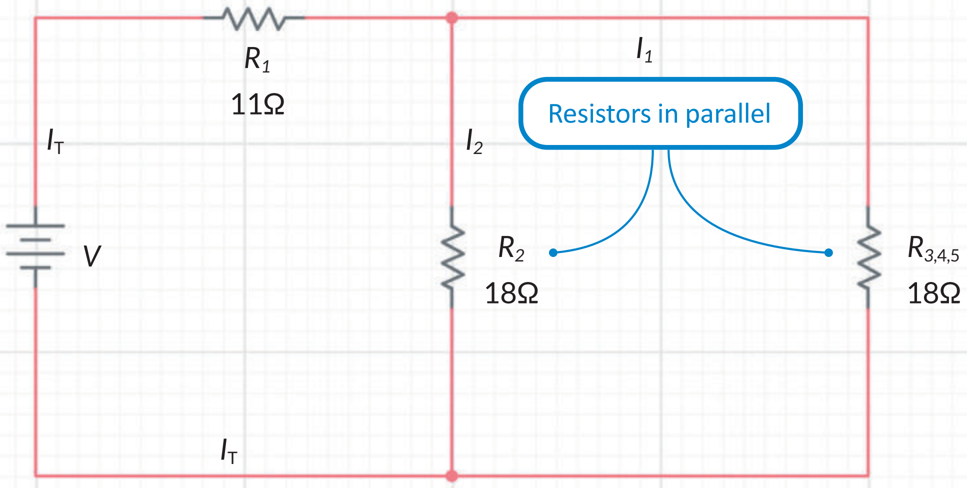


First we note that resistors R_3,R_4 and R_5 are connected in series, so: $R_3,R_4,R_5 = 4 + 8 + 6 = 18\Omega$

We can now consider an equivalent circuit:

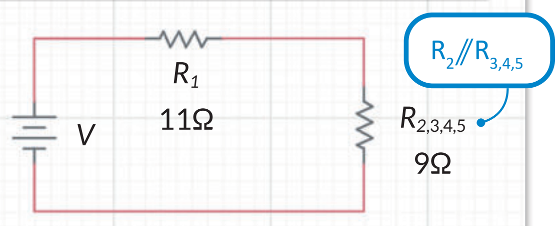


In the equivalent circuit, we observe that $R_{3,4,5}$ and R_2 are connected in parallel.



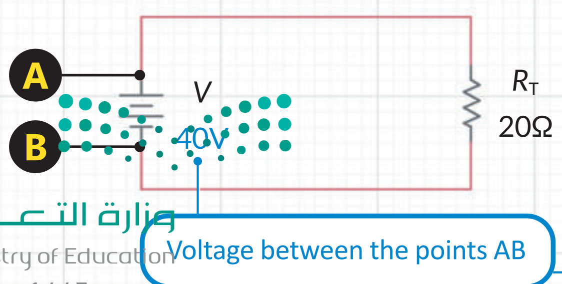
Therefore: $R_2 /\!/ R_{3,4,5} = \dfrac{R_{3,4,5} \times R_2}{(R_{3,4,5} + R_2)} = 9\Omega$

So we consider the following equivalent circuit:



From this,we find the total resistance:

$$R_T = R_1 + R_{2,3,4,5} = 11 + 9 = 20\Omega$$



We can calculate the voltage between points A and B, if the current flowing through R_2 is I_2=1A.

So the voltage across the ends of R_2 will be:

$$V_2 = I_2 \times R_2 = 1 \times 18 = 18V$$

Since the resistor $R_{3,4,5}$ is connected in parallel , with R_2 and therefore has a voltage of $V_{3,4,5}$ = 18V.

So $I_{3,4,5} = \dfrac{V_{3,4,5}}{R_{3,4,5}} = \dfrac{18}{18} = 1A$

The current flowing through the source and R_1 is:

$$I_T = I_2 + I_{3,4,5} = 1 + 1 = 2A$$

Thus, the voltage across A and B is:

$$V_{AB} = I_T \times R_T = 2 \times 20 = 40V$$

Exercises

1 Tick the correct sentences below.

A resistor is connected to the poles of a generator that has negligible internal resistance. If we connect another identical resistor in series with the first resistor, then the intensity of the current:	True	False
1. will double.	○	○
2. will remain constant.	○	○
3. will drop to half.	○	○
4. will quadruple.	○	○

2 Tick the correct sentences below.

When two resistors, R_1 and R_2, with different resistances are connected in parallel:	True	False
1. They display the same voltage at their ends.	○	○
2. A current of equal intensity flows through each.	○	○
3. Their equivalent resistance is R_T from the equation $R_T = R_1 + R_2$.	○	○
4. Currents of different intensities flow through each.	○	○

3

Read the sentences and tick ✓ True or False.	True	False
1. An ammeter measures voltage.	○	○
2. A voltmeter is connected across a branch in the circuit.	○	○
3. The energy that the electric current transmits to a resistor, is completely converted into thermal energy.	○	○
4. Resistors connected in series have the same current flowing through them.	○	○
5. $R_T = R_1 + R_2 + R_3 + ... + R_n$ holds true for resistors connected in series.	○	○
6. Resistors that are connected in parallel display the same voltage at their ends.	○	○
7. A voltmeter measures the intensity of current.	○	○
8. For resistors that are connected in parallel, the total resistance of the circuit is $R_T = R_1 + R_2 + R_3 + ... + R_n$.	○	○

4 Match the items in the first column with those in the second.

Quantities	**Units**
Resistance	V
Voltage	W
Electrical energy	J
Power	Ω

5 On a piece of paper, draw a circuit consisting of two identical light bulbs X_1 and X_2, the source V and the switch S in series. Closing the switch, electrical current begins flowing through the circuit. Determine whether the two light bulbs X_1 and X_2 will emit the same amount of light? Justify your answer.

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6 Three resistors $R_1 = 20\Omega$, $R_2 = 5\Omega$ and $R_3 = 4\Omega$, are connected in parallel to a voltage $V = 20V$. The resistor R_2 is connected to an ammeter in series which shows the current I_2 that flows through R_2. The source is connected to a switch S and a second ammeter in series, which shows the intensity of the current I, which flows through the source. The resistances of the power source and the ammeters are considered negligible.

1. Draw the circuit diagram.

2. Find the total resistance R_T.

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3. Find the ammeter readings when switch S is closed.

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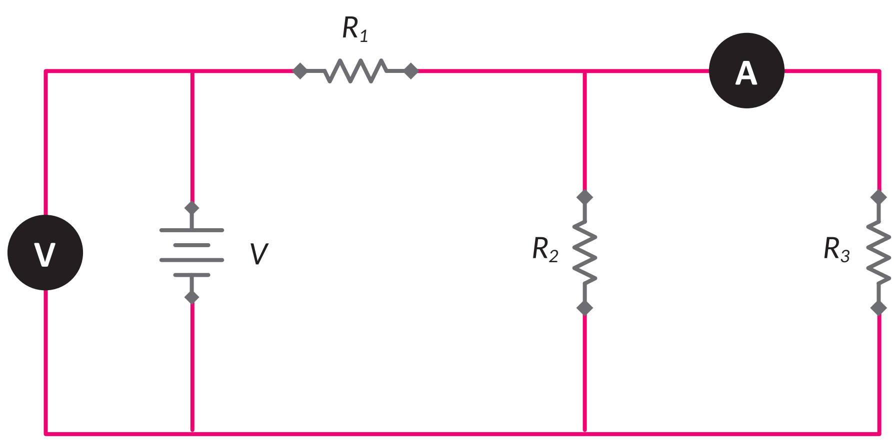
7 In the circuit diagram, the source has voltage V. The power source and the two measurement instruments, the ammeter (A) and voltmeter (V), have negligible internal resistances.

The resistors have values $R_1 = 100\Omega$, $R_2 = 50\Omega$, $R_3 = 50\Omega$, and the ammeter displays a reading of 0.8A. Calculate the following:

1. The total resistance of the circuit.

2. The intensity of the current flowing through each resistor.

3. The voltmeter reading.



Use the physics laboratory and try to apply it practically under the supervision of the teacher or the assistant, then explain how both the ammeter and the voltmeter are connected to the electrical circuit?

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Lesson 2

Circuit Simulation

Link to digital lesson

www.ien.edu.sa

Electronic circuits are hardware projects which exist in the physical domain, but this also means that malfunctions may occur that are not related to the design of the circuit but are caused by faulty conductors, power sources, etc. This means that you cannot focus on the circuit design alone. For this reason, circuit simulation software can be very helpful and is used by professionals.

These programs allow an engineer to design any circuit freely without a restriction on materials, components and in a controlled environment. When the desired circuit design has been achieved, the engineer then proceeds to build it in the physical domain.

In this lesson, you will use **Multisim Live** to design and simulate electrical circuits.

What is Multisim Live?

Multisim live allows you to simulate electrical circuits and schematics built on the SPICE simulation architecture. Multisim Live allows you to simulate electronic circuits on any device which has access to a web browser.

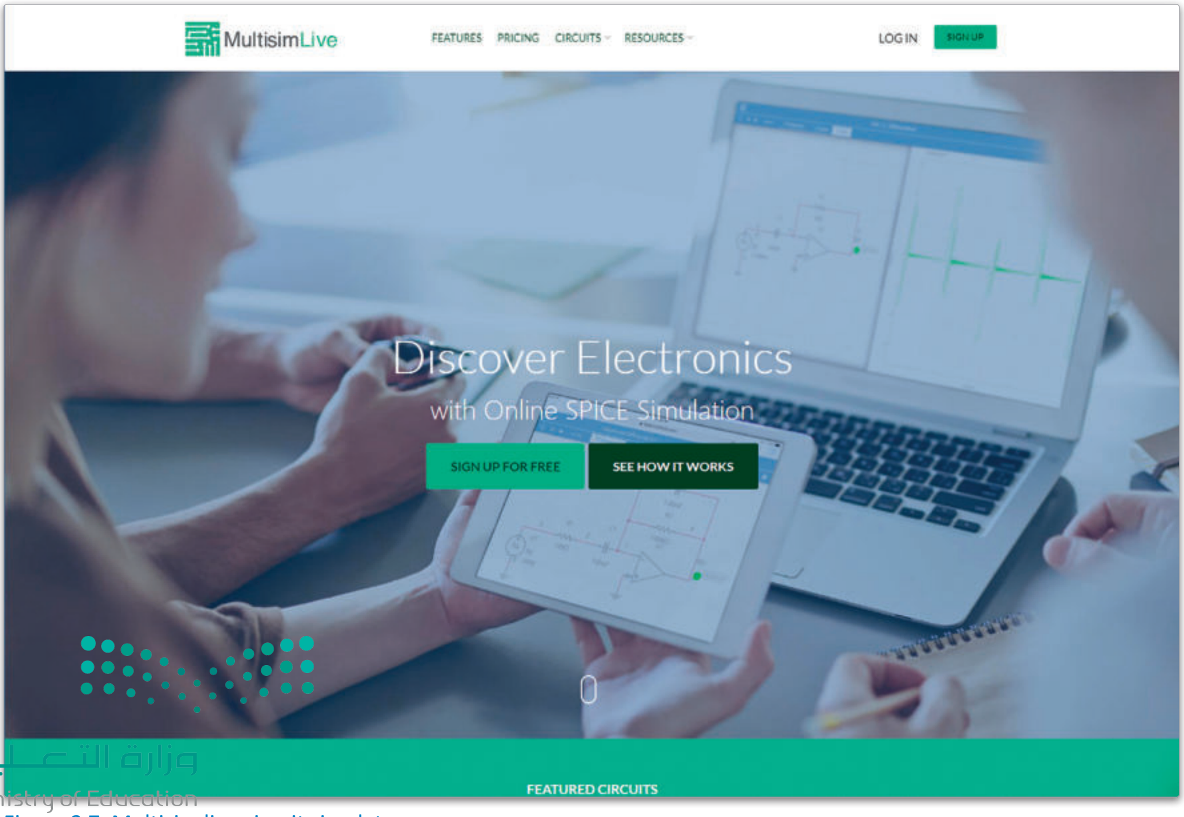


Figure 2.7: Multisim live circuit simulator

Create an Account

Go to https://www.multisim.com to access Multisim Live.

The first thing you need to do is to create an account so you can save your projects.

This is simple, click on **sign up** and fill in the necessary fields.

After you have created your account, go back to https://www.multisim.com, then click Log in.

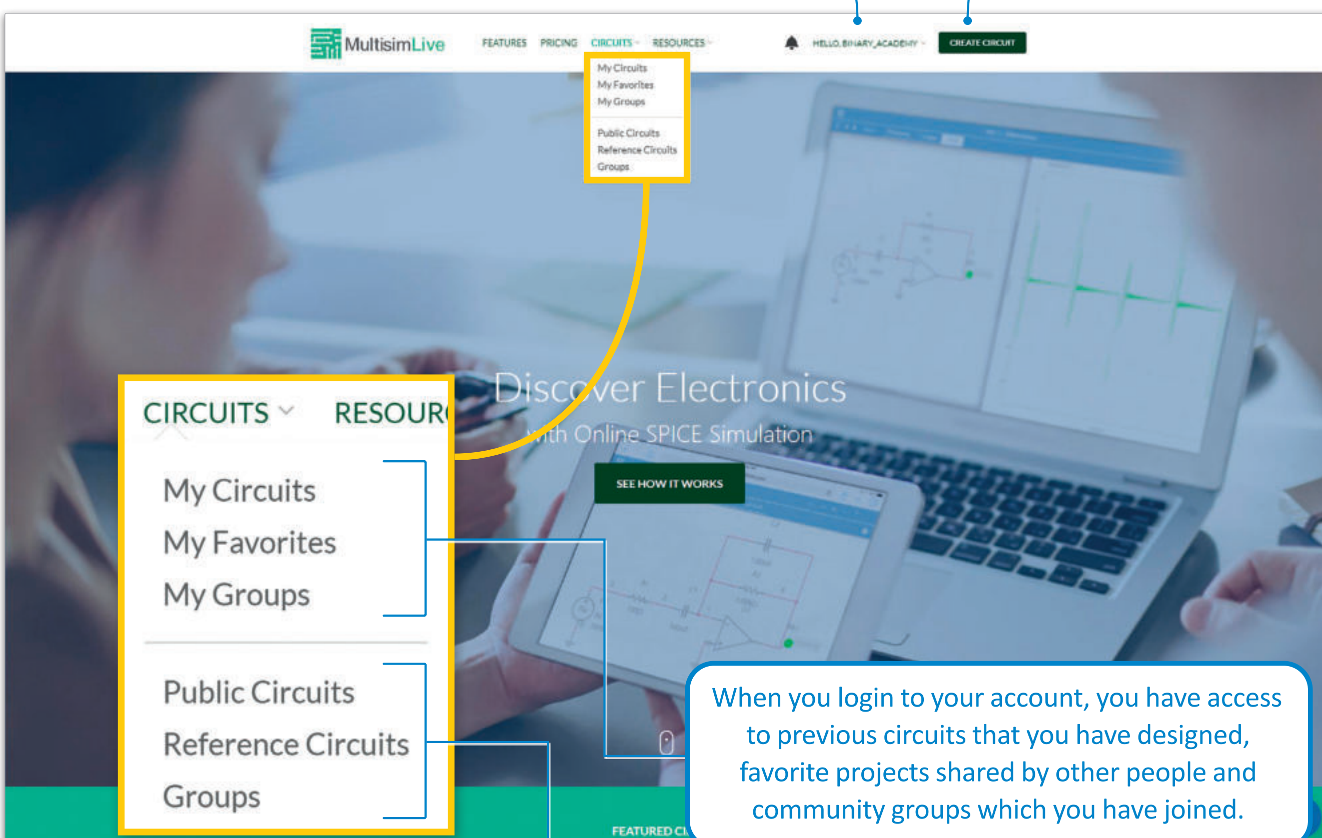
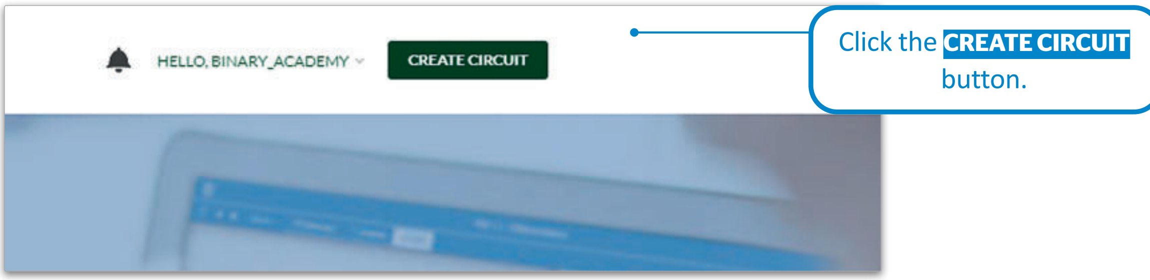


Figure 2.8: Create an account

Design a Circuit

Let's see how we can use Multisim Live to create our first circuit.



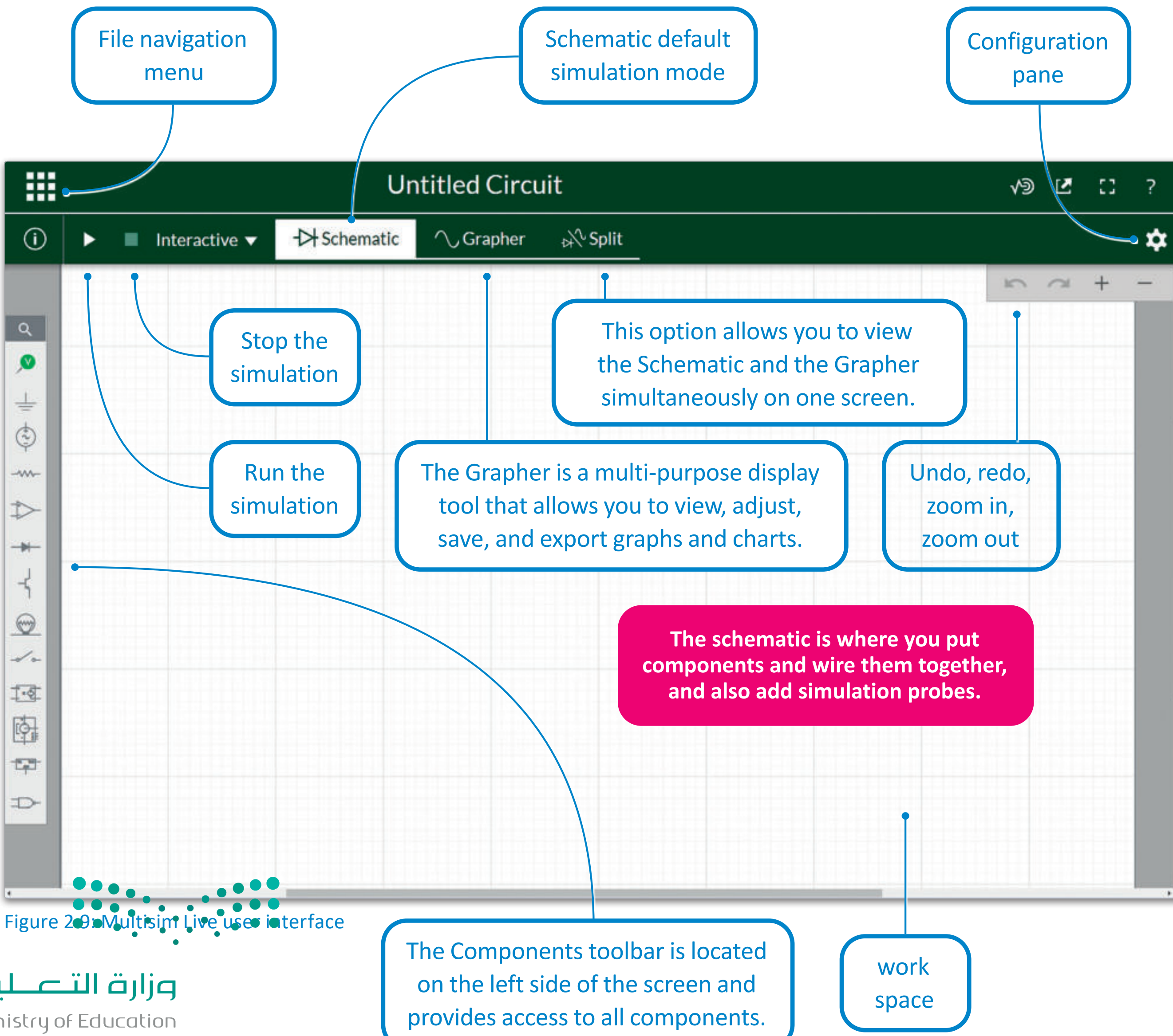
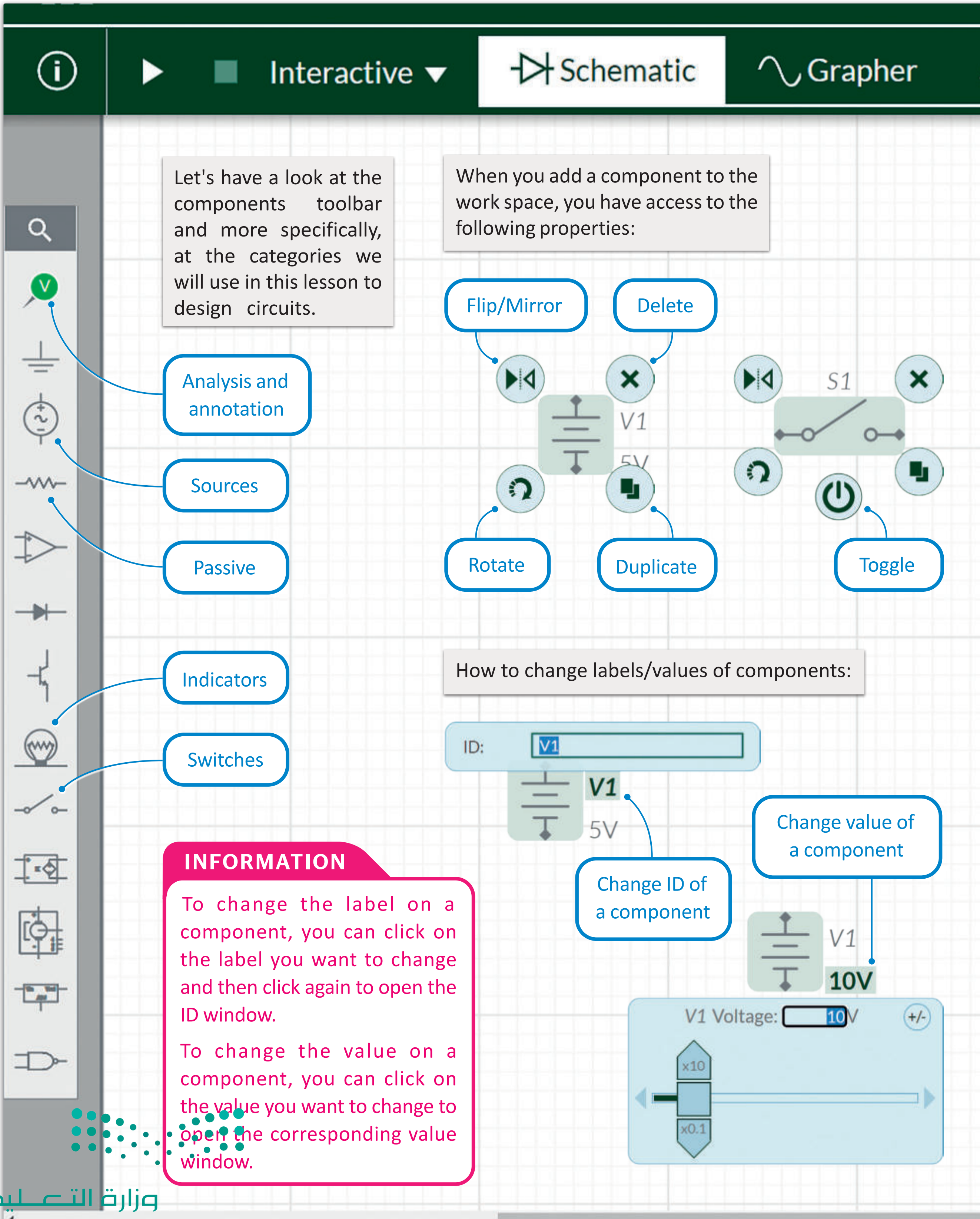


Figure 2.9: Multisim Live user interface



INFORMATION

To change the label on a component, you can click on the label you want to change and then click again to open the ID window.

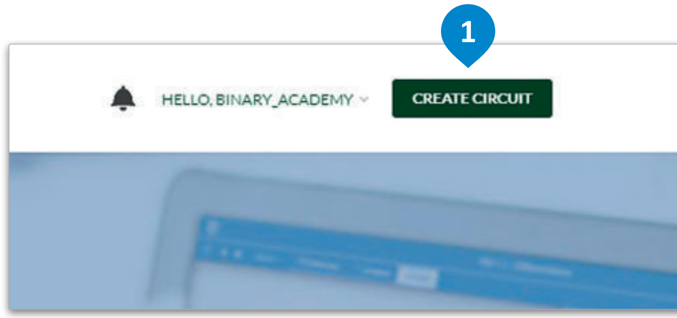
To change the value on a component, you can click on the value you want to change to open the corresponding value window.

Figure 2.10: Multisim Live toolbox

Now you will design your first circuit in Multisim Live. First you are going to connect a resistor of 1kΩ.

To connect a resistor:

> Go to https://www.multisim.com/ and click **CREATE CIRCUIT**. 1
> On the **Components toolbar** click the **Passive** tab. 2
> Drag 3 and drop a **Resistor** into the **work space**. 4



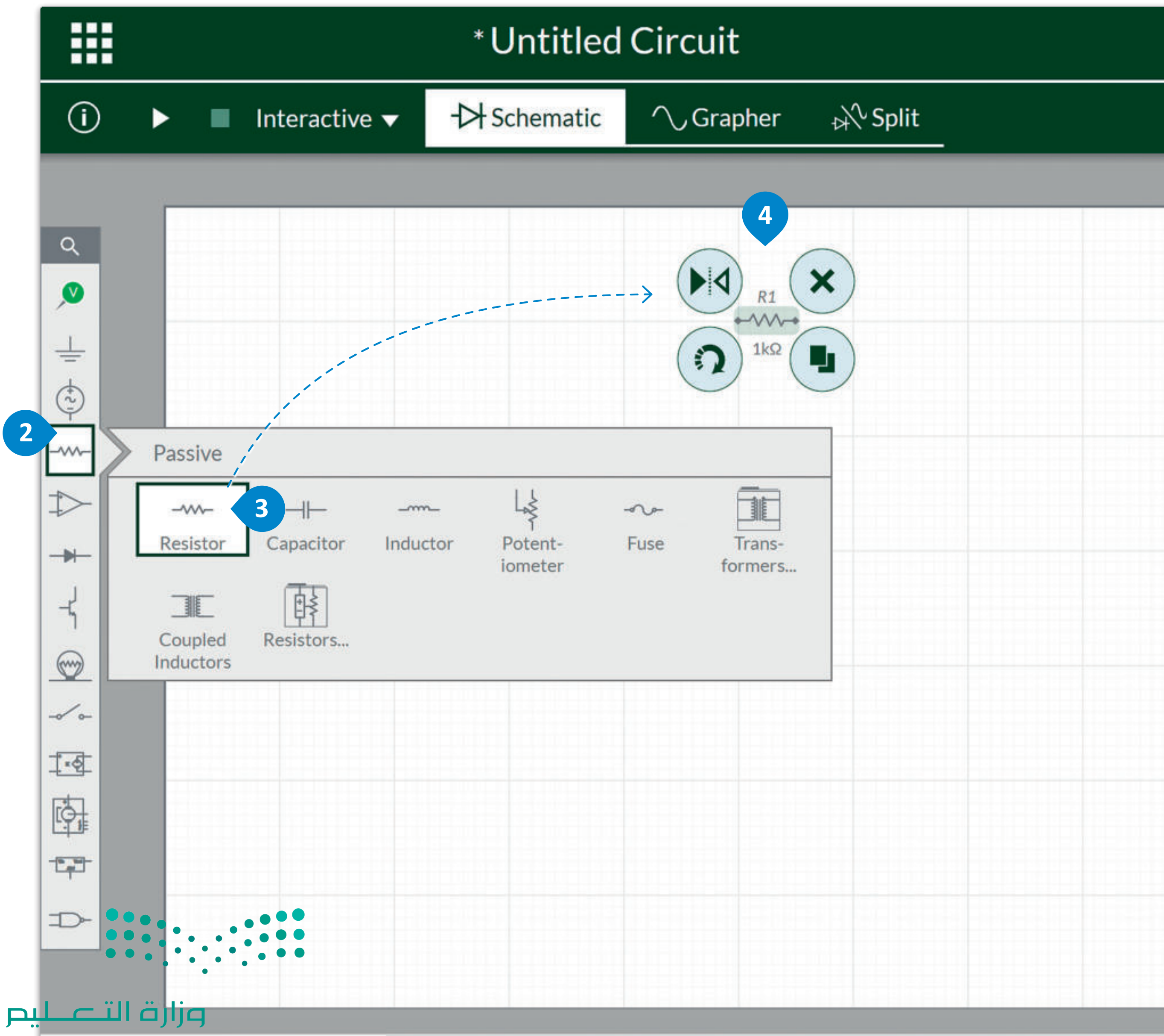


Figure 2.11: Connect a resistor

Next you are going to connect the source.

To connect the source:

> On the **Components toolbar** click the **Sources** tab. 1

> Drag 2 and drop **DC Voltage (VCC)** into the **work space**. 3

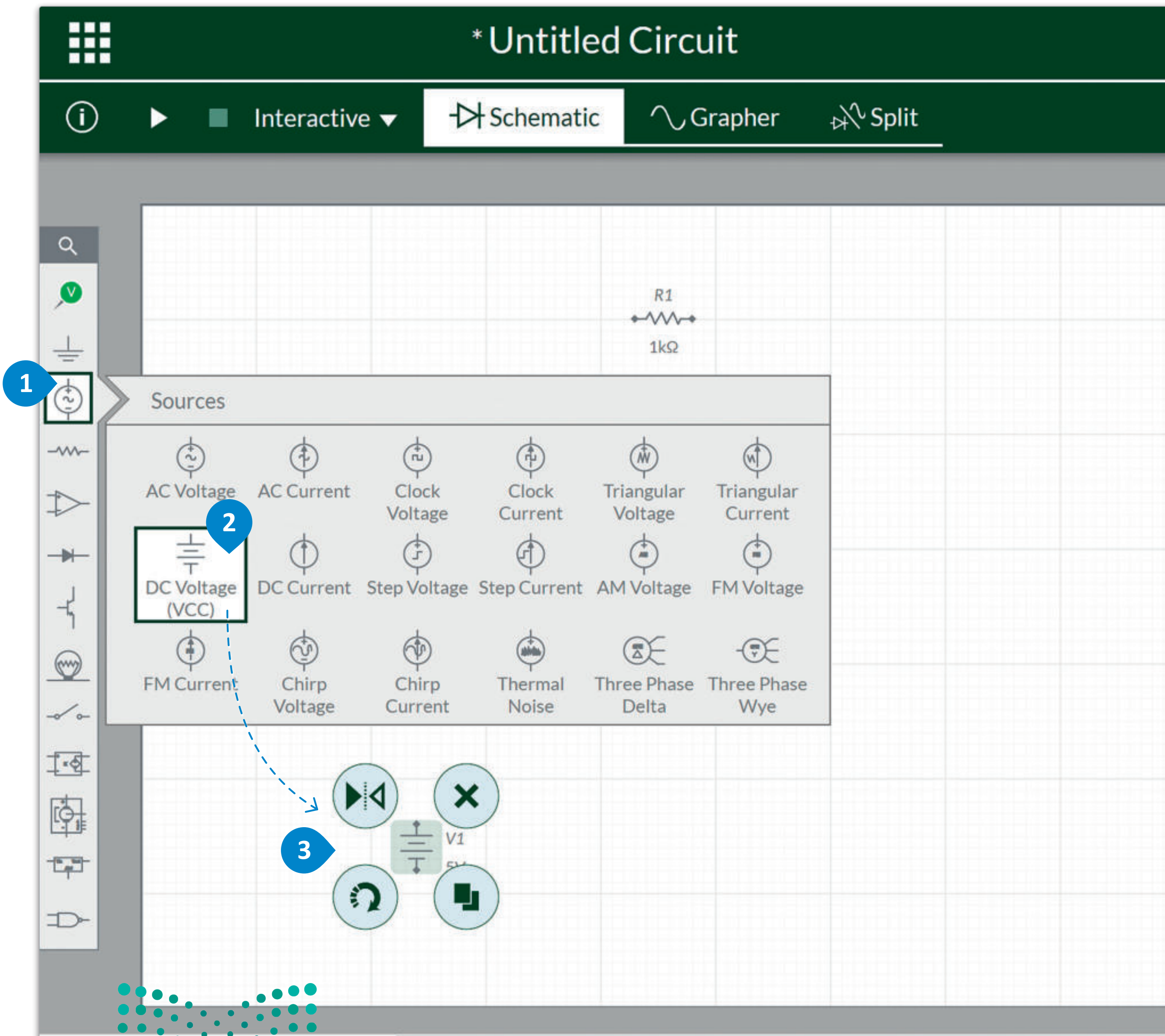


Figure 2.12: Connect the source

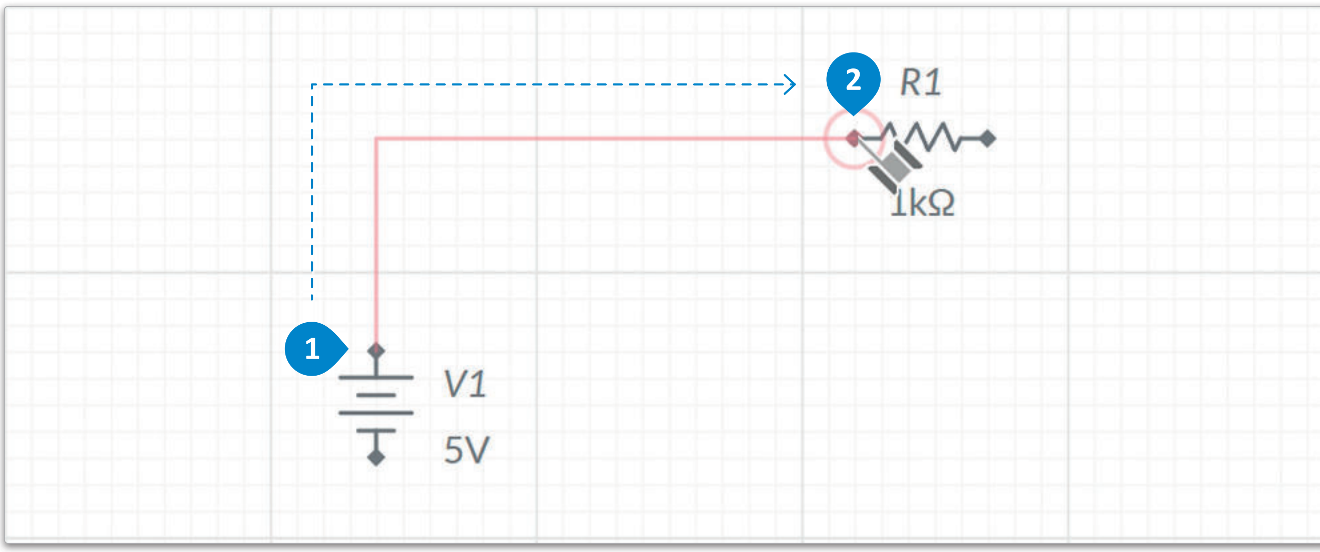
Now that you have placed the resistor and source in your work space, you need to connect them using a wire.

Connections:

> Click on the **Source** positive upper **node** 1 and then on the **Resistor** left **node**. 2

> Click on **Resistor** right **node** 3 and then on **Source** negative lower **node**. 4

A branch of the circuit is a section of a loop in which there is no node present.



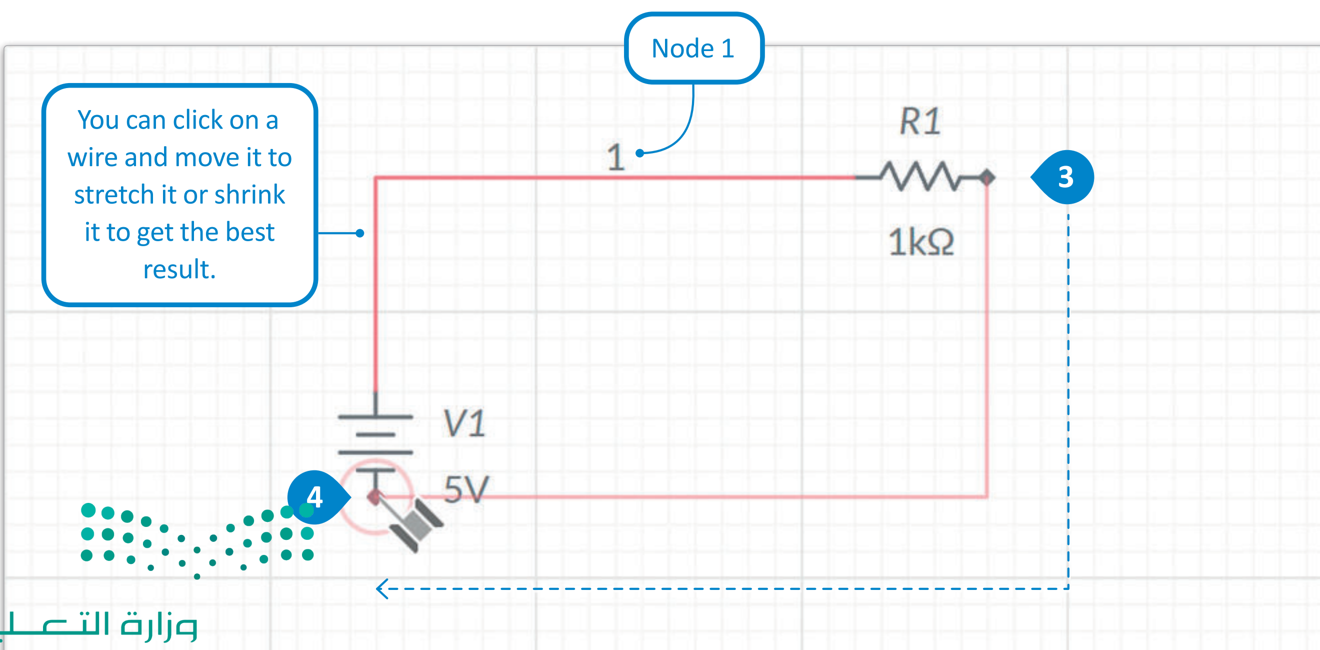


Figure 2.13: Connections

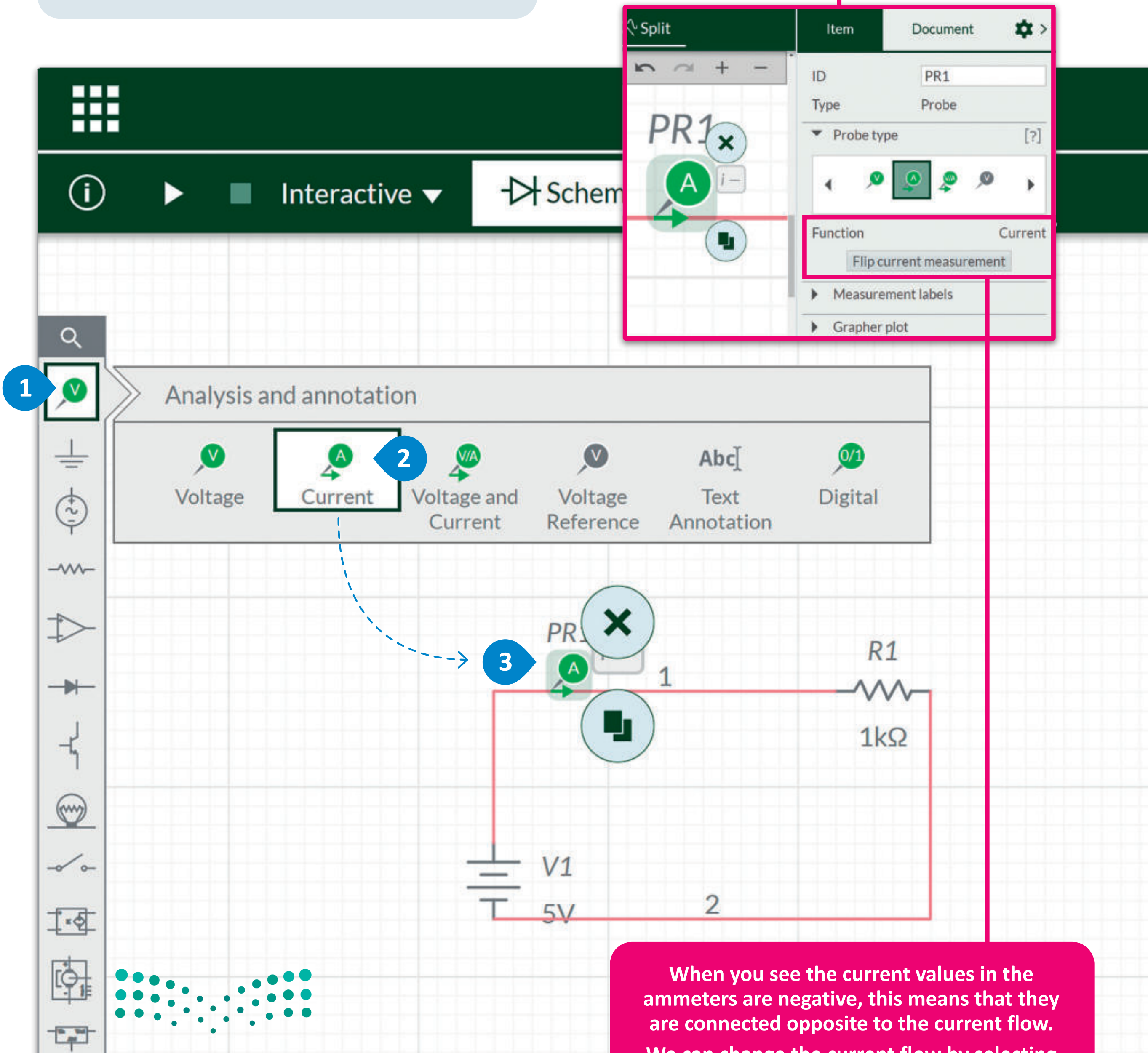
The design part is almost finished, the last thing we need to do is to add probes so you can see the measurements on the circuit.

To add a Current probe:

> On the **Components toolbar** click the **Analysis and annotation** tab. 1

> Drag 2 and drop **Current probe** in **series** with the **Resistor**. 3

When we connect a Current probe with its arrow pointing from the negative end (-) to the positive end (+) of the power source, then the value of the current will be negative.



When you see the current values in the ammeters are negative, this means that they are connected opposite to the current flow.

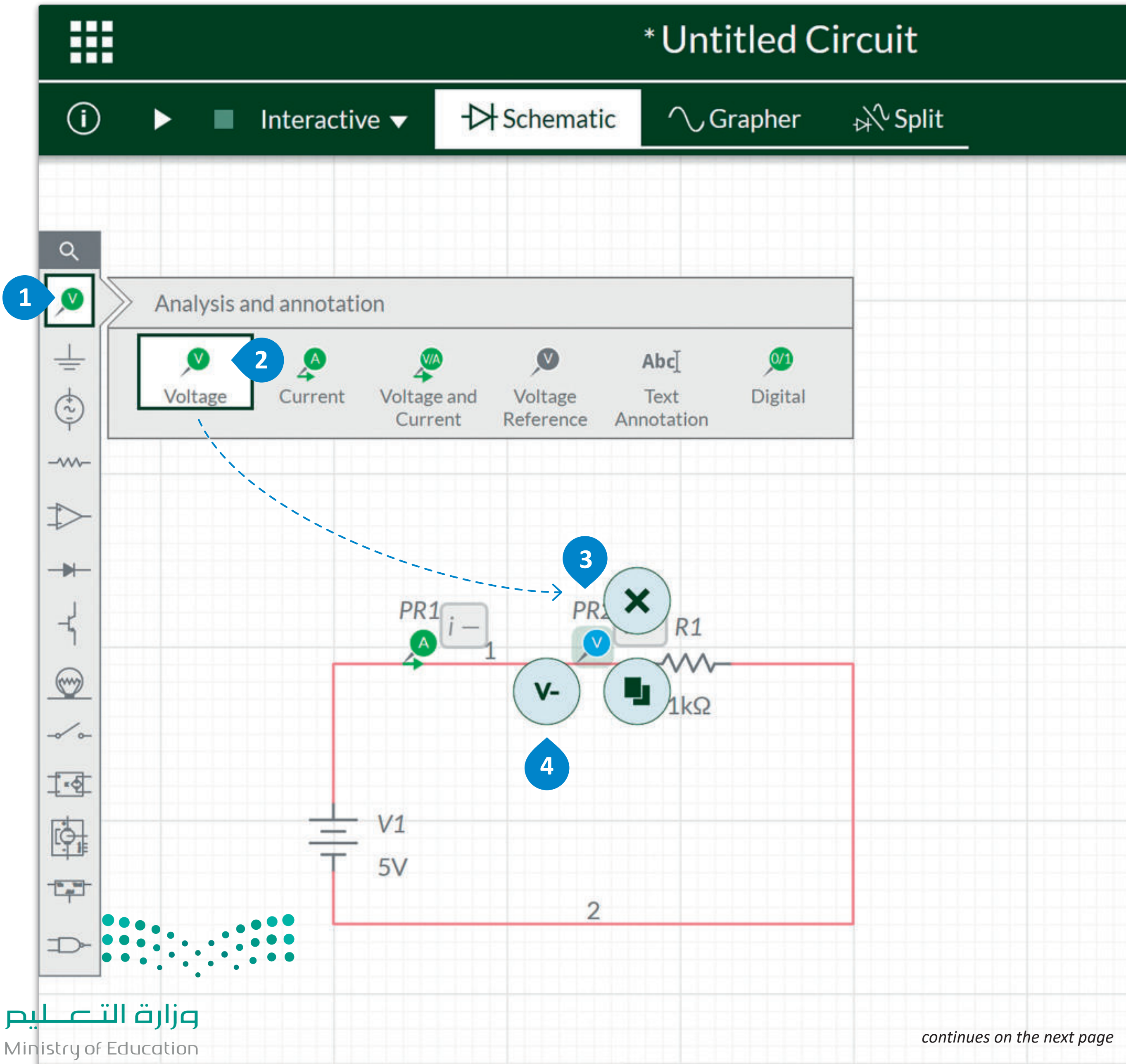
We can change the current flow by selecting the current probe, going to the configuration pane, and clicking "Flip current measurement".

Figure 2.14: Add a Current probe

You can also add probes to see voltage measurements.

To add a Voltage probe:

> On the **Components toolbar,** click the **Analysis and annotation** tab. 1
> Drag 2 and drop a **Voltage probe** on the left side of the **Resistor**. 3
> Click to **add a reference probe**, 4 and drop it on the right side of the **Resistor**. 5



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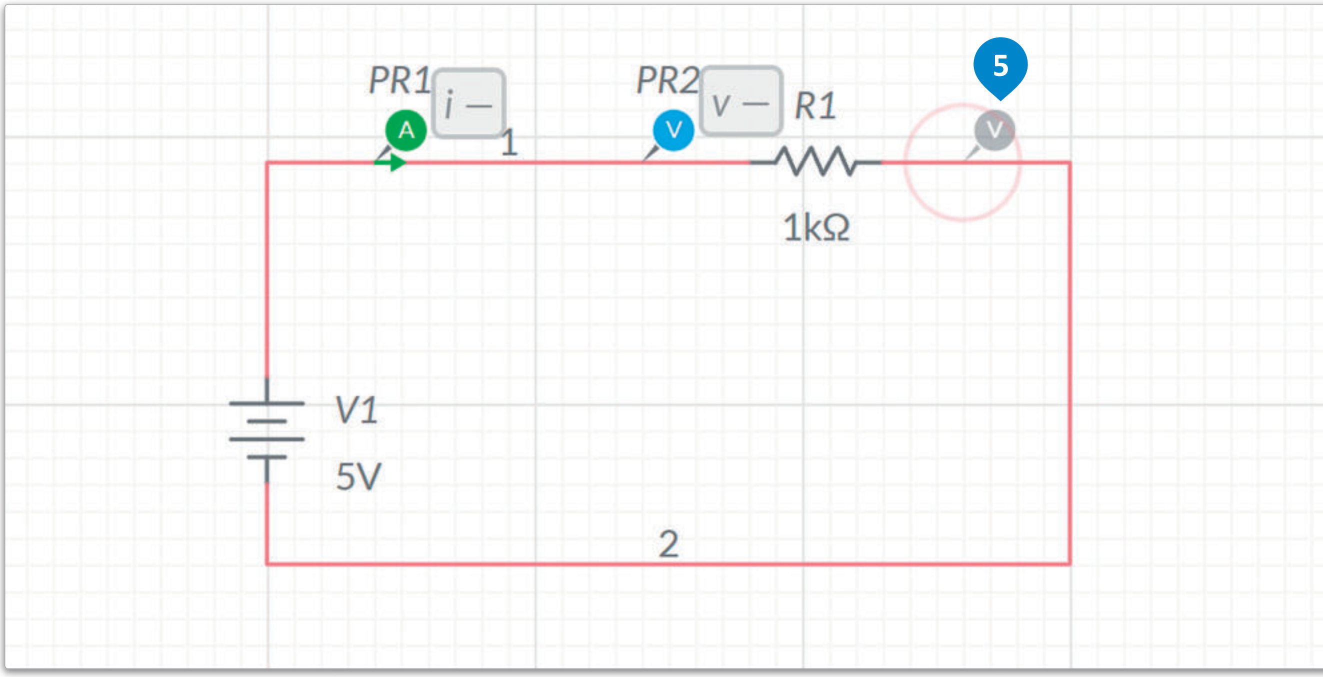
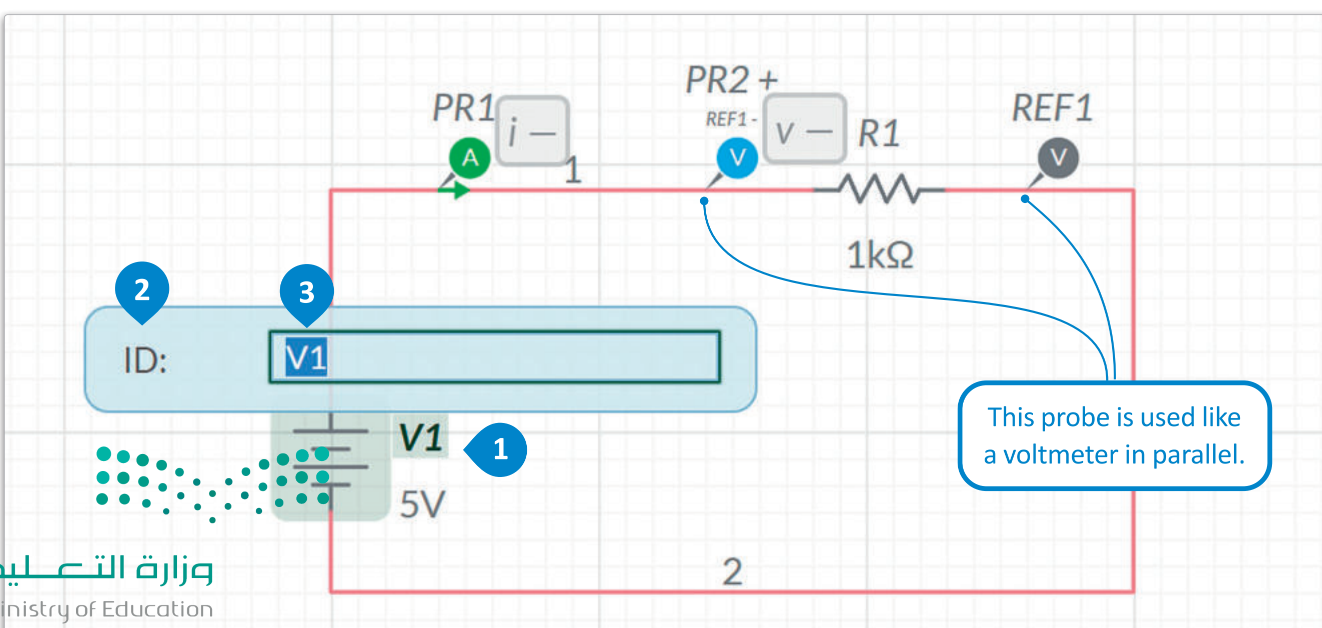


Figure 2.15: Add a Voltage probe

It's important to name the components and detectors you have in your circuit.

To name the components and detectors:

> Click on **Source V1** to select it. 1
> Click again on **Source V1** to open the **ID:** box. 2
> Change name to **V**. 3



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Your circuit should now look like the image below..

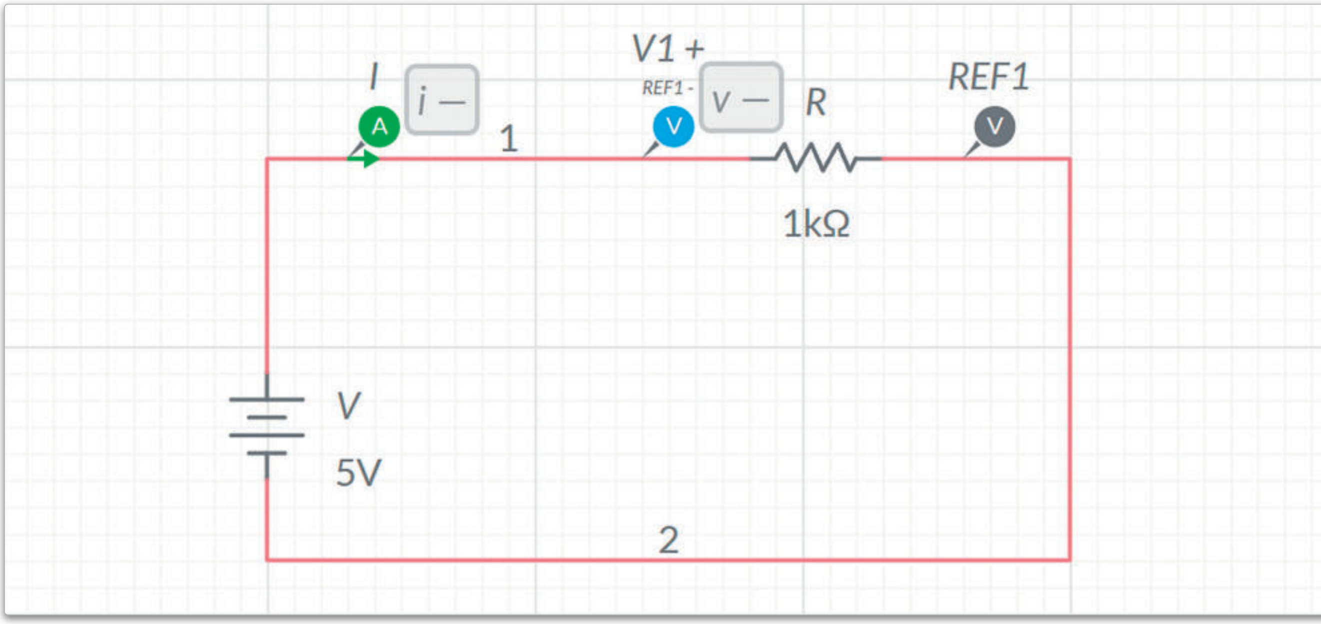


Figure 2.16: Name the components and detectors

Avoid placing your circuit in an environment where there are liquids, humidity, or dust in proximity. These environmental factors can cause short-circuits which can lead to accidents.

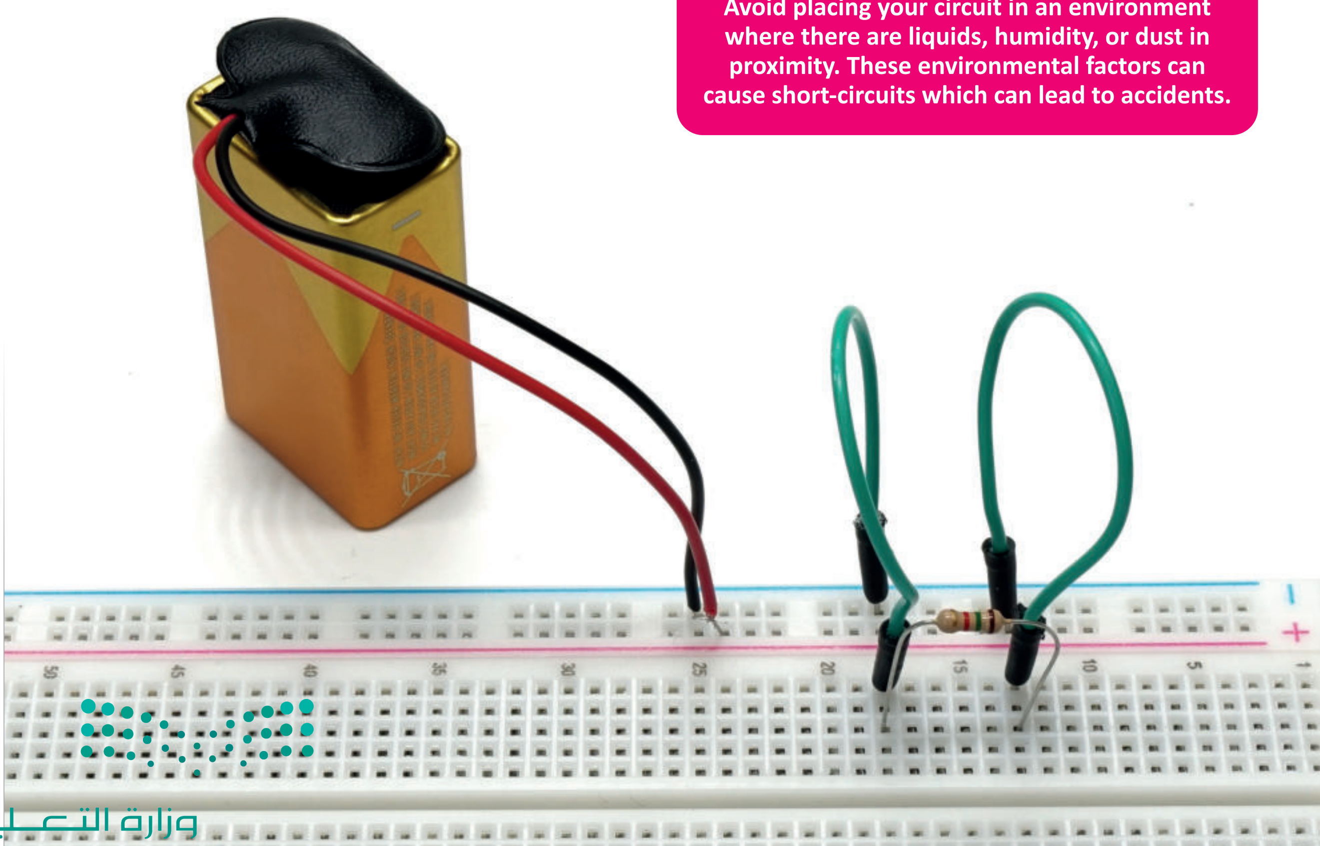


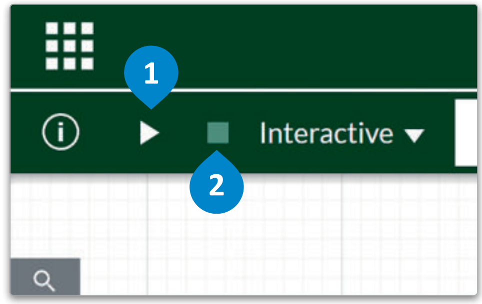
Figure 2.17: Example of actual circuit connections

Now we are ready to run the simulation and see the measurements from the probes.

To run simulation:

> Click on **Run simulation** and run the simulation for a short time. 1

> Click to **stop/reset simulation.** 2



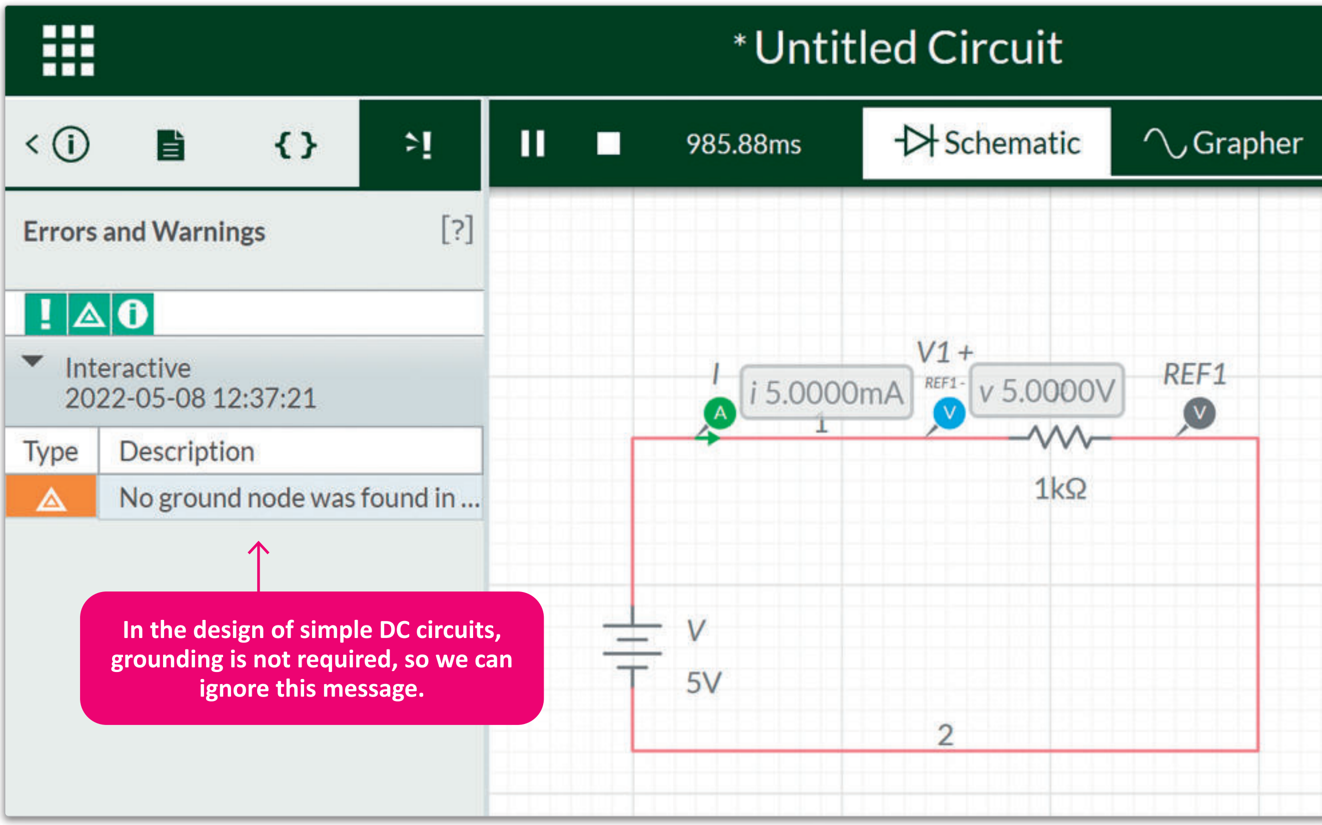


Figure 2.18: Run simulation

Now that we have designed the circuit with specific the values for the source and the resistor, we can check with Ohm's law:

Resulting to $5\text{mA} = \dfrac{5\text{V}}{1\text{k}\Omega} \Rightarrow 5 \times 10^{-3} = \dfrac{5}{10^{3}}$

The simulation follows Ohm's law verified by the values displayed by the measurement instruments.

You can save your project to use it again later.

To save project:

> Click on the **File navigation menu**. 1
> Click on **Save**. 2
> In the **Save Circuit** window, change the name to **Ohm's law**. 3
> Click **OK**. 4

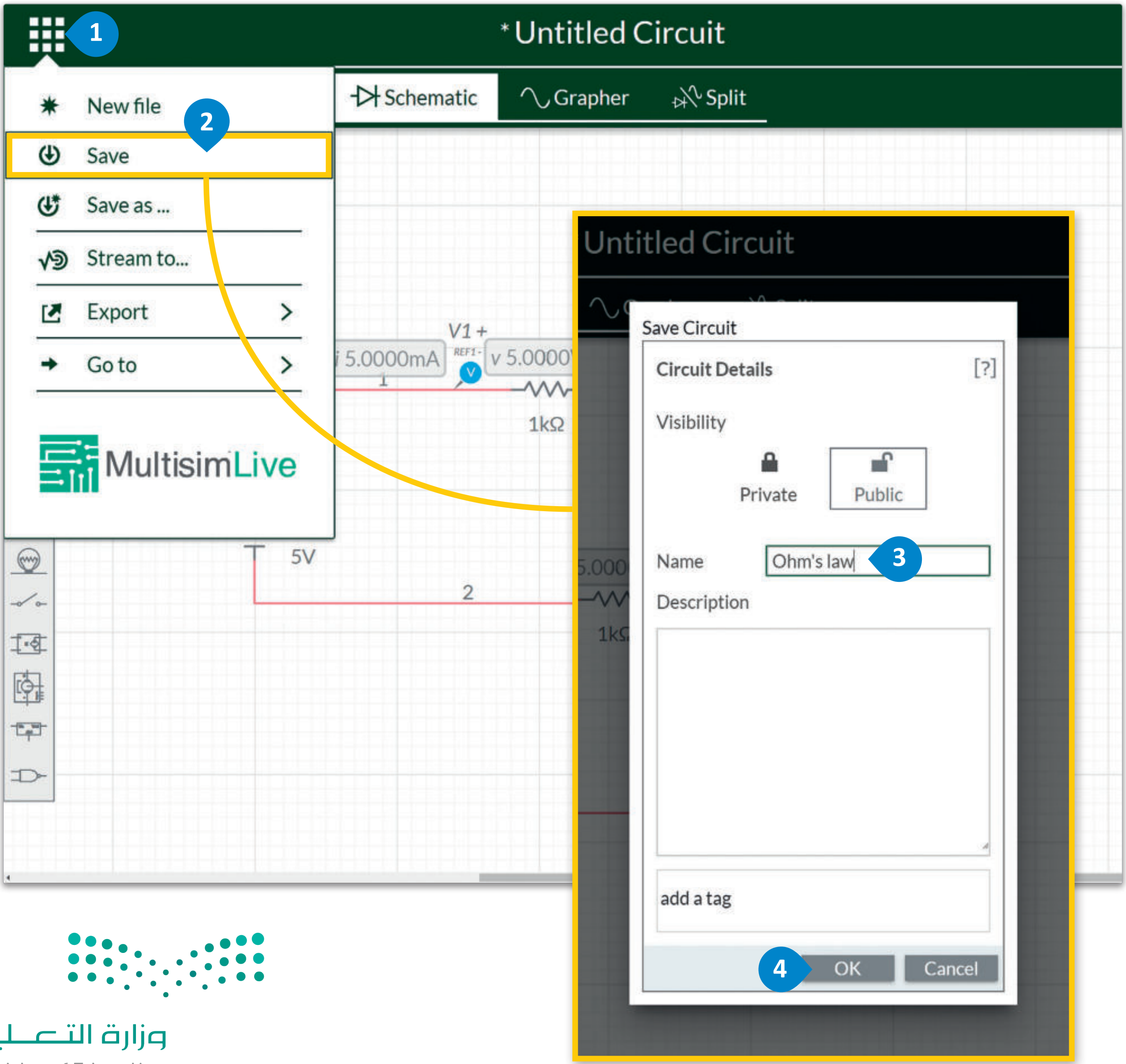


Figure 2.19: Save project

To check previous circuits that you have designed, you can go to **My Circuits**.

To open project:

> Click on the **File navigation menu.** 1
> Click on **Go to.** 2
> Click on **My Circuits.** 3

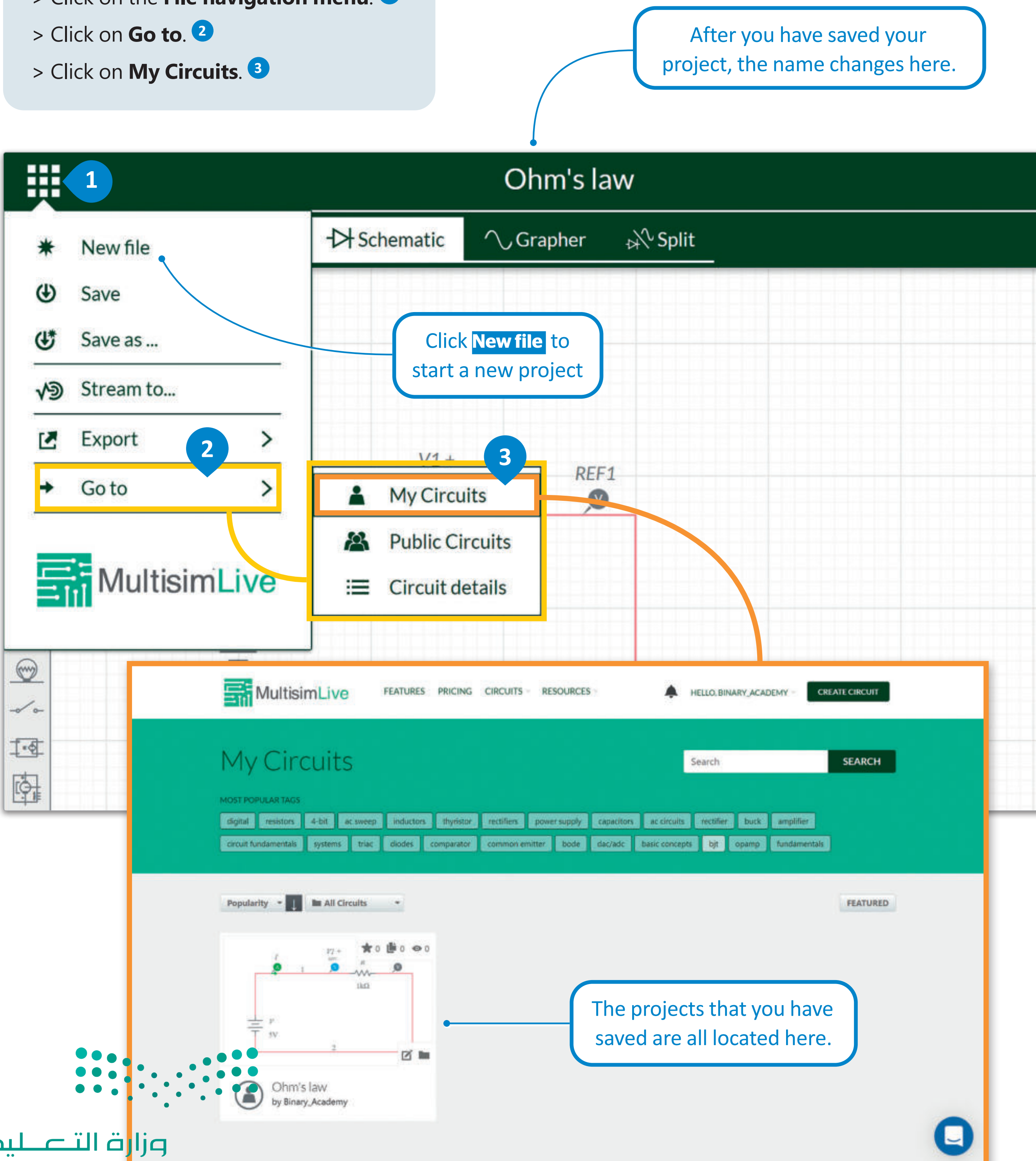
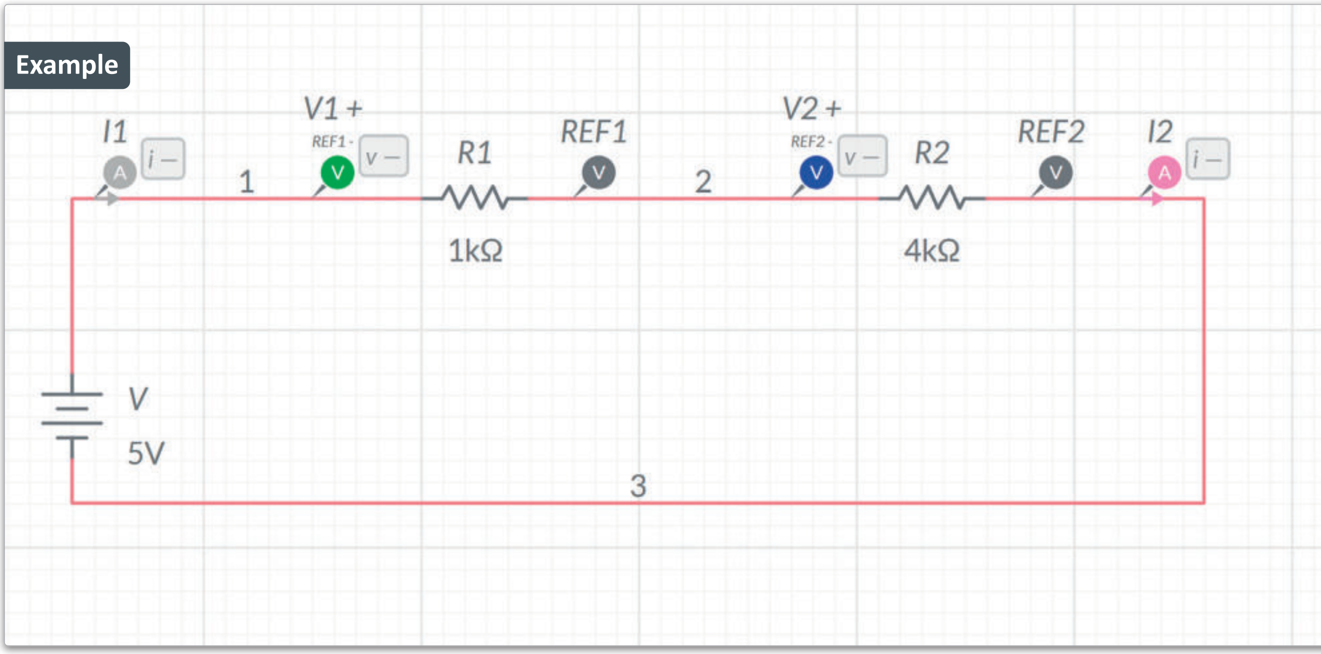
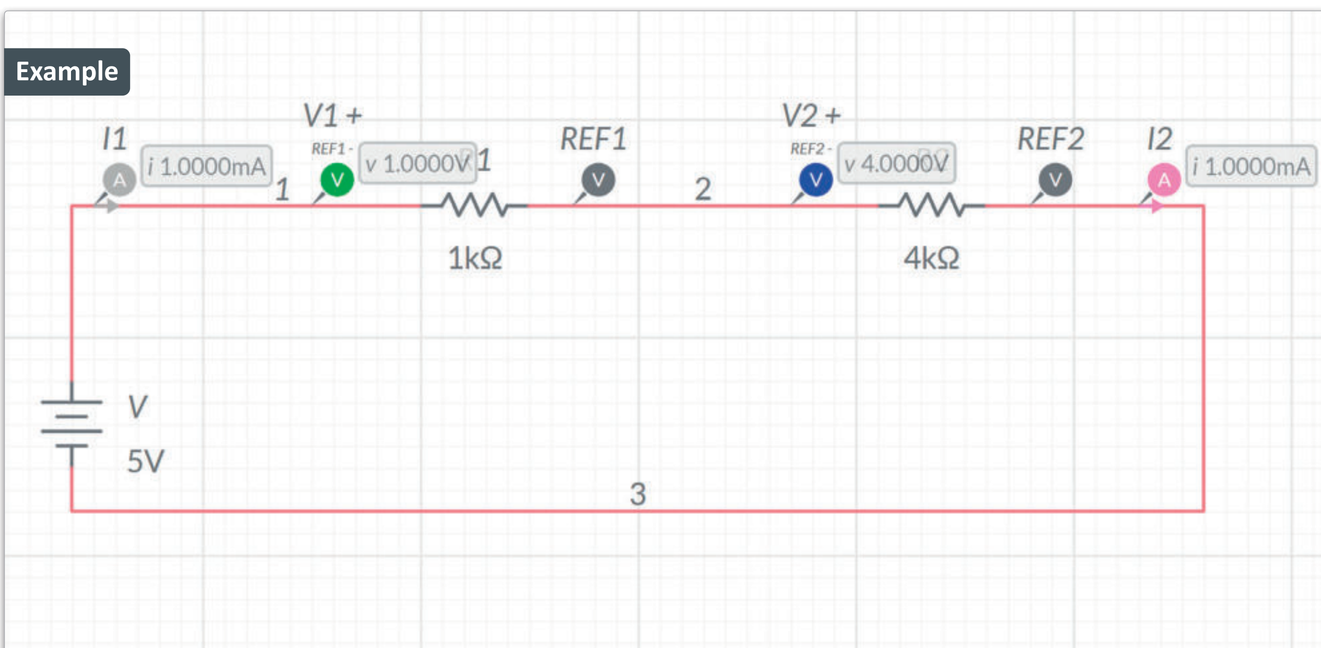


Figure 2.20: Open project

Example 1: Series Connection

In a circuit with connections that are all in series as shown in the example, we observe that:





$$V_T = V_1 + V_2$$

Resulting in

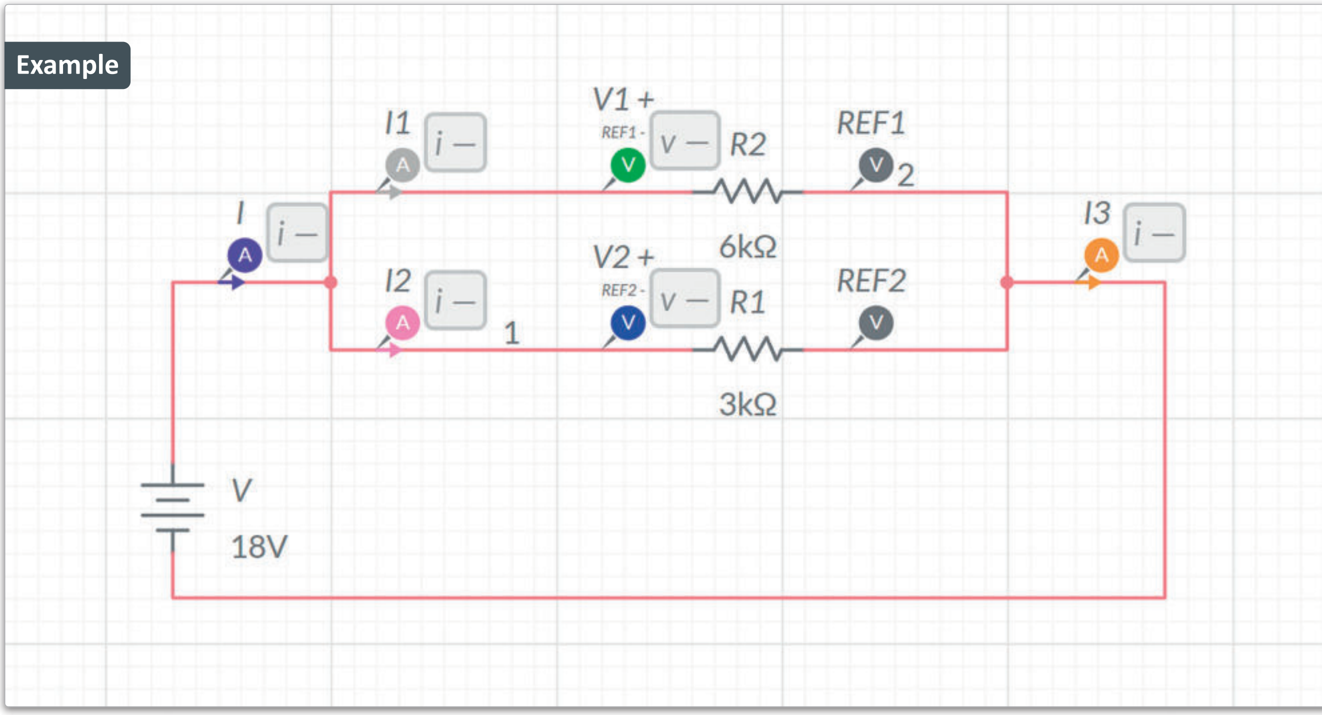
$$5V = 1V + 4V$$

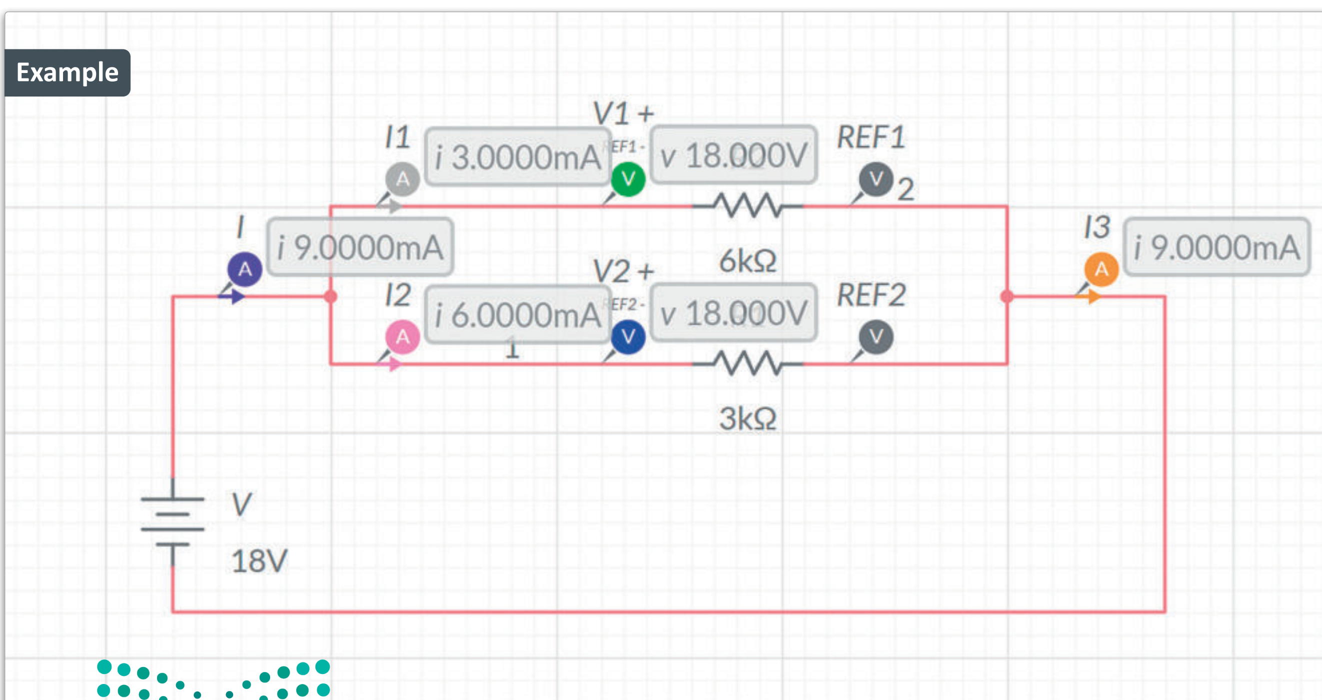
The values displayed by the measurement instruments verify the result. We also note that our ammeters display the same current intensity:

$$I = 1mA$$

Example 2: Parallel Connection

In a circuit with connections that are in parallel as shown in the example, we observe that:



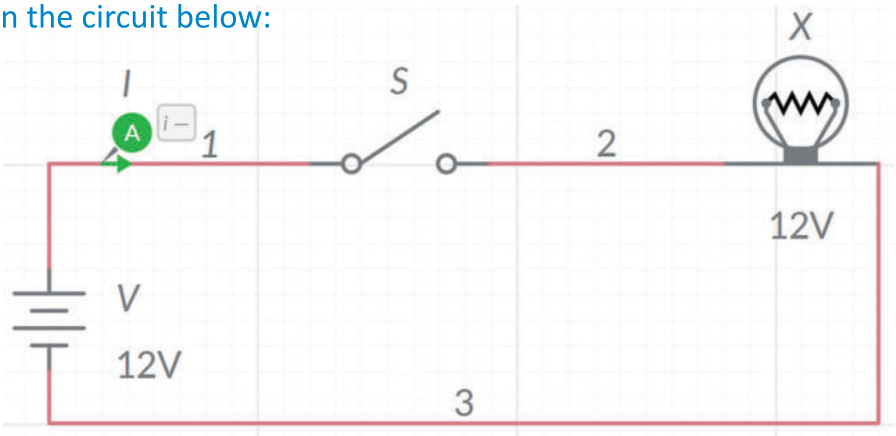


$$V_T = V_1 = V_2 = 18V$$

$$I_T = I_1 + I_2 = I_3 \Rightarrow 9mA = 3mA + 6mA = 9mA$$

Exercises

1 Design the circuit below:



1. Run the simulation and after you close the switch S, write down what you observe.

____

____

2. Connect an ammeter to the circuit and write down the value it displays.

____

____

3. Change the voltage value of the source to 5V and then to 1V, what do you notice in each case?

____

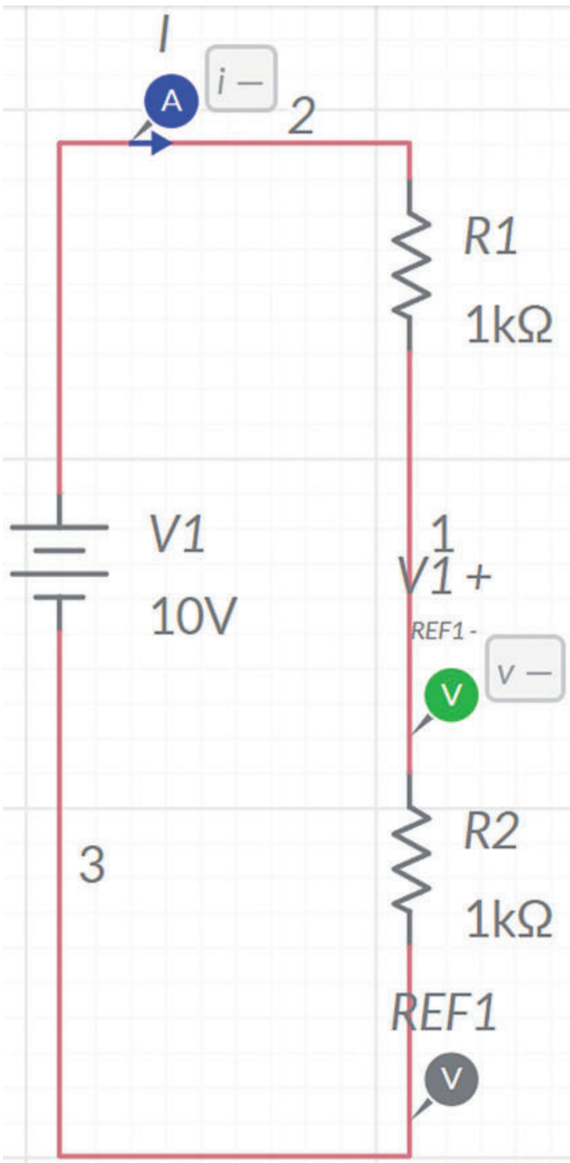
____

4. Change the value of the voltage of the source to 15V, and then to 20V, what do you notice in each case?

____

____

2 Design the following circuit:



Observe and write down the values on the instruments in the table below.

Measuring instrument	Value
Ammeter	
Voltmeter	

What do you notice about the voltage across R_2?

Explain your answer.

____

____

____

____

____

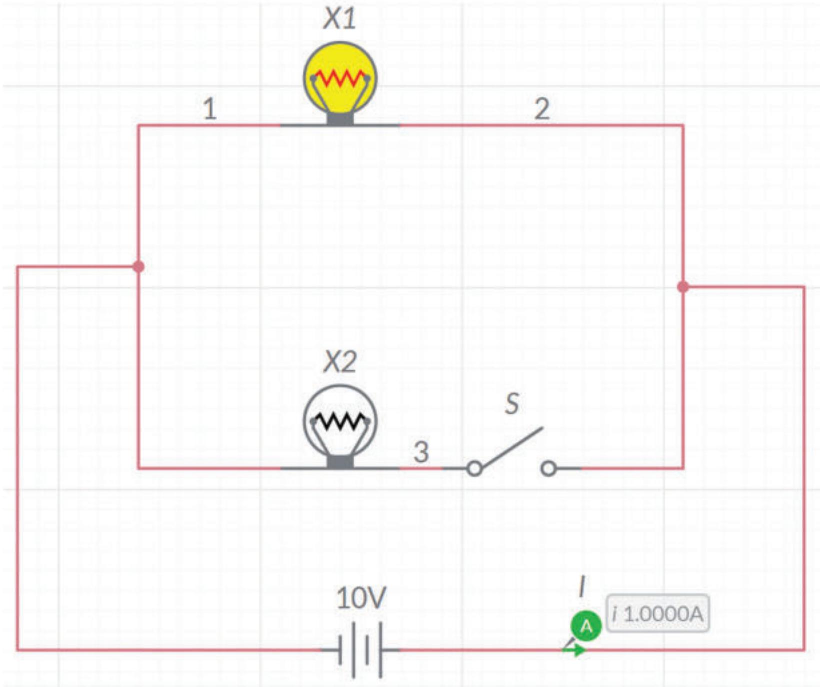
____

____

____

3 Design the following circuit:

Set lamps X_1 and X_2 to have 10V normal operating voltage.



Run the simulation and write down what you notice about the two light bulbs. Explain your observation.

____

____

____

____

Now close the switch S. What do you notice about the light bulbs and the ammeter? Explain your observation.

____

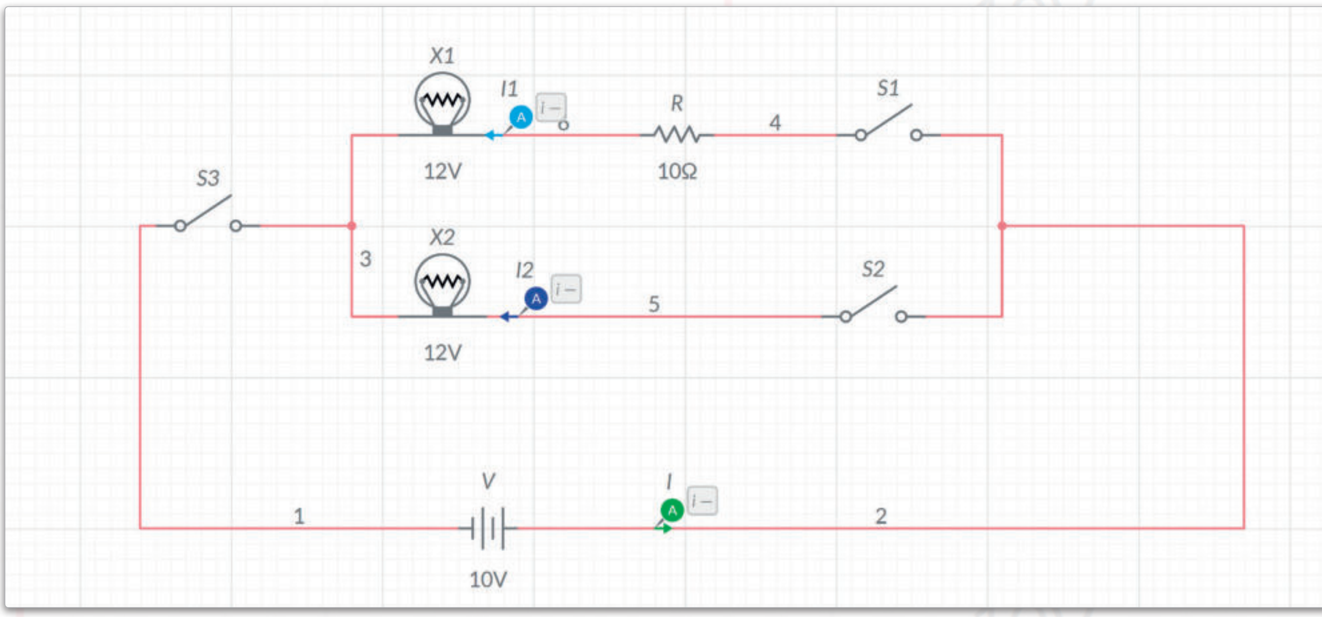
____

____

____

Project

***Design the** following circuit:*



***Connect 2** lamps X1 and X2 to this circuit, each of which operates normally at a voltage of 12V and is damaged at a voltage greater than 15V.*

***Connect 1** resistor in series with X1, with resistance R = 10Ω.*

***Connect 3** switches S1, S2, S3.These show very little resistance in the circuit, of the order of $10^{-7}\Omega$ when closed, according to the program, can therefore be considered negligible.*

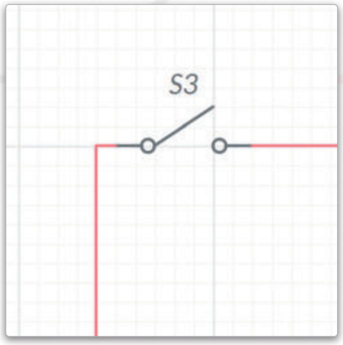
***Connect 3** ammeters, to measure the current in each branch of the circuit.*

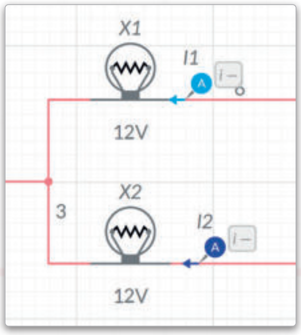
Do the *following:*

Open switch *S3. What do you notice? Explain what you see.*

With S3 *closed, and S2 open, close S1. What do you notice? Explain what you observe.*

With S3 *and S1 closed, close S2. What do you notice? Explain what you observe.*



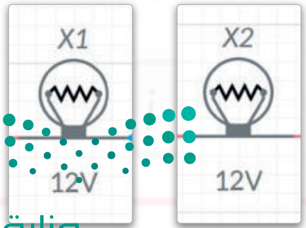


Find the *relationship of the current intensities I_T, I1 and I2 from the readings of the ammeters.*

Find the *resistance R1 from the voltage V1 and the current I1, and the resistance R2 from the voltage V2 and the current I2, where R1 is the resistance of lamp X1 and R2 is the resistance of lamp X2.*

After stopping *the simulation, change the source voltage from 10V to 20V and close switches S1 and S2.*

Then close *S3 and write down what you notice about the bulbs X1 and X2. Also, write what you notice about the values of current intensities I_T, I1 and I2.*



With S3 *and S1 open, close S2 and write down what you notice about the bulbs X1 and X2. Explain your observations.*

Wrap up

Now you have learned :

> to distinguish between direct (DC) and alternating (AC) electrical currents.

> to read and draw simple circuits and how they work.

> to apply Ohm's law.

> to use Multisim Live to design and simulate electical circuits.

> to use probes to measure voltage and current in simulations.

KEY TERMS

AC	Electron	Resistor
Ammeter	Joule	Source
Ampere	Multimeter	Volt
Coulomb	Node	Voltage
Current	Ohm	Voltmeter
DC	Ohmmeter	Watt

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3. Digital Circuits

In this unit, you will learn about Boolean Algebra. You will also learn how to use Karnaugh maps. Finally, you will use Multisim Live to draw digital circuits.

Learning Objectives

In this unit, you will learn to:

> Understand the basics of the digital circuit.
> Define the rules of Boolean Algebra.
> Apply Boolean Algebra to simplify functions.
> Differentiate among logic gates.
> Create logic functions by combining logic gates.
> Apply Karnaugh maps to simplify logical designs.
> Recognize the core hardware components of a digital circuit.
> Define what integrated circuits (IC) are.
> Simulate designed digital circuits with Multisim Live.

Tools

> Multisim Live

Link to digital lesson

www.ien.edu.sa

Lesson 1

Digital Circuits

Basics of the Digital Circuit

Digital circuits are used to implement **Boolean logic** and operations on a system. The main difference between **digital** and **electrical** circuits is that electrical circuits operate with continuous signals, created by the electrical current flowing through the circuit,while digital signals are "discrete," and take as input sequences of 0's and 1's.Digital circuits are used in Integrated circuits and microcontrollers to store information and perform logical functions in conjunction with an electrical circuit.

The 2 main types of digital circuits are the following:

Table 3.1: States of digital circuits

State	Binary numbers
TRUE	1
FALSE	0

Combinational Circuits

Combinational circuits take input values and produce output results based on the logical function that is implemented. The following are types of combinational circuit:

- **Multiplexers**: Take multiple inputs from a digital source and output a single result value.
- **Demultiplexers**: Take a single input value and output multiple result values.
- **Encoders**: Convert a signal input into a coded binary result.
- **Decoders**: Reconstruct the original signal from produced by an encoder.

Table 3.2: Common voltage levels

Logic level	Binary number	Volts
5 Volt logic	1	5
	0	0
3.3 Volt logic	1	3.3
	0	0

Sequential Circuits

Sequential circuits take as inputs the outputs that were produced by previous iterations of the circuit. Examples of sequential circuits are the following:

- **Flip-flops**: They are used for storing digital signal sequences.
- **Counters**: They are used to time, track, coordinate and orchestrate other components of a digital circuit.

INFORMATION

Analog signals can be found everywhere in nature, but digital signals are man-made. The main difference is that analog signals are inputs that have variations in the frequency and amplitude of the waves. In digital signals, there is only an on/off state represented by ones and zeroes, also called binary code.

Boolean Algebra

Boolean Algebra is defined according to a set of two elements: {0, 1}

It defines operations **AND (·)** and **OR (+)**, which obey the following rules:

If A, B belong to the set {0, 1}, then:

$$A + B = B + A = Y$$

$$A \cdot B = B \cdot A = Y$$

The results (Y) of operations (+) and (·) belong to the set {0, 1}.

Properties of the operation AND in Boolean Algebra.

$$A \cdot 1 = A$$

$$A \cdot 0 = 0$$

$$A \cdot A = A$$

$$A \cdot \overline{A} = 0$$

Properties of the operation OR in Boolean Algebra.

$$A + 1 = 1$$

$$A + 0 = A$$

$$A + A = A$$

$$A + \overline{A} = 1$$

The distributive law of Boolean Algebra.

$$A \cdot (B + C) = A \cdot B + A \cdot C$$

$$A + (B \cdot C) = (A + B) \cdot (A + C)$$

Double negative rule

$$\overline{\overline{A}} = A$$

Example If $A = 0$ then $\overline{A} = 1$. While if $A = 1$ then $\overline{A} = 0$.

The rules mentioned apply exactly the same to the logic of the operations:

Operation	Expression
AND	$A \cdot B$
OR	$A + B$

Logic gates may have more than two inputs, but they will always have one output.

DeMorgan's Theory

To get the complement of a complex representation, it is enough to change each element with its complement and each operation from AND to OR and OR to AND.

Theorem

$$\overline{(A \cdot B \cdot C)} = \overline{A} + \overline{B} + \overline{C}$$

$$\overline{(A + B + C)} = \overline{A} \cdot \overline{B} \cdot \overline{C}$$

Example

Let's see an example of a method using a truth table and Boolean Algebra to prove the following relation:

We create a truth table where rows represent variables of the functions and columns represent terms of the equation.

$Y = (A + B) \cdot (A + C) = (A + B \cdot C)$

The two columns are identical. This means that equality applies.

Input values

A	B	C	(A + B)	(A + C)	(B · C)	(A + B) · (A + C)	(A + B · C)
0	0	0	0	0	0	0	0
0	0	1	0	1	0	0	0
0	1	0	1	0	0	0	0
0	1	1	1	1	1	1	1
1	0	0	1	1	0	1	1
1	0	1	1	1	0	1	1
1	1	0	1	1	0	1	1
1	1	1	1	1	1	1	1

Now let's prove the function using the rules of Boolean Algebra that we have learned.

$Y = (A + B) \cdot (A + C) = \boxed{(A + B \cdot C)}$

$$
\begin{aligned}
Y = (A + B) \cdot (A + C) &= A \cdot A + A \cdot C + B \cdot A + B \cdot C \\
&= A + A \cdot C + B \cdot A + B \cdot C \\
&= A \cdot \boxed{(1 + C + B)} + B \cdot C \\
&= \boxed{A \cdot 1} + B \cdot C \\
&= \boxed{(A + B \cdot C)}
\end{aligned}
$$

$(1 + C + B) = 1$

$A \cdot 1 = A$

Logic Gates

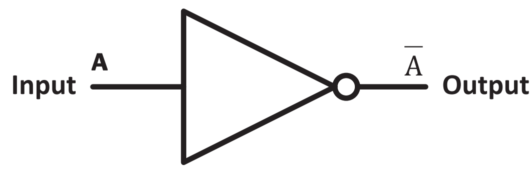
Logic gates are small electronic components that take a set of Boolean input values and output Boolean values that are determined by the ruleset of the gate. They apply Boolean operations to produce their result values. Each logic gate has a unique result set. Logic gates are combined to design more complex functions and integrated components. In this section we will analyze each type of logic gate.

Logic Gate NOT

A **NOT** gate accepts one input value and produces one output value. The NOT operator inverts the input.

Input A	Output NOT A
0	1
1	0

$Y = \overline{A}$

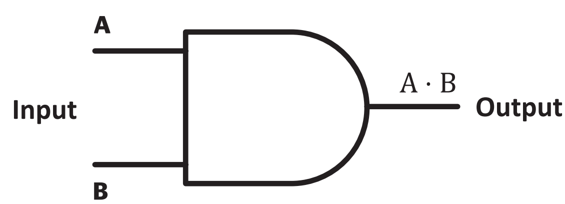


Logic Gate AND

An **AND** gate uses two input values, which both determine the output.

Input A	Input B	Output A AND B
0	0	0
0	1	0
1	0	0
1	1	1

$Y = A \cdot B$

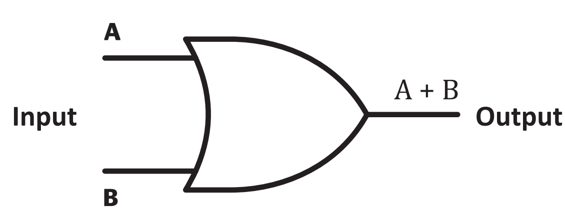


Logic Gate OR

An **OR** gate has two inputs which both generate the output.

Input A	Input B	Output A OR B
0	0	0
0	1	1
1	0	1
1	1	1

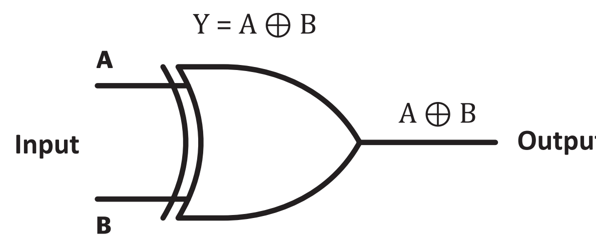
$Y = A + B$



Logic Gate XOR

An **XOR**, or exclusive OR, gate produces 0 if both inputs are the same, and 1 if they are different.

Input A	Input B	Output A XOR B
0	0	0
0	1	1
1	0	1
1	1	0



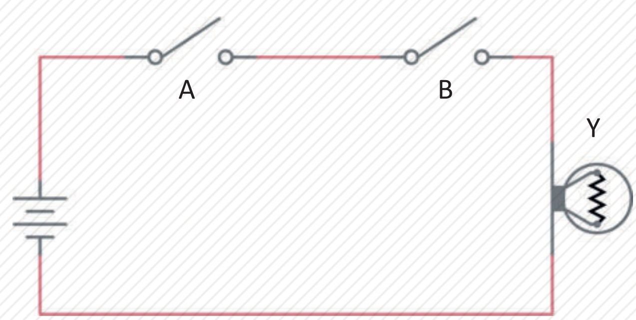
Let's see examples with lamp circuits.

Example

A AND B

The lamp will glow when both the series connected switches are closed.

Input A	Input B	Lamp A AND B
OFF	OFF	OFF
OFF	ON	OFF
ON	OFF	OFF
ON	ON	ON

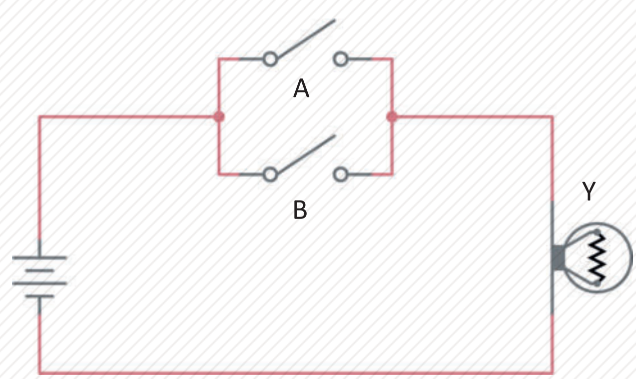


Example

A OR B

The lamp will glow when either of the parallel connected switches is closed.

Input A	Input B	Lamp A OR B
OFF	OFF	OFF
OFF	ON	ON
ON	OFF	ON
ON	ON	ON

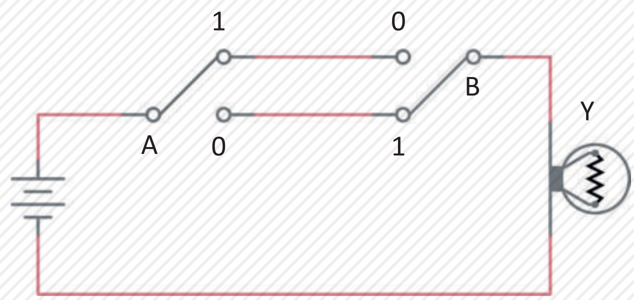


Example

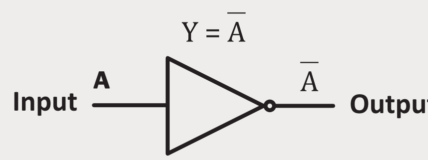
A XOR B

The lamp will glow when both of its two input terminals are at different logic levels with respect to each other.

Input A	Input B	Lamp A XOR B
OFF	OFF	OFF
OFF	ON	ON
ON	OFF	ON
ON	ON	OFF



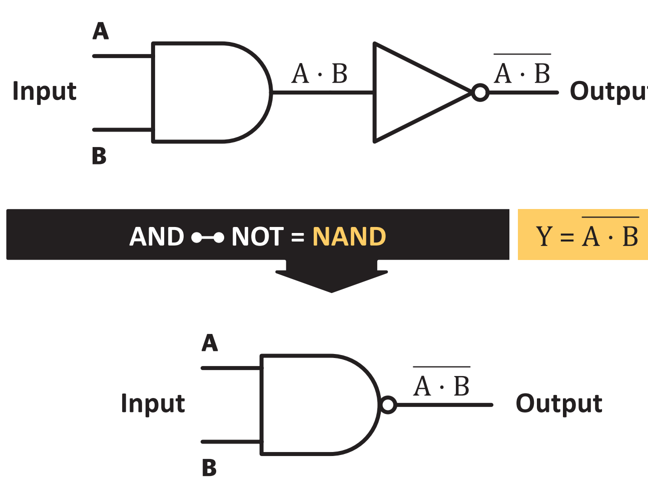
If the outputs of the logic gates OR, AND and XOR are connected with an input of a logic gate NOT, then new gates will be created.



Logic Gate NAND

A **NAND** gate inverts the result produced by an AND gate.

Input A	Input B	Output NOT (A AND B)
0	0	1
0	1	1
1	0	1
1	1	0

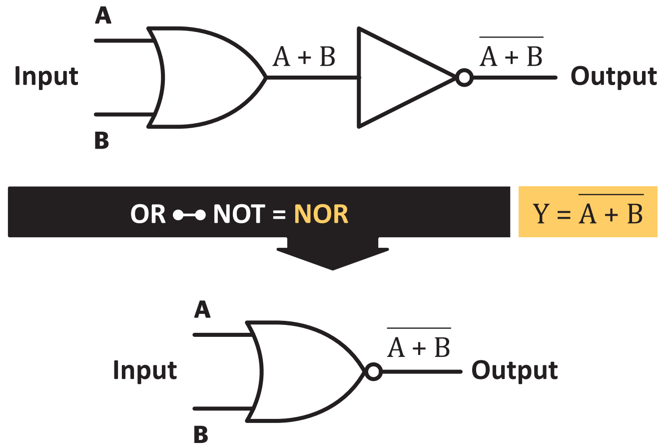


In most logic systems, NAND and NOR functions actually require fewer transistors than AND and OR gates.

Logic Gate NOR

A **NOR** gate inverts the result produced by an OR gate.

Input A	Input B	Output NOT (A OR B)
0	0	1
0	1	0
1	0	0
1	1	0



Logic Gate XNOR

An **XNOR** gate produces the inverse results of an XOR gate. This gate produces 0 if both inputs are different and 1 if they are the same.

Input A	Input B	Output NOT (A OR B)
0	0	1
0	1	0
1	0	0
1	1	1

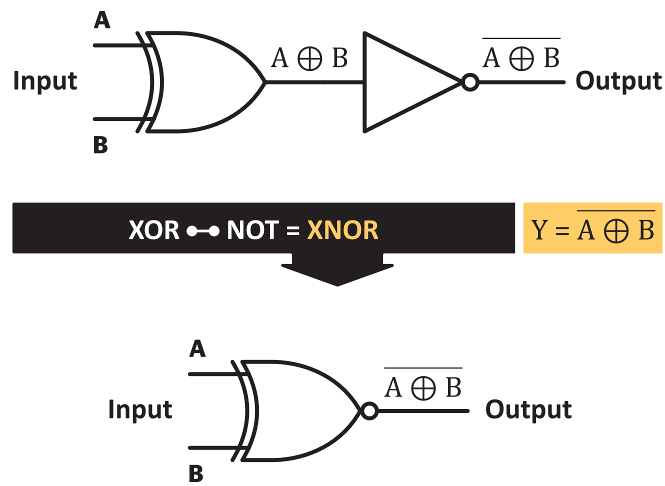


Table 3.3 shows the logical operations and expressions for each logic gate.

Table 3.3: Logical operations and expressions

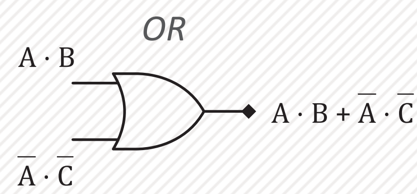
Operation	NOT	AND	OR	XOR	NAND	NOR	XNOR
Expression	$\overline{A}$	$A \cdot B$	$A + B$	$A \oplus B$	$\overline{A \cdot B}$	$\overline{A + B}$	$\overline{A \oplus B}$

When drawing a logic circuit for a function, it is important to start from the outputs and continue to the inputs. Let's look at the following example:

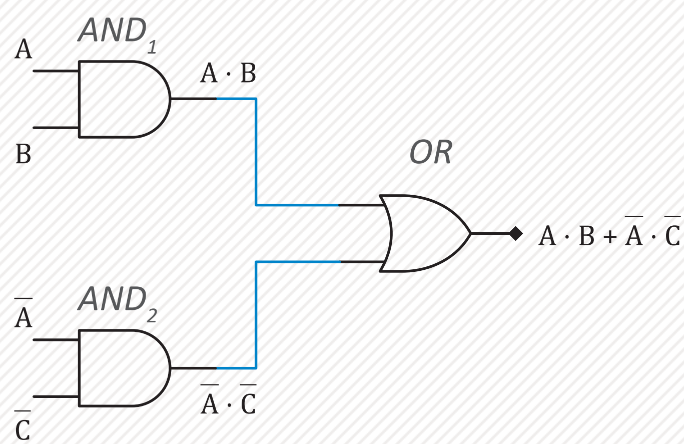
Example

Create the following function circuit: $Y = A \cdot B + \overline{A} \cdot \overline{C}$

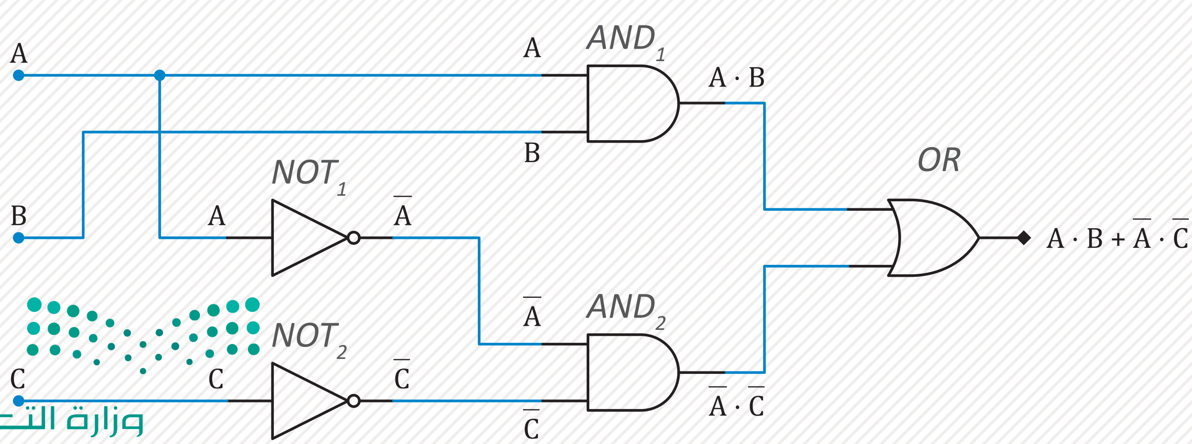
1 You must first create the logic gate **OR** at the output.



2 Then you must create the logic gates **AND**$_1$ and **AND**$_2$.



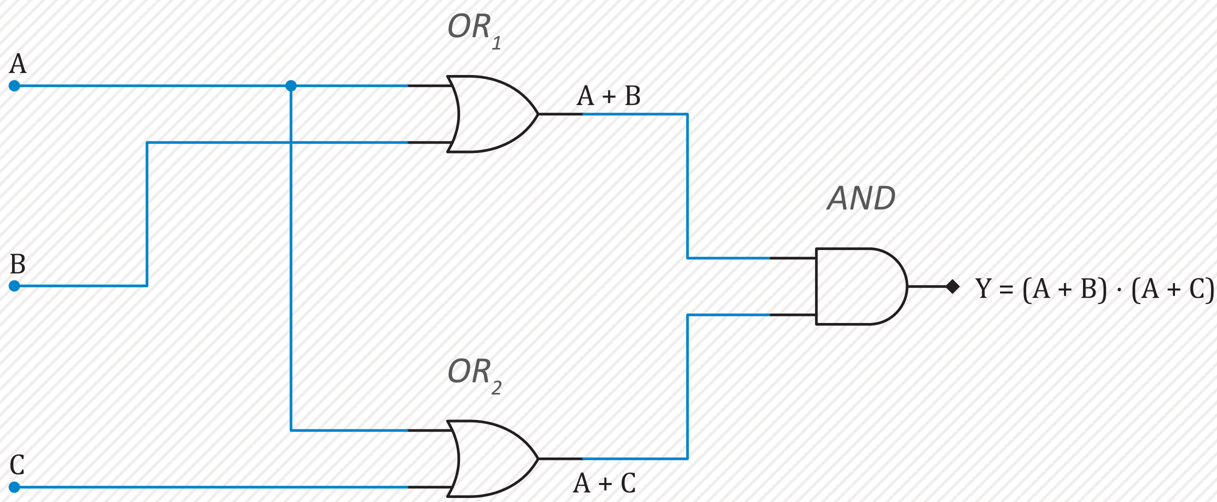
3 Finally you must create the logic gates **NOT**$_1$ and **NOT**$_2$ for $\overline{A}$ and $\overline{C}$.



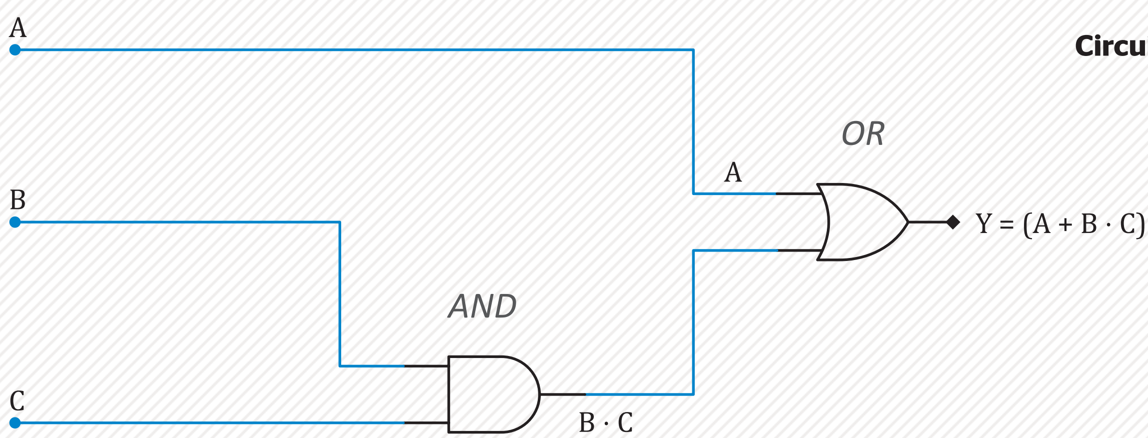
Now we will look at how the function $Y = (A + B) \cdot (A + C)$ is designed with logic gates and how we can simplify it using the distributive property to take the form it to $Y = (A + B \cdot C)$ to save gates.

Example

Circuit 1



Circuit 2



Observing the two circuits, we observe that in circuit 2 we have the same result as circuit 1 but with one gate less.

INFORMATION

In the process of designing electronic devices that use many logic gates, by simplifying the circuit we can save materials.

Exercises

1 What is the main difference between digital and electrical circuits?

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2 Which logic gate outputs 1 only when it has different inputs (e.g. A = 0 and B = 1).

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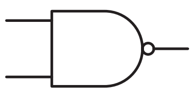
3 Match the items in the first column with those in the second.

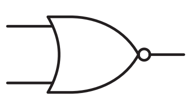
Operation	Expression
NOT	$\overline{A \cdot B}$
AND	$\overline{A + B}$
OR	$A \cdot B$
XOR	$A \oplus B$
NAND	$A + B$
NOR	$\overline{A \oplus B}$
XNOR	$\overline{A}$

4 Identify the names of these logic gates and complete the truth table, then write the Boolean expression for each of these logic gates and the Boolean Algebra relationship between the entries (A,B) and the output (Y).



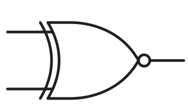
A	B	Output
0	0	
0	1	
1	0	
1	1	

Y =



A	B	Output
0	0	
0	1	
1	0	
1	1	

Y =



A	B	Output
0	0	
0	1	
1	0	
1	1	

Y =

5 Convert the function $Y = \overline{A} \cdot (B + \overline{C})$ to a sum of least terms and draw a truth table.

6 Use Boolean Algebra to convert the function $Y = A \cdot [\overline{B} + C \cdot (D + \overline{E})]$ its simplest form.

____

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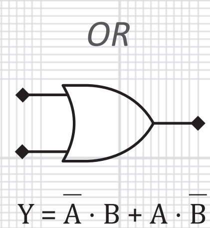
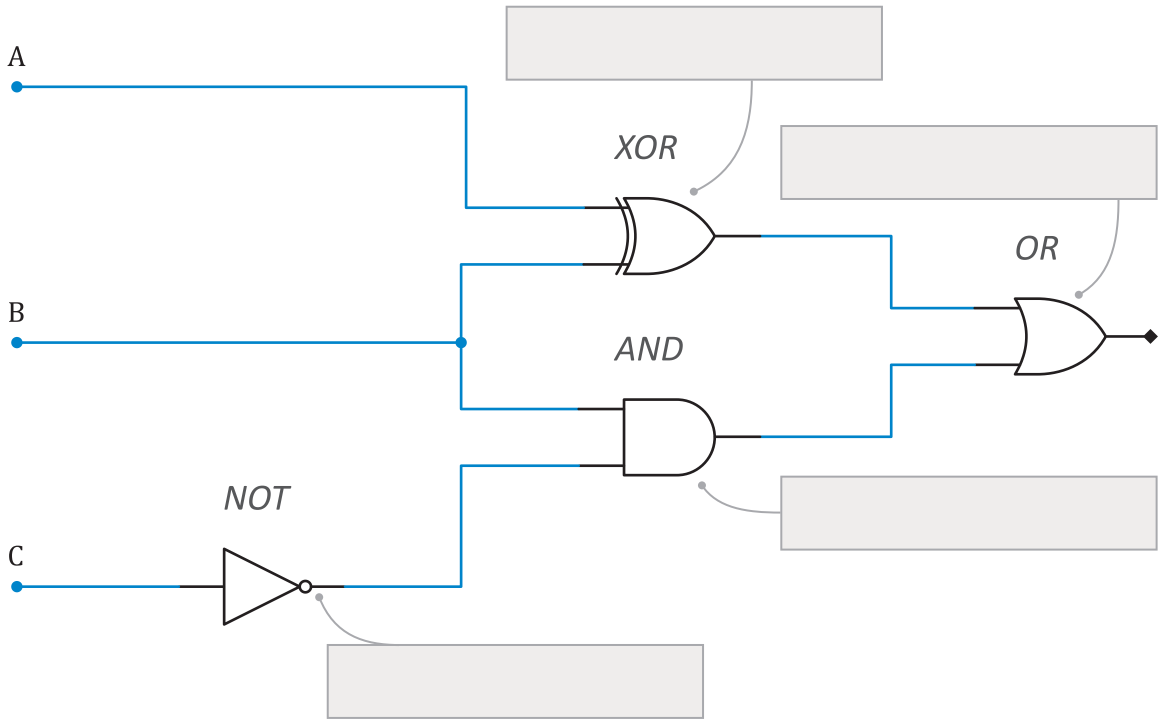
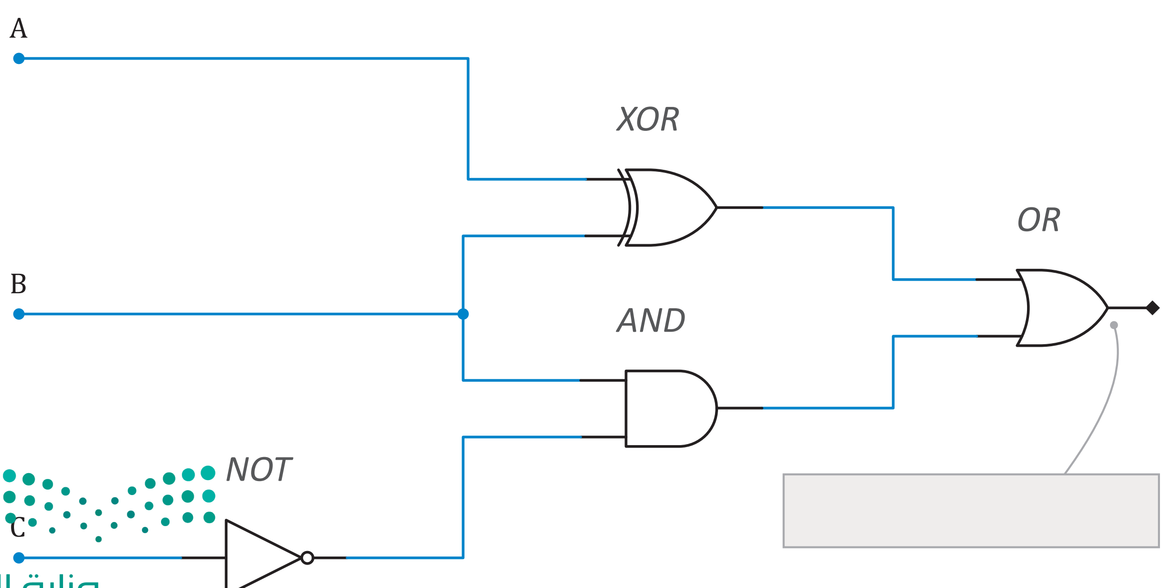
7 Use the function $Y = \overline{A} \cdot B + A \cdot \overline{B}$ to draw the circuit from the output to the inputs.



8 Write the Boolean expression for each logic gate represented by the logic diagram below, using symbols.



What is the output if A, B and C are all True (1)?



Lesson 2

Karnaugh Maps

Link to digital lesson

www.ien.edu.sa

Karnaugh Maps

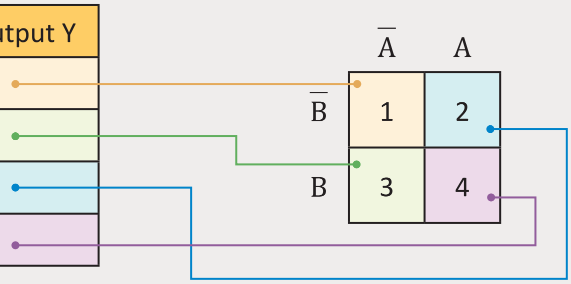
Karnaugh maps were introduced by Maurice Karnaugh in 1953 at Bell Labs and are used to simplify the design ofdigital circuits.

Karnaugh maps are used to clearly depict the output results of a complex digital circuit. They are especially helpful when we have a circuit with more than 2 inputs. If we were to use a truth table for this task, it would use a lot of space and it would be difficult to read. Karnaugh maps depict the same information in a more compact format.

The following is a depiction of a truth table and a Karnaugh map.

For a function with two inputs, we can see how to place the corresponding results of function Y in positions 1, 2, 3 and 4 of the **Karnaugh map**.

Input A	Input B	Output Y
0	0	
0	1	
1	0	
1	1	

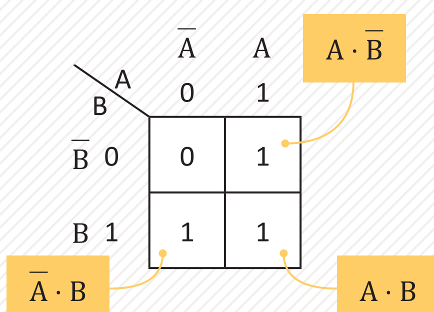


Karnaugh maps are used to group Boolean expressions instead of going through the Boolean Algebra calculations for multiple variable inputs.

Let's see an example of the function $Y = \overline{A} \cdot B + A \cdot \overline{B} + A \cdot B$ to see how we create a **Karnaugh map**.

Example

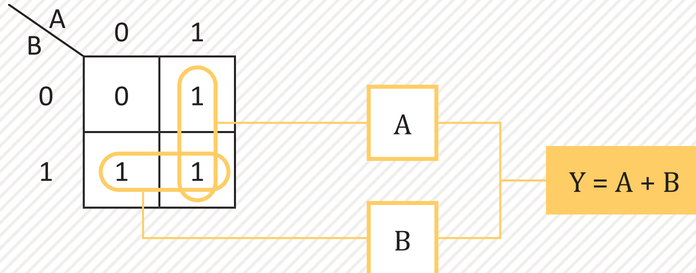
In a Karnaugh map, the variables are replaced by 1 and their complement by 0.



When placing the variables A and B in the Karnaugh map, it is your choice which will be horizontal and which will be vertical.

Then with the help of the Karnaugh map, we can simplify the function $Y = \bar{A} \cdot B + A \cdot \bar{B} + A \cdot B$ using fewer terms.

Example



The aces you merge must always be an even number.

Here we are deleting terms that contain a term and its complement in a loop. In the vertical loop, we notice that the term B changes and is therefore eliminated, and the result becomes only the term A.

Terms of the Function

The terms of the function are referred to as minterms. That is, a term $A \cdot B$ is called minterm, while a term $A + B$ is called maxterm.

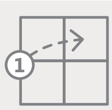
The procedure for simplification of the above Boolean function has been completed. We could summarize the process in the following steps:

1

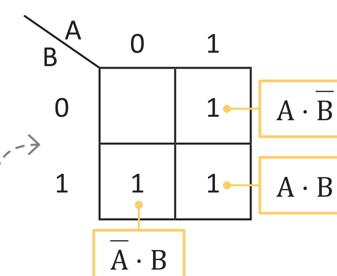
Find the minimum terms of the function.

Function: $A \cdot \bar{B} + A \cdot B + \bar{A} \cdot B$

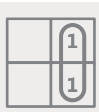
2



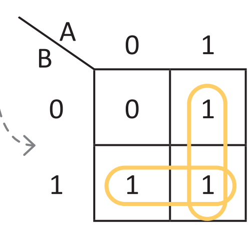
Find the aces (1) and place them in the Karnaugh map.



3



Create loops around adjacent aces (1) in an even number of squares (2, 4 or 8).



4

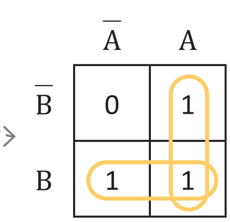
We simplify the minimum terms that result by deleting terms that contain a term and its complement in a loop.

Deleted terms: $A \cdot \bar{B}$, $\bar{A} \cdot B$

5

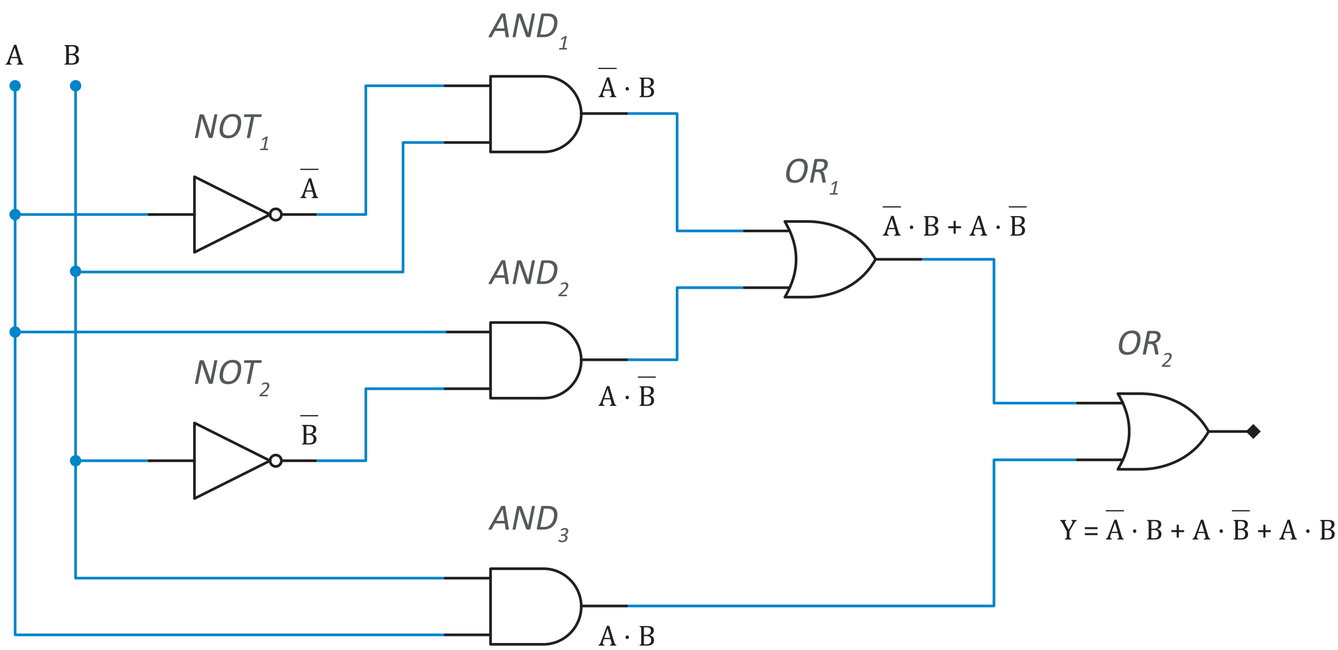
The remaining terms, one from each loop, are linked by the operation OR (+) in the final form of the function.

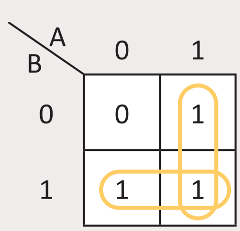
Final form of the function: Y=A+B

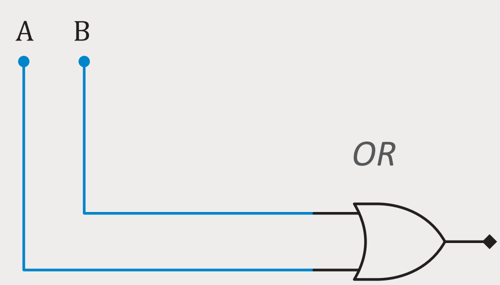


Let's see how the Y function can be implemented with far fewer logic gates after its simplification.

$$Y = \overline{A} \cdot B + A \cdot \overline{B} + A \cdot B$$







INFORMATION

It is not usual to use the Karnaugh map for 2 inputs because the simplification can be achieved very easily with Boolean Algebra, but for 3 or more inputs it can be extremely helpful.

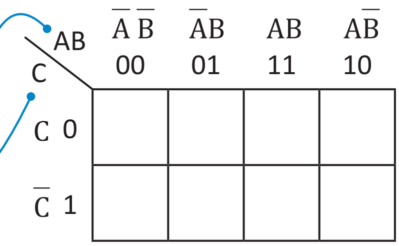
It is not necessary to use a Karnaugh map for two-input logic gate functions, as they are usually simplified using Boolean Algebra. However, in cases when we have functions that have logic gates with more than two inputs, the Karnaugh map helps to simplify the circuit.

Let's look at an example of a Karnaugh map with 3 inputs (A, B, and C).

Example

In the horizontal row, we place in pairs the 0 and 1 for the variables A and B so that in successive squares the value of only one variable changes.

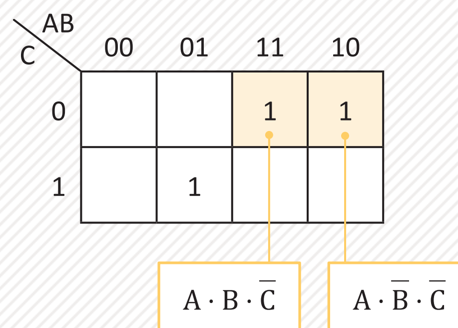
Choose 2 inputs in the row and 1 input in the column



Let's see where the aces (1) will be placed in the Karnaugh map for the following function:

The term $\mathbf{A \cdot \overline{C}}$ lacks the variable **B**. So according to Boolean Algebra, the term $\mathbf{A \cdot \overline{C} = A \cdot B \cdot \overline{C} + A \cdot \overline{B} \cdot \overline{C}}$.

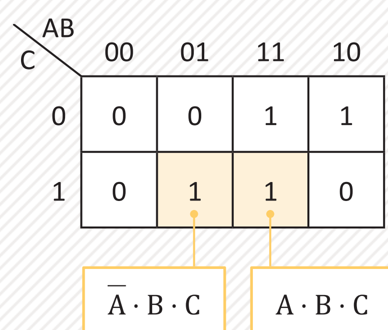
$B + \overline{B} = 1$



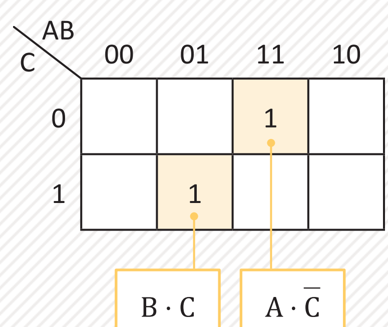
The term $\mathbf{B \cdot C}$ lacks the variable **A**. So according to Boolean Algebra, the term $\mathbf{B \cdot C = A \cdot B \cdot C + \overline{A} \cdot B \cdot C}$.

$A + \overline{A} = 1$

The new minimum terms may lead you to cells that already have an ace.



$Y = B \cdot C + A \cdot \overline{C}$



Now let's look at an example with 4 variables (A, B, C and D).
We will simplify the function using a Karnaugh map:

Example

$$Y = A \cdot \overline{B} \cdot \overline{C} \cdot \overline{D} + A \cdot \overline{B} \cdot \overline{C} \cdot D + A \cdot \overline{B} \cdot C \cdot D + A \cdot \overline{B} \cdot C \cdot \overline{D}$$

CD \ AB	00	01	11	10
00	0	0	0	1
01	0	0	0	1
11	0	0	0	1
10	0	0	0	1

After simplifying the function, using the Karnaugh map, we get the following function:

$$Y = A \cdot \overline{B}$$

Aces that appear at the edges of the map are considered adjacent to those at the opposite edge.

Let's see some examples :

Example

$$Y=A\cdot\overline{B}\cdot\overline{C}\cdot\overline{D}+A\cdot B\cdot\overline{C}\cdot\overline{D}+A\cdot\overline{B}\cdot\overline{C}\cdot D+A\cdot B\cdot C\cdot\overline{D}+A\cdot\overline{B}\cdot C\cdot\overline{D}$$

CD \ AB	00	01	11	10
00	0	0	1	1
01	0	0	0	1
11	0	0	0	0
10	0	0	1	1

$A \cdot \overline{B} \cdot \overline{C}$

$A \cdot \overline{D}$

After simplifying the function using the Karnaugh map, we obtain the following result:

$$Y = A \cdot \overline{D} + A \cdot \overline{B} \cdot \overline{C}$$

Example

$$Y=\overline{A}\cdot\overline{B}\cdot\overline{C}\cdot D+A\cdot\overline{B}\cdot\overline{C}\cdot D$$

CD \ AB	00	01	11	10
00	0	0	0	0
01	1	0	0	1
11	0	0	0	0
10	0	0	0	0

After simplifying the function using the Karnaugh map, we obtain the following result:

$$Y = \overline{B} \cdot \overline{C} \cdot D$$

Exercises

1 Why do you use the Karnaugh map in digital circuits?

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2 Use the following numbered positions of the output Y to complete the Karnaugh map below.

Input A	Input B	Input C	Output Y	
0	0	0		← 1
0	0	1		← 2
0	1	0		← 3
0	1	1		← 4
1	0	0		← 5
1	0	1		← 6
1	1	0		← 7
1	1	1		← 8

C \ AB	00	01	11	10
0	1			
1				

3 Using the given function, circle the errors in the Karnaugh map.

$$Y = A \cdot B \cdot C + \overline{A} \cdot \overline{B} \cdot C + A \cdot B \cdot \overline{C}$$

C \ AB	00	01	11	10
0	1	0	0	0
1	0	1	0	1

4 Use the Karnaugh map to find the minimum function from three inputs.

C \ AB	00	01	11	10
0	0	0	1	1
1	1	0	1	1

Y =

5 Use the Karnaugh map to find the minimum function from four inputs.

CD \ AB	00	01	11	10
00	0	0	1	0
01	1	0	0	1
11	1	0	0	1
10	0	0	1	0

Y =

6 When we have each of the binary numbers (000), (100), (110) and (111) as inputs (A, B and C) in a circuit, then (1) appears at the output.

Place the aces on the Karnaugh map and find the simplified function.

C \ AB	00	01	11	10
0				
1				

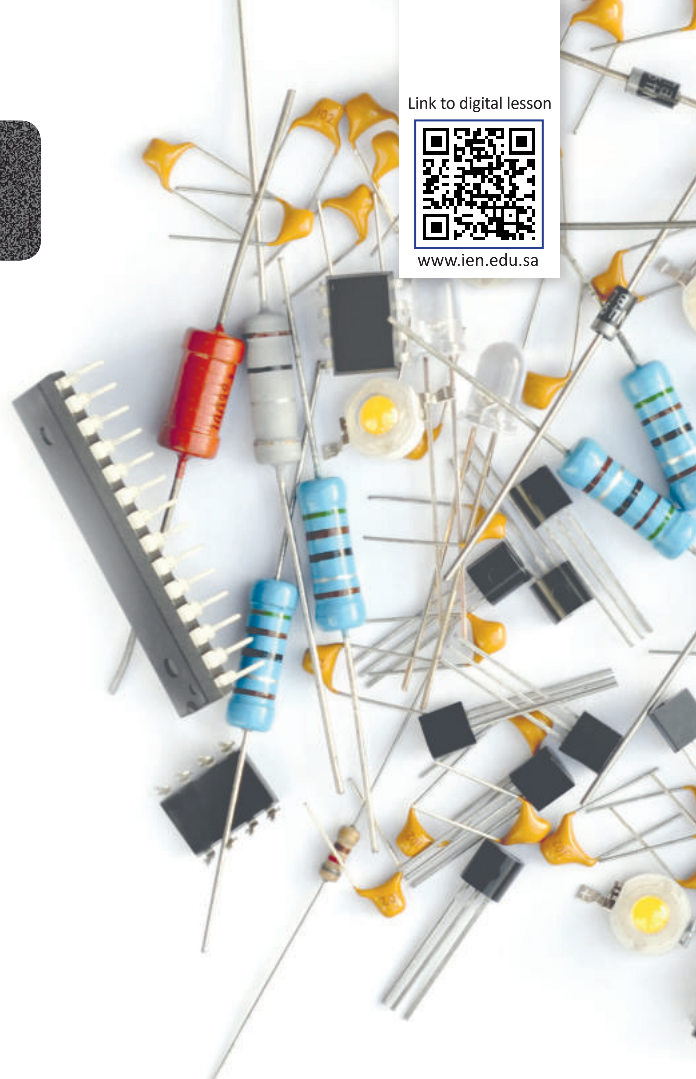
Y =

After you have found the simplified function, draw the corresponding digital circuit.

Lesson 3
Drawing Digital Circuits

Link to digital lesson

www.ien.edu.sa



Core Hardware Components of a Digital Circuit

Digital circuits are built with the following core components:

> Conducting wires or traces, which connect all the components in a circuit. Current direction is guided with the use of **diodes**.

> **Transistors** that switch digital signals between the Boolean values 0 & 1.

> **Logic gates**, which are special arrangements of transistors that implement **Boolean logic** in the circuit. These are combined to create components that implement more complex logic. The 2 main types are:

- **Adders**, which implement the basic numerical operations of addition, subtraction, multiplication, and division.

- **Flip-flops**, the fundamental components of computer memory, which store inputs and outputs.

Diodes

Diodes are semiconductor components that conduct and direct electrical current in a single direction. They consist of two terminals, an anode and a cathode, and have negligible resistance in one direction, and high resistance in the opposite direction. They therefore direct the current flowing through them in one direction.

Terminals of Diodes

Cathodes are electrodes that divert current away from the component that they inhibit.

Anodes draw current towards the same component.

The polarity of these two electrodes allows them to divert and control the flow of electrical current at a point in a circuit.

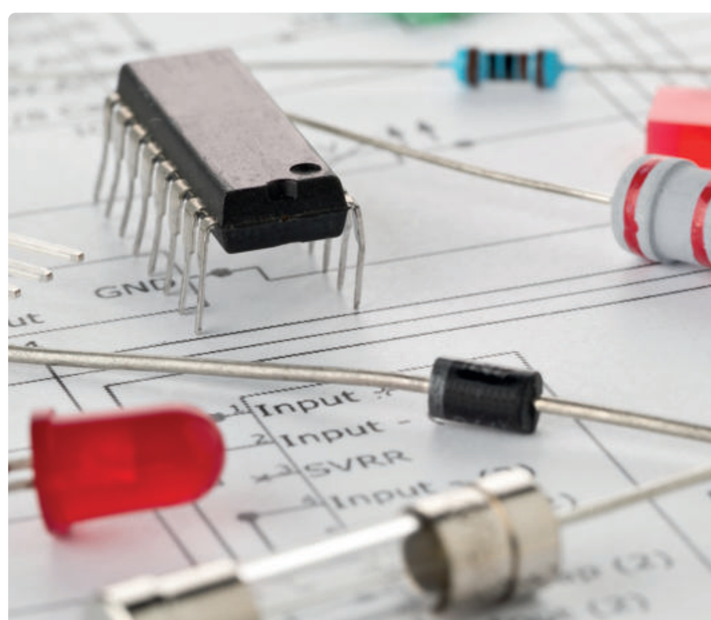


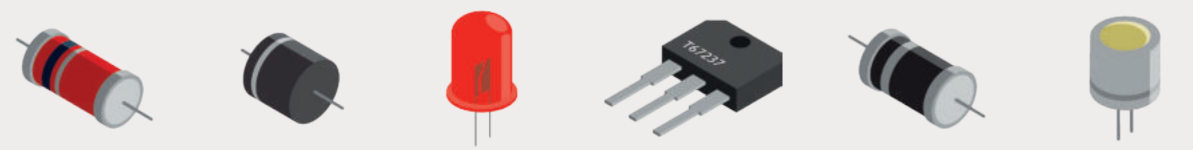
Figure 3.1: Electronic components

Some of the most common use of diodes include:

- Converting **Alternating Current** into **Direct Current** in a rectifier.
- Building simple logic gates (**AND**, **NOT**, **OR**).
- Recovering and decoding radio signals through demodulation in radio receiving devices.
- The production of **LED** lights (Light Emitting Diodes). These diodes emit light when an electric current flows through them.

Figure 3.2: DC voltage graph

The basic diode types are:



Signal diodes | Power diodes | LEDs | Schottky diodes | Zener diodes | Photodiodes

Transistors

Transistors are one of the most important inventions of modern technology. They are semiconductors that can switch and amplify signal inputs.

They were invented in order to replace vacuum tubes because they had two significant advantages.

They are very small in size relative to vacuum tubes, which means that they can be embedded in digital and integrated circuits.

They also consume much less power, which makes them a more cost effective and energy efficient alternative to vacuum tubes. Transistors are the basic building blocks of complex logic gates.

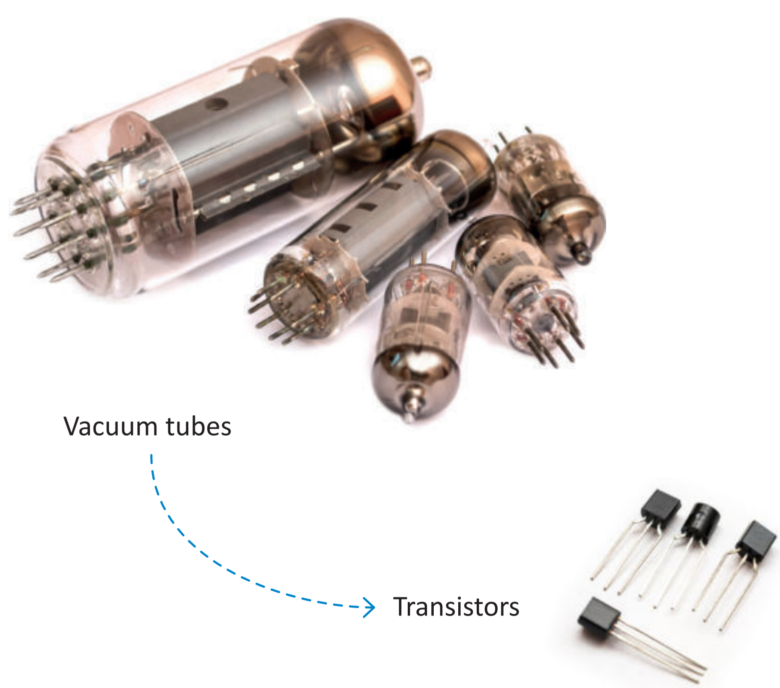


Figure 3.3: Vacuum tube and transistor size comparison

Integrated Circuit (IC)

If you open an electronic or digital device, you will see small components with a series of pins, called chips or microchips. A microchip is a flat piece of semiconductor material, usually silicon, that integrates transistors, resistors and capacitors. Logic gates are comprised of resistors and transistors, or diodes. By joining a variety of logic gates, the circuit can perform simple or complex operations. All this digital circuitry is called an integrated circuit (IC).

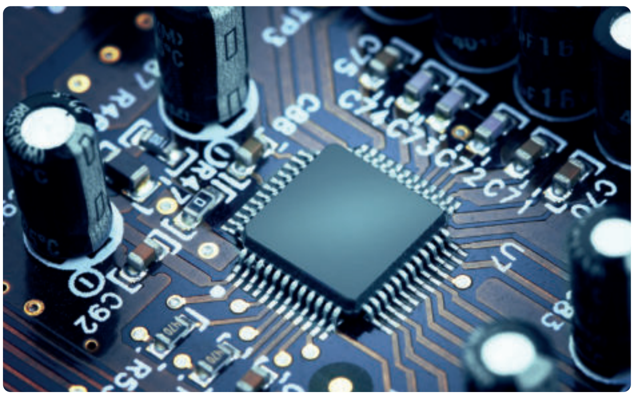


Figure 3.4: Typical IC packaging

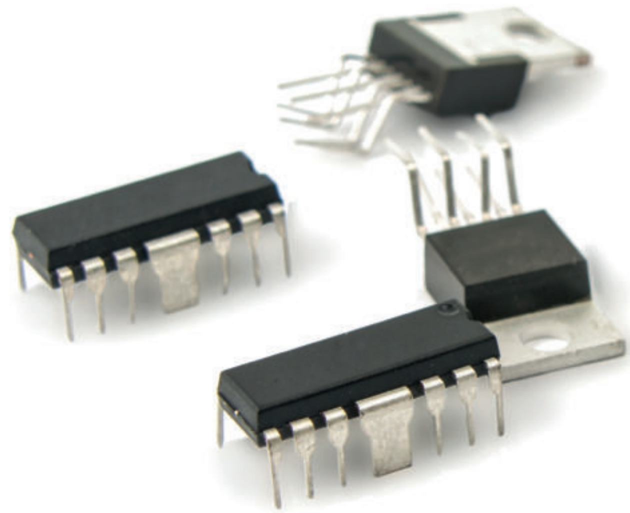


Figure 3.5: VLSI packaging

The integrated circuit is the building block of all modern electronic and digital devices. The integrated circuit is orders of magnitude smaller, faster, and less expensive than a circuit constructed of discrete electronic components. But, the high initial costs of design and preparation require high production volumes to keep the cost per chip low.

Based on their design and thevnumber of transistors per chip, integrated circuits are categorized as:

> Small Scale Integration (SSI): Tens to hundreds of transistors

> Medium Scale Integration (MSI): Hundreds to thousands of transistors

> Large Scale Integration (LSI): Thousands to several hundred thousand transistors

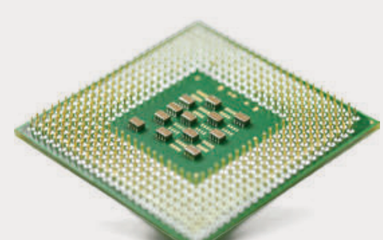
> Very Large-Scale Integration (VLSI): Up to two millions transistors

> Ultra-Large-Scale Integration (ULSI): Millions and billions of transistors

Table 3.4: Integrated Circuit

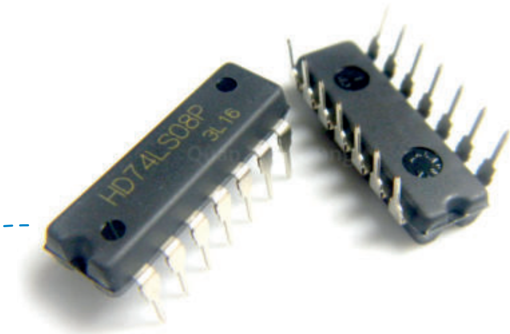
Scale of Integration	Number of Transistors
SSI	2 ≈ 100
MSI	100 ≈ 2.000
LSI	2.000 - 100.000
VLSI	100.000 - 2.000.000
ULSI	> 2.000.000

An integrated circuit can also be classified as being digital, analog or a combination of both. Its primary objective is to embed as many logic gates as possible as well as other digital circuitry on a single semiconductor chip. A computer's CPU is a type of integrated circuit and a modern CPU may embed hundreds of billions of transistors.



If we could open a simple IC such as 74LS08, we would see that its circuitry implements four AND logic gates as shown in the illustration below.

The actual implementation is done through transistors, diodes and resistors, but the chip's functionality resembles that of the illustration. The schematic shows the actual circuit of just one AND gate.



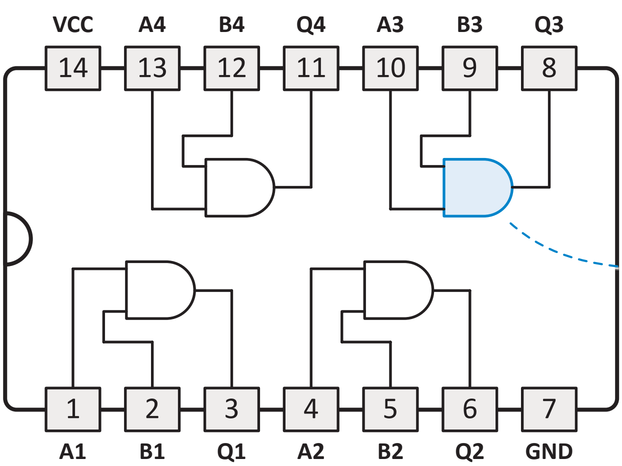


Figure 3.6: The logic gates of 74LS08 IC

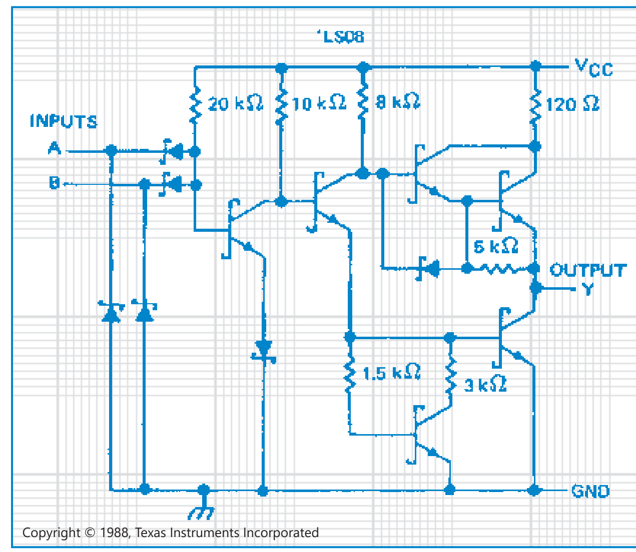


Figure 3.7: Schematic diagram of one AND gate in 74LS08

Similarly, a CPU consists of billions of logic gates to perform arithmetic and logic operations and to temporarily store data for processing.

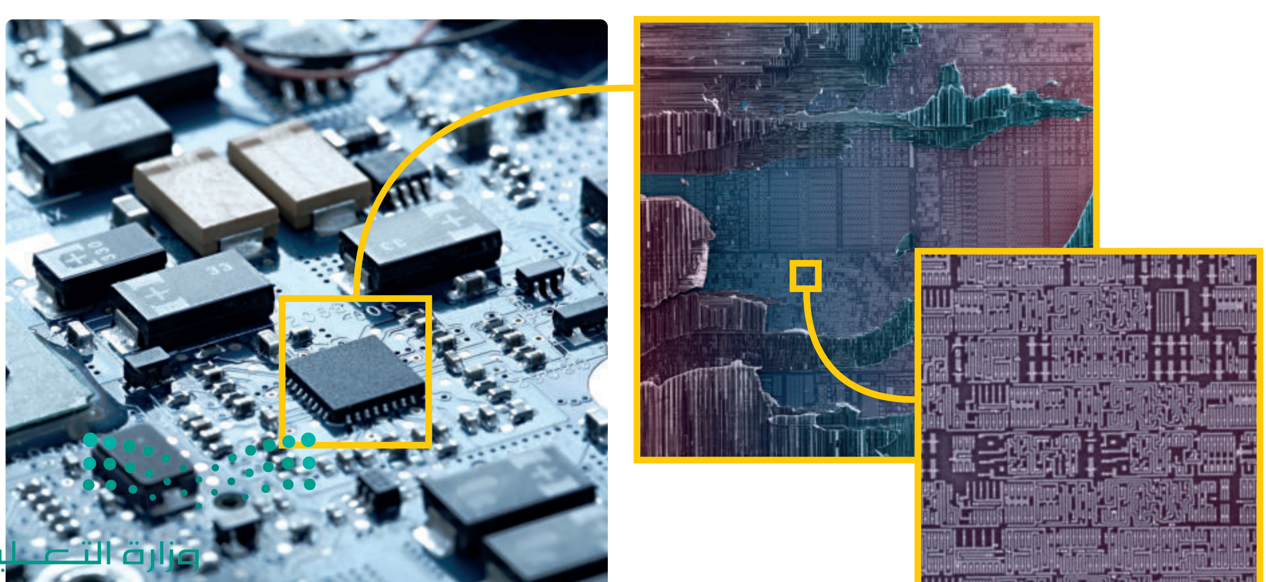
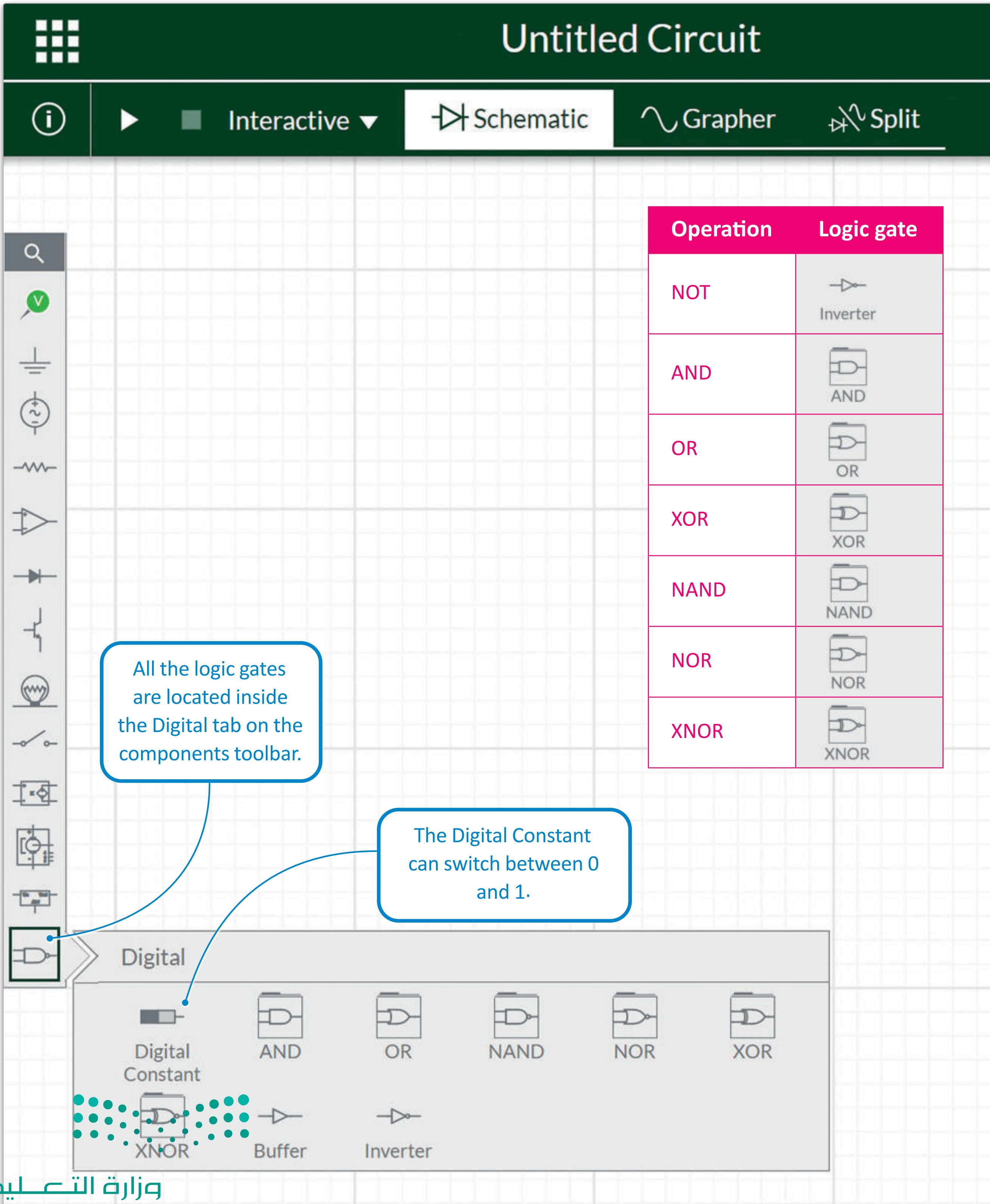


Figure 3.8: Magnified images of a typical CPU

Logic Gates on Multisim Live



Operation	Logic gate
NOT	Inverter
AND	AND
OR	OR
XOR	XOR
NAND	NAND
NOR	NOR
XNOR	XNOR

Figure 3.9: Multisim Live circuit simulator

Drawing Digital Circuits

Let's go to **www.multisim.com** to log in to your account and create a new file.
You will create the digital circuit of an **AND** logic gate.
First you will add a switch and name it **"A"**.

To add Digital Constant A:

> On the **Components toolbar**, click the **Digital** tab. (1)
> Drag (2) and drop a **Digital Constant** into the **work space**. (3)
> Change the name of the **Digital Constant** to "**A**". (4)

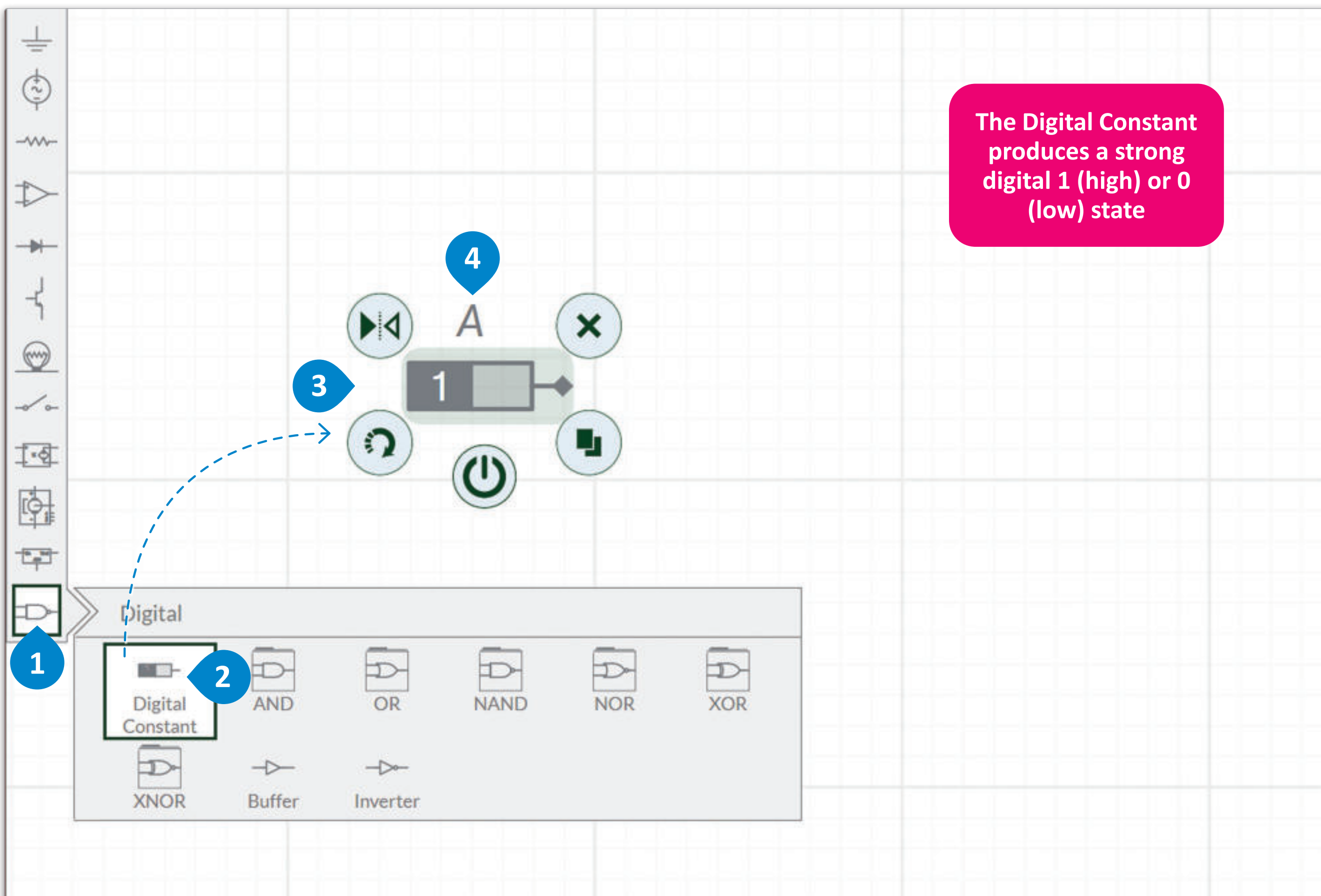


Figure 3.10: Add Digital Constant A

SMART TIP

A digital constant works like a switch and you can change its state from 1 (high) to 0 (low) just by clicking the toggle button or by clicking directly on the switch when the simulation is running.

Then you will add a second switch and name it "**B**".

To add Digital Constant B:

> On the **Components toolbar**, click the **Digital** tab. 1
> Drag 2 and drop a **Digital Constant** into the **work space**. 3
> Change the name of the **Digital Constant** to"**B**". 4

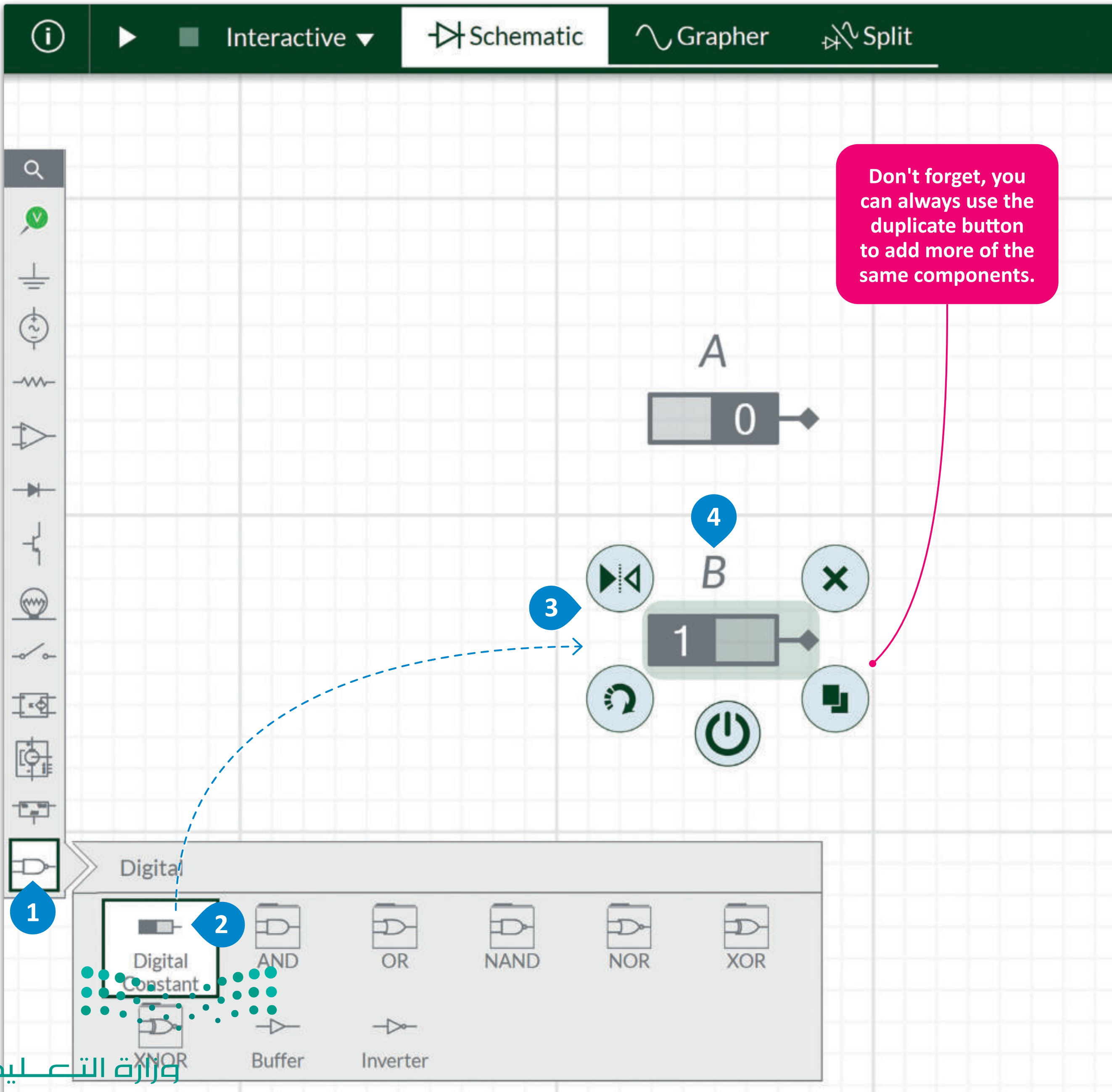


Figure 3.11: Add Digital Constant B

Now, let's add your first logic gate.

To add logic gate AND:

> On the **Components toolbar**, click the **Digital** tab. 1
> Click on the **AND folder**. 2
> Drag 3 and drop **2-Input AND** into the **work space**. 4
> Change the name of **the 2-input AND** to "**AND**". 5

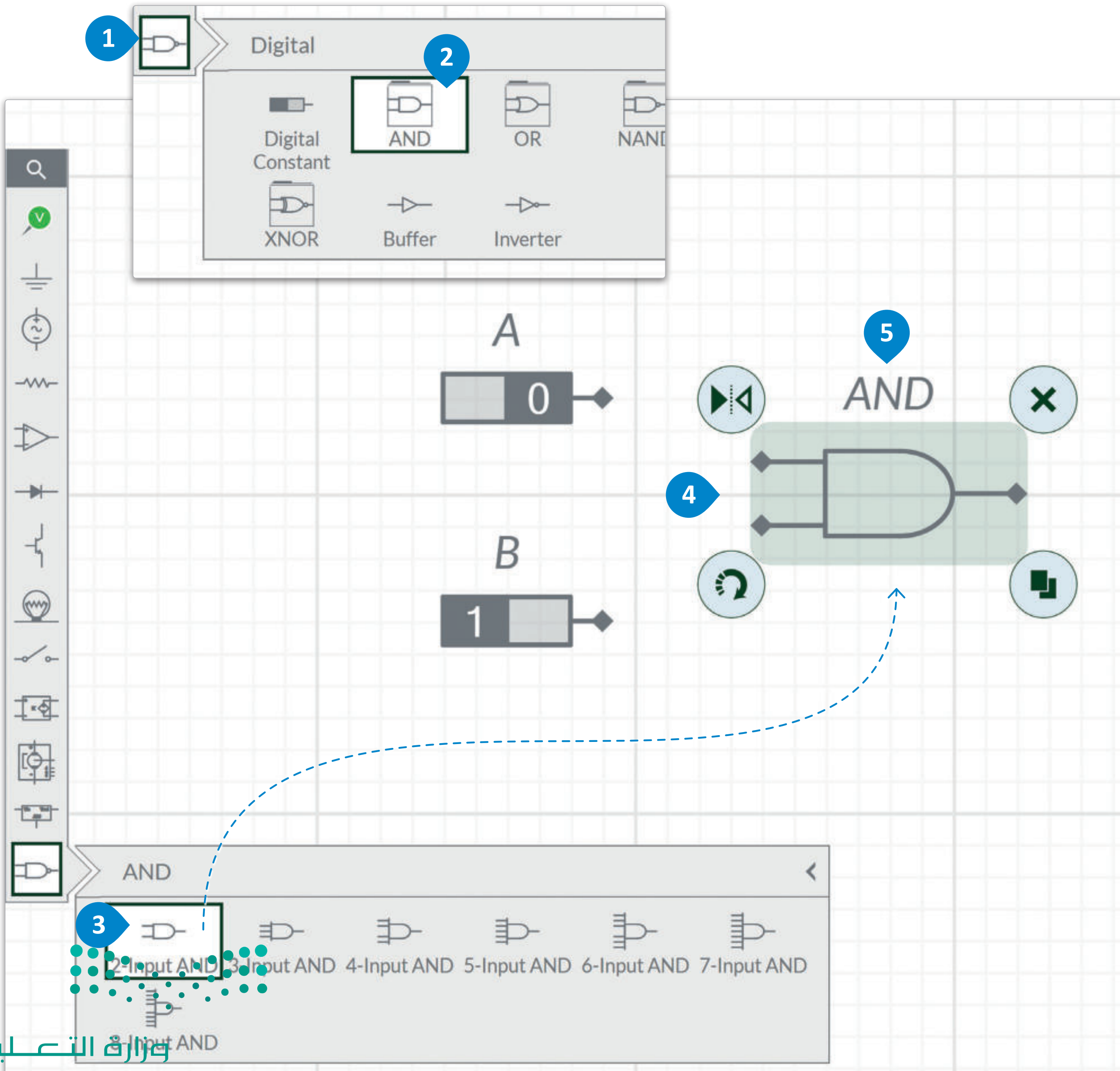


Figure 3.12: Add logic gate AND

Continue by connecting the **AND** gate with switches "**A**" and "**B**".

Connections:

> Click on the **Digital Constant A** 1 and then on the upper input of the **2-input AND**. 2

> Click on the **Digital Constant B** 3 and then on the lower input of the **2-input AND**. 4

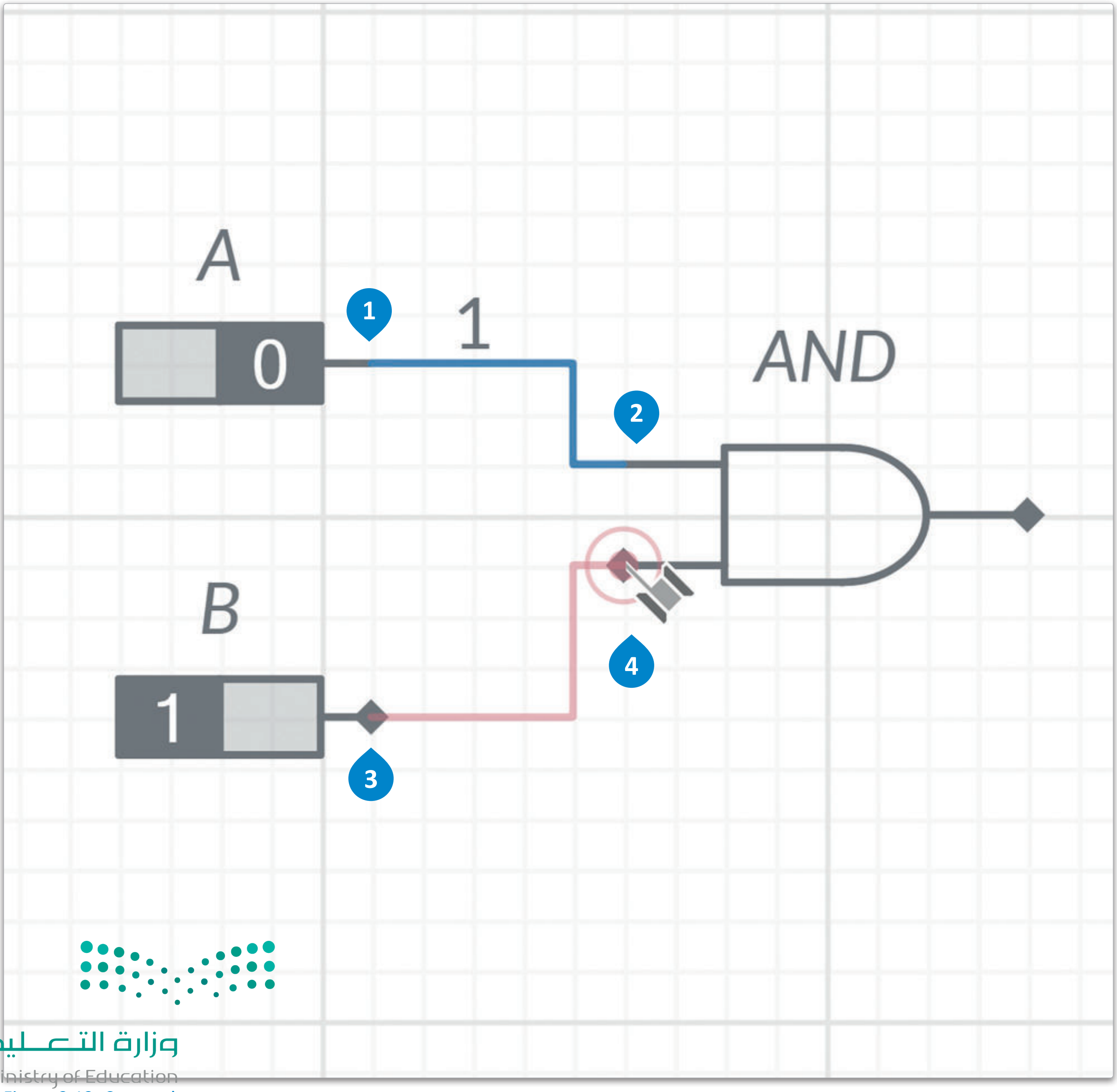


Figure 3.13: Connections

Now we will add an **LED** so you can see when the result is 1 (high state) or 0 (low state).

To add LED:

> On the **Components toolbar**, click the **Diodes** tab. 1

> Drag 2 and drop an **LED** into the **work space**. 3

> Click the **Rotation** button 4 to rotate the **LED** into this position. 5

LED

A light-emitting diode (LED) is a semiconductor device that emits light when an electric current flows through it.

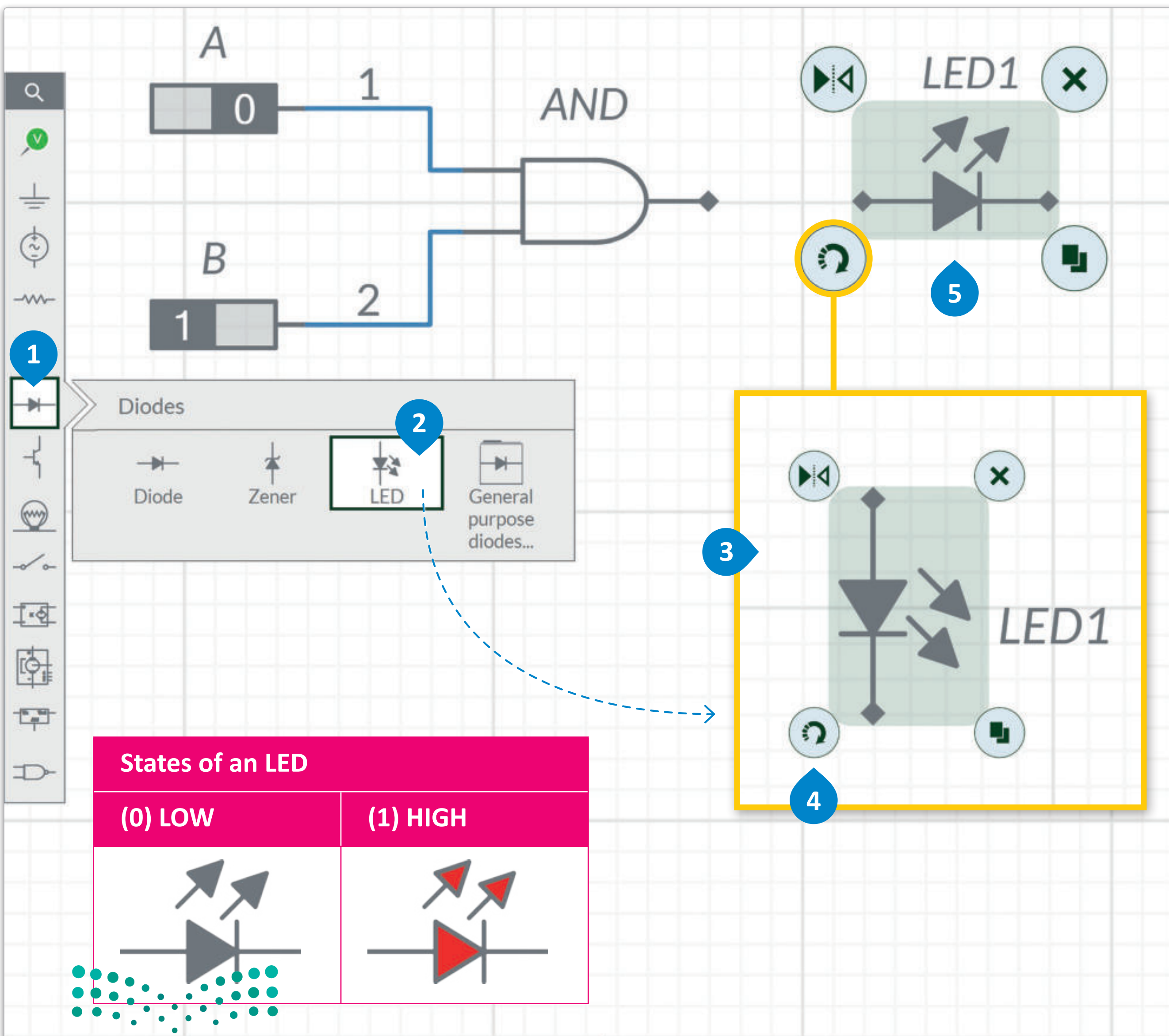


Figure 3.14: Add LED

Then you will connect the **AND** gate with **LED1**.

Connections:

> Click on the output of the **2-input AND** 1 and then on the input of **LED1**. 2

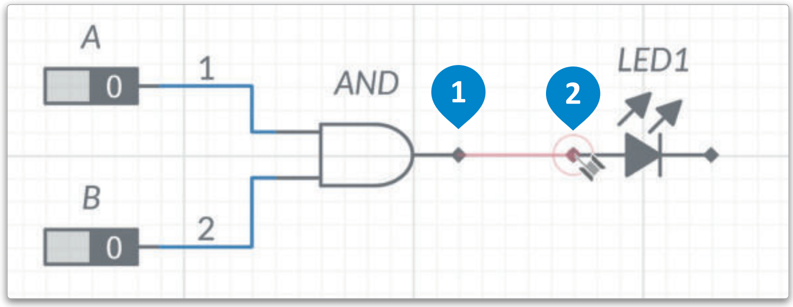


Figure 3.15: Connections

Now, let's add a digital probe.

To add a probe:

> On the **Components toolbar**, click the **Analysis and annotation** tab. 1

> Drag 2 and drop a **Digital probe** in **series** with **LED1**. 3

Digital probes can be added to a digital circuit to show us if the value is 0 (low) or 1 (high) at the specific point where the probe is located.

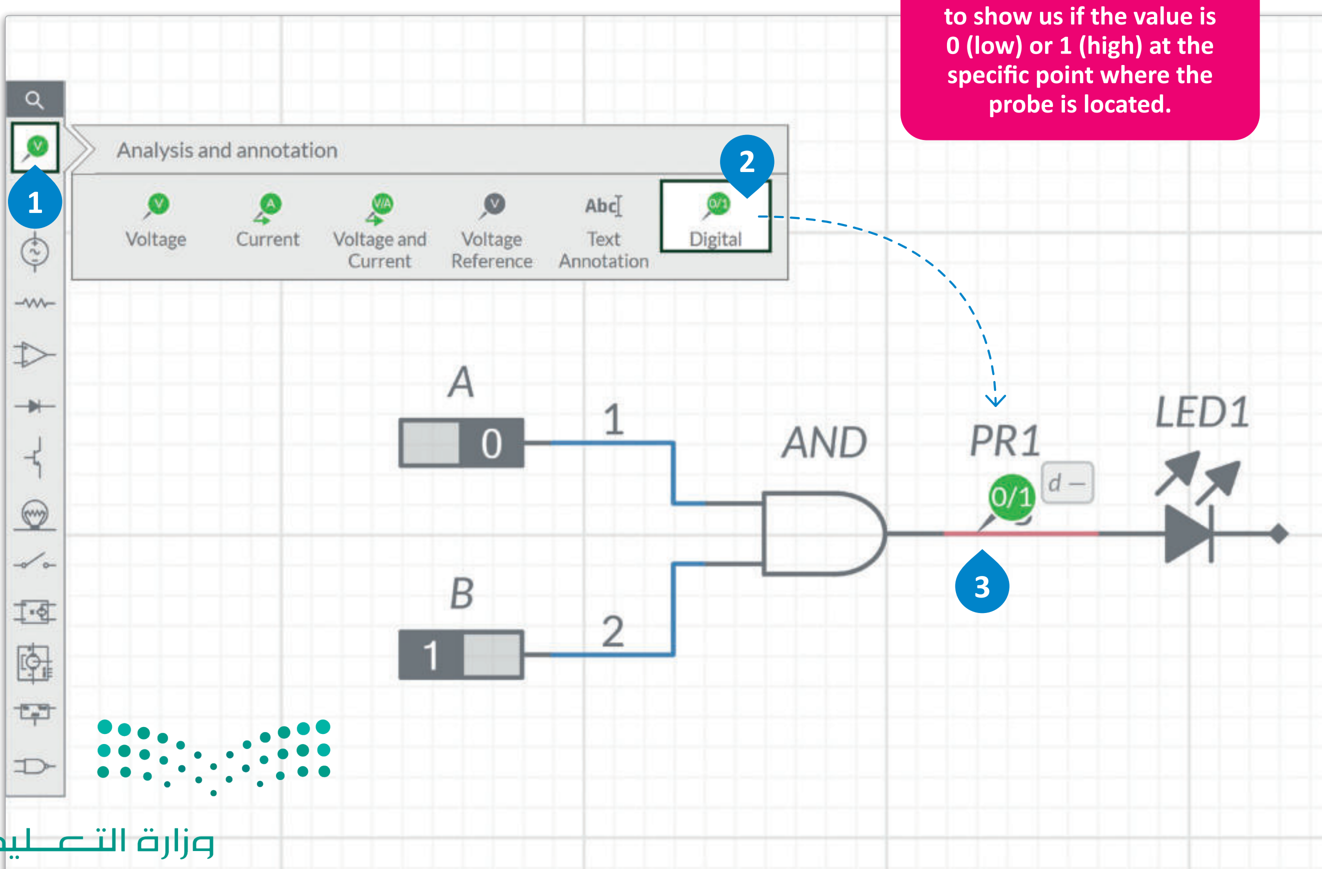


Figure 3.16: Add a probe

Then you will add a ground to your digital circuit.

To add ground:

> On the **Components toolbar**, click the **Schematic connectors** tab. 1
> Drag 2 and drop **Ground** into the **work space**. 3

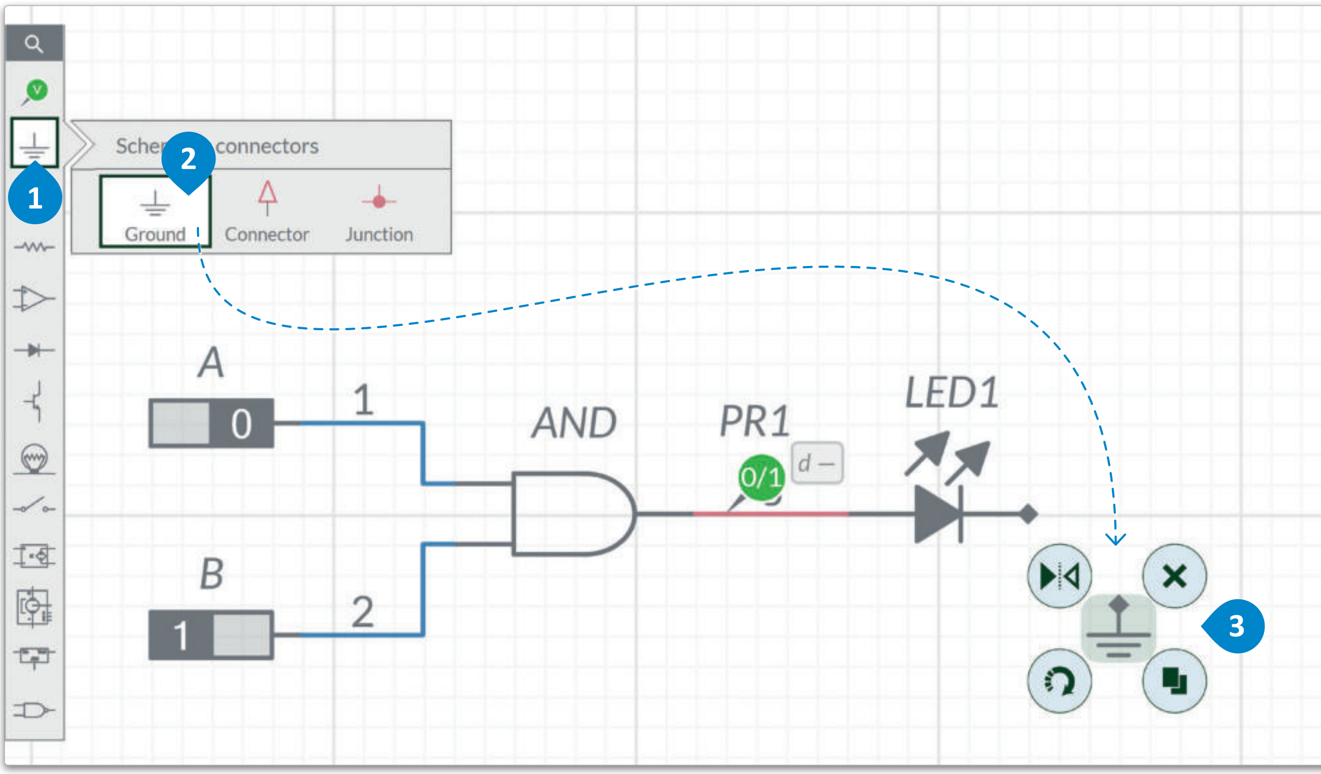


Figure 3.17: Add ground

Finally, you need to connect **LED1** with the **Ground**.

Connections:

> Click on the output of **LED1** 1 and then on the **Ground**. 2

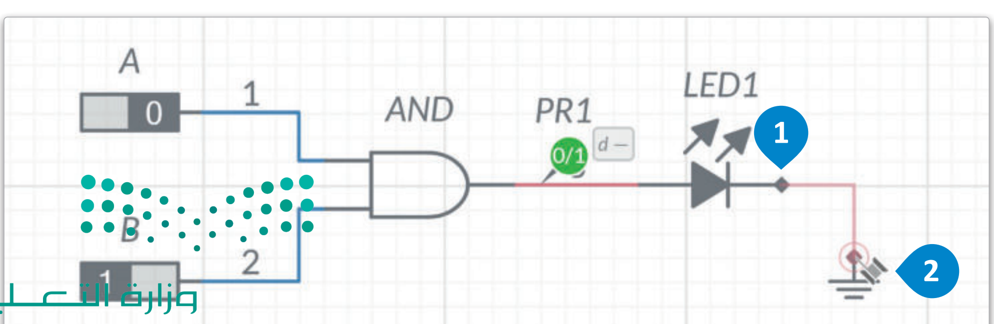


Figure 3.18: Connections

Ground

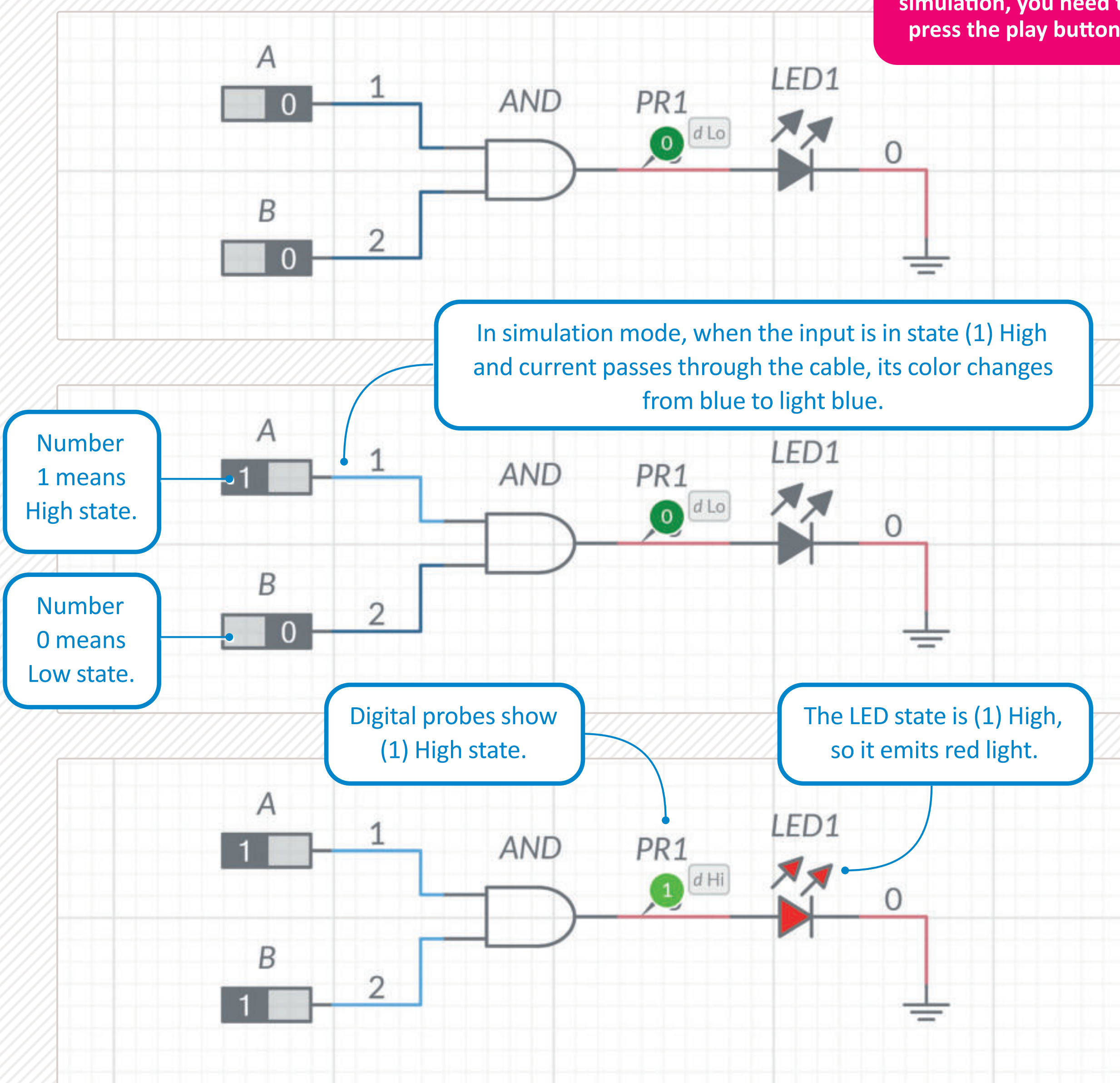
Grounding in integrated circuits is a reference point (0) for measuring voltages. It also serves as a fail-safe mechanism in the event that a fault or damage occurs in the circuit.

Let's take a look at how the digital circuit works in simulation mode.

> In the first example, both inputs "**A**" and "**B**" are **(0) Low** and the output is also **(0) Low**.
> In the second example, input "**A**" is **(1) High**, input "**B**" is **(0) Low** and the output is **(0) Low**.
> In the third example, both inputs "**A**" and "**B**" are **(1) High** and the output is **(1) High**.

Example

Don't forget, to run the simulation, you need to press the play button.



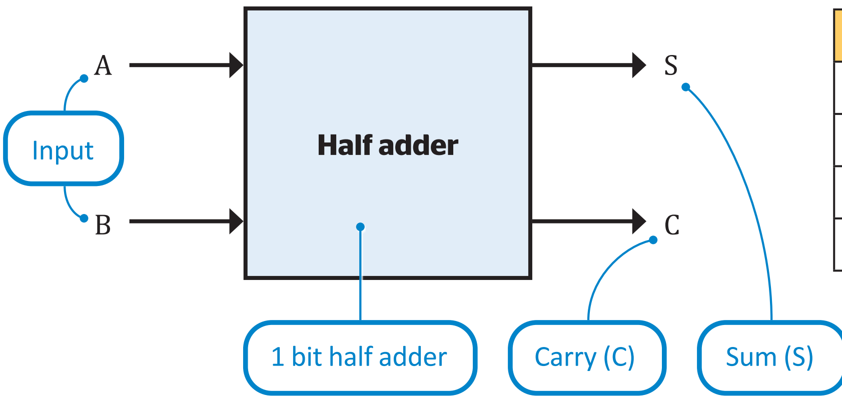
INFORMATION

When you use digital probes, d Lo = (0) Low and d Hi = (1) High.

Half Adder

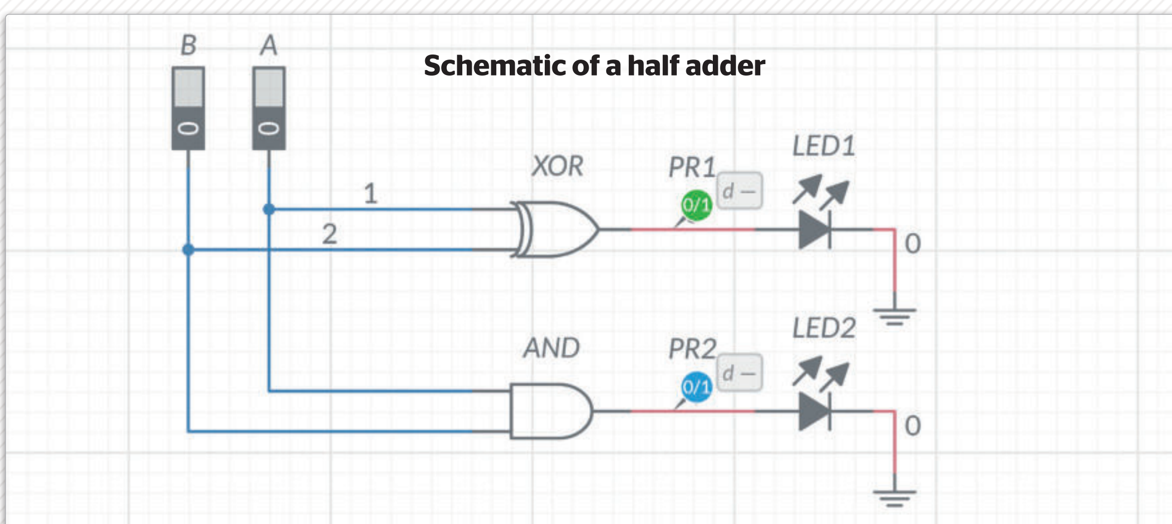
A half adder is a digital circuit that performs addition of numbers. A half adder adds two single-digit binary numbers and the result is a two-digit output denoting the sum and the carry. It has two inputs, called A and B, and two outputs S (sum) and C (carry). The most common circuit uses one XOR and one AND logic gate.

If we combine two half adders together with the use of an OR gate, the result is a full adder.



A	B	S	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Example



INFORMATION

Half adders and full adders are both digital circuits that are used to implement combinational logic. They are both used to sum calculations. The main difference is that full adders use the carry from a previous calculation as a third input in a 2-bit calculation, whereas half adders ignore any previous values for a carry bit. Full adders are made of 2 half adders and an OR logic gate.

Exercises

1 Which are the two types of gates you can make when you combine logic gates? How you can use each one?

2 What is the function of diodes and what are their two terminals?

3 What are the advantages of using transistors?

4 What is an integrated circuit (IC)?

____

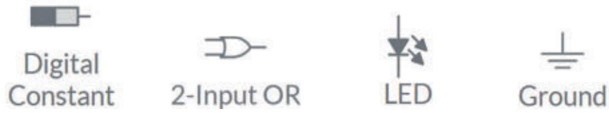
____

____

____

____

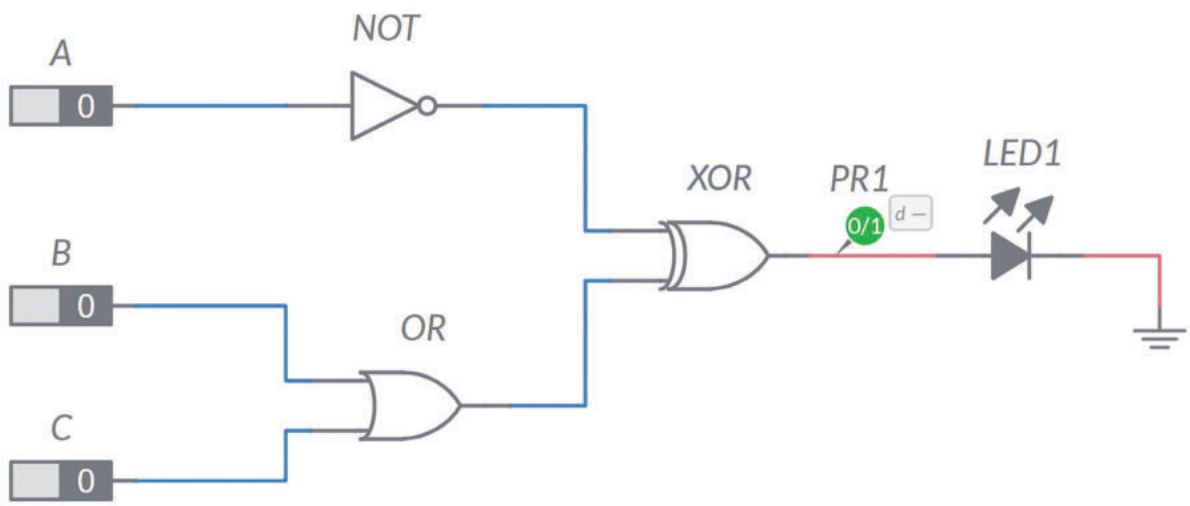
5 Open Multisim Live and draw the basic circuit of an OR logic gate. The components that you will need are shown below:



6 Use Multisim Live to draw the digital circuit that corresponds to the following function.

$$Y = (\overline{A} + B) \cdot (\overline{A \cdot C})$$

7 Create the following digital circuit in Multisim Live:



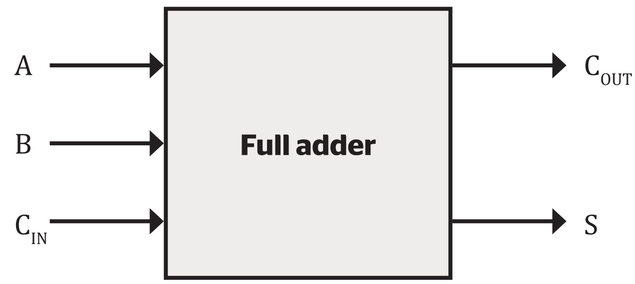
In which states is the probe (output) (0) Low and in which states is it (1) High?

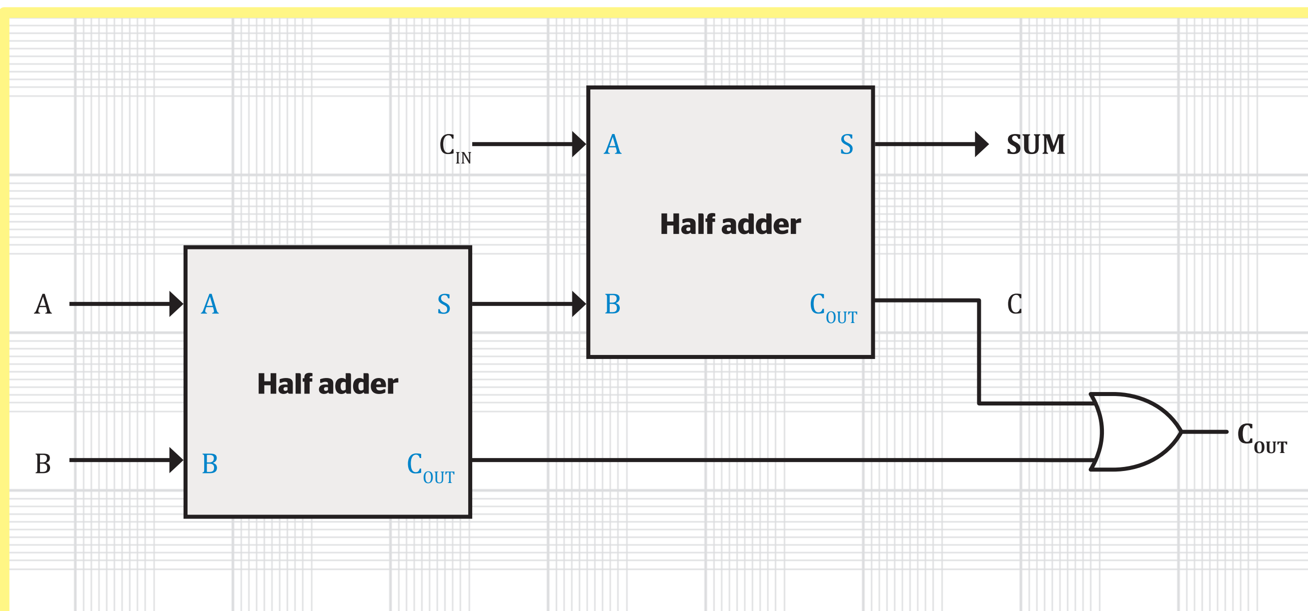
Run the simulation and fill in the table below:

Input A	Input B	Input C	Output Y
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	
1	0	1	
1	1	0	
1	1	1	

Project

In this *project, you can see how a full adder is simplified into two half adders.*





Do the *following:*

Use Multisim *Live to design a* ***full adder*** *and connect all the logic gates in the correct manner.*

After you *have built the circuit, write the truth table and the* ***Karnaugh map****, and see if it can be simplified.*

Wrap up

Now you have learned how to:

- **> use the rules of Boolean Algebra.**
- **> use Boolean Algebra to simplify functions.**
- **> combine logic gates.**
- **> use Karnaugh maps to simplify functions.**
- **> use Multisim Live to design and simulate digital circuits.**

KEY TERMS

Boolean Algebra	Encoder	LED
Decoder	Flip-Flop	Logic Gate
Demultiplexer	Integrated Circuit	Multiplexer
Diodes	Karnaugh Map	Transistor

وزارة التعليم
Ministry of Education
2023 - 1445

4. Circuit Simulation with Tinkercad Circuits

In this unit, students will learn how to use an application to simulate electronic circuits. More specifically, students will learn how to create, edit, and simulate electronic circuits in Tinkercad Circuits. Students will also learn how to use the application to make measurements and to troubleshoot circuits.

Learning Objectives

In this unit you will learn to:

> Design an electronic circuit with Tinkercad Circuits.
> Apply best selection practices while connecting electronics components.
> Simulate an electronic circuit.
> Design experiments in electric circuits.
> Measure current on an electronic circuit using various techniques.
> Troubleshoot an electronic circuit.

Tools

> Autodesk Tinkercad Circuits

Lesson 1
Electronic Circuit Design and Simulation

Link to digital lesson

www.ien.edu.sa

What Tinkercad Circuits is

Tinkercad Circuits is a free web-based application, created by Autodesk for education, that lets you create digital and analog prototypes of electronic circuits. Simple circuits with LEDs, buzzers, switches and even sensors can be easily created and tested on this platform. A microcontroller, the most basic type of programmable computer, may be included in the design of these prototypes to control electronic components such as LEDs and motors. Tinkercad Circuits is part of a group of tools that includes utilities for 3D design and modeling. Coding can be used in your 3D designs and microcontroller circuits.

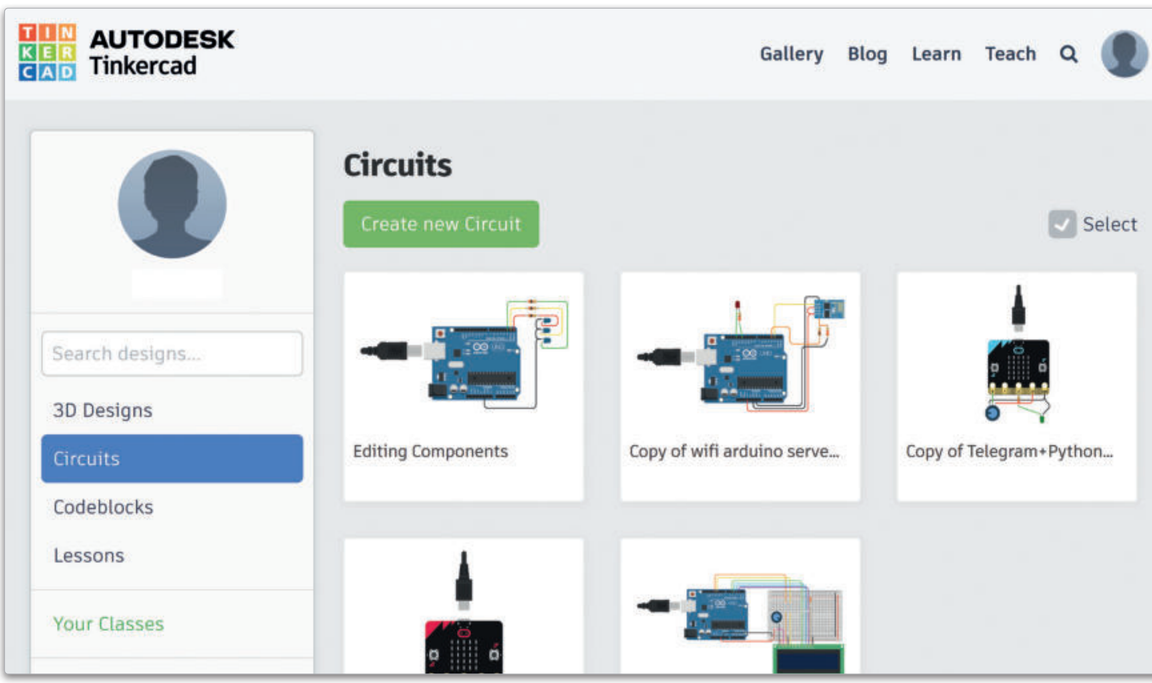


Figure 4.1: Autodesk Tinkercad Circuits

Tinkercad Circuit is a prototyping tool, it allows users to design and build an early model of a product in order to test and evaluate it. A prototype can serve as a proof of concept, showing that the system or device can be built and will perform as expected. Despite its simplicity, Tinkercad Circuits has strong simulation capabilities. This means that there is no need to buy physical components such as sensors, Arduino boards or motors in order to test if a prototype will work, and no physical components are damaged if the circuit is faulty.

You can access Tinkercad Circuits from **https://www.tinkercad.com**, and you can create a personal account to save and share your circuits with others. There is also a gallery of public designs for the three categories of projects: **Designs**, **Circuits** and **Codeblocks**.

You can reuse and expand any public circuit with the **Copy and Tinker** button.

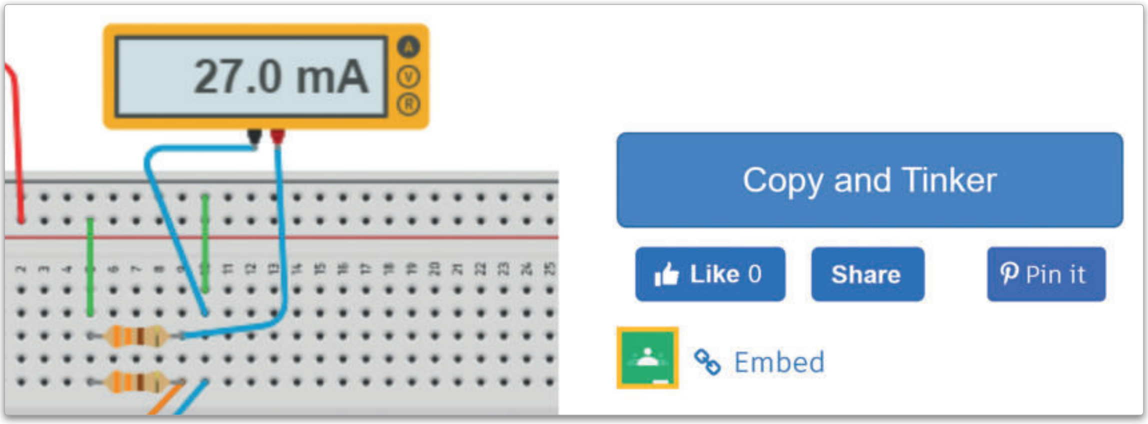


Figure 4.2: Tinkercad Circuits Copy and Tinker feature

Electrical and electronic circuits are the cornerstone of each and every device, and everyone working in the field of electronics must understand their design and implementation. In this unit, you will learn the basics of building an electronic circuit with Tinkercad Circuits. You will explore the interactive circuit editor and simulate your prototypes in a safe environment.

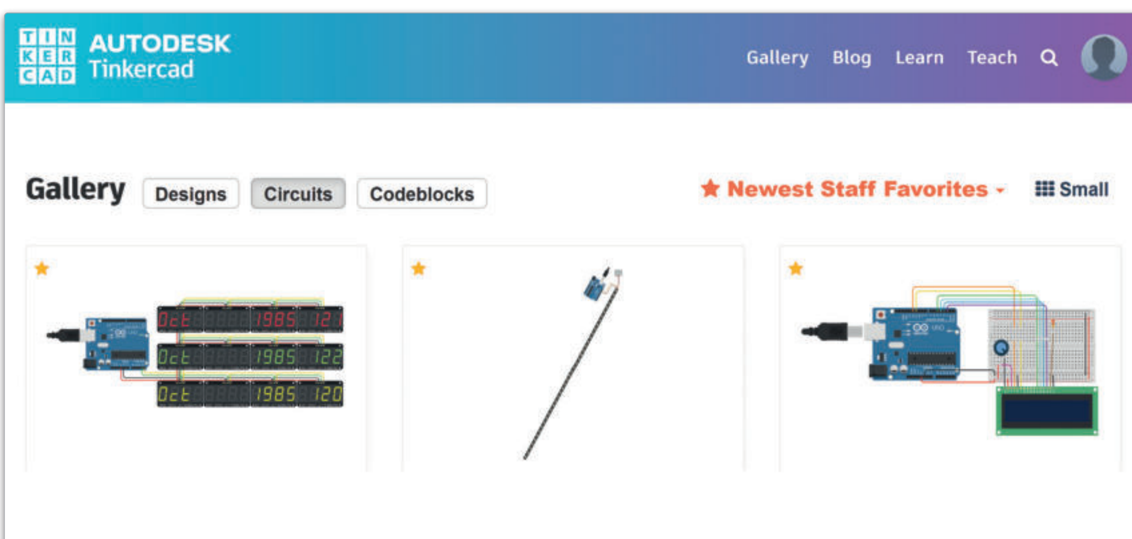
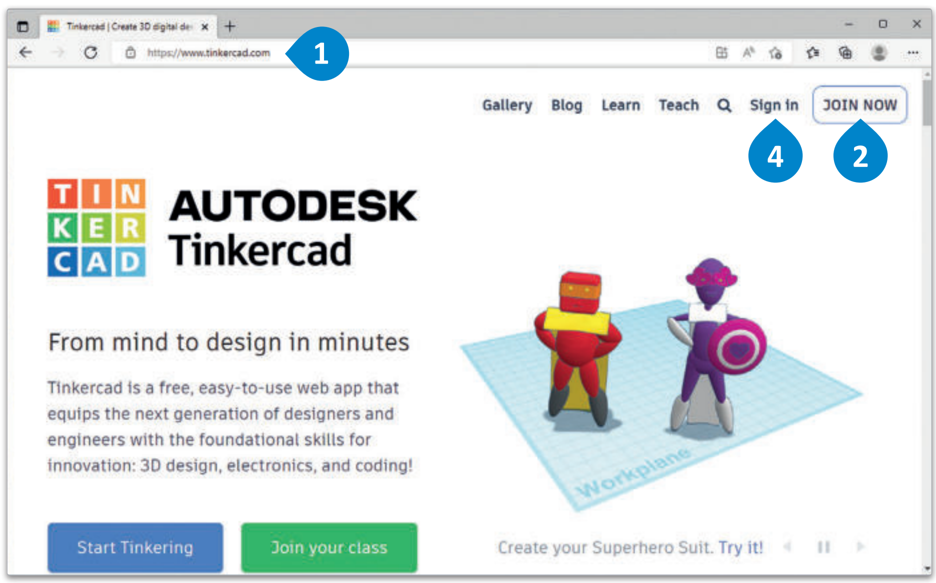


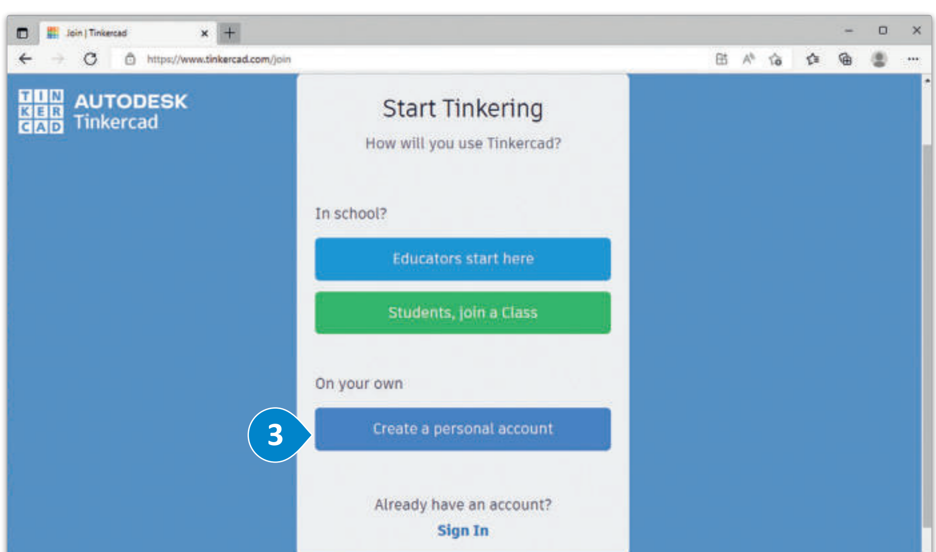
Figure 4.3: Tinkercad Circuits Gallery

Before you start designing your electronic circuit in Tinkercad Circuits, you should get a rough idea of what your circuit should look like by creating a hand-drawn sketch. When you are satisfied with your drawing, go to the Tinkercad website. In this lesson, we will create a circuit and use the **Start Simulation** button to turn an LED ON or OFF.

To create an electronic circuit:

> Open a web browser and go to **https://www.tinkercad.com**. 1
> Click on **JOIN NOW**. 2
> Create an account, 3 and **Sign in**. 4
> On the Tinkercad home page, click **Circuits**. 5
> Click **Create new Circuit**. 6
> A circuit project is created and opened. 7





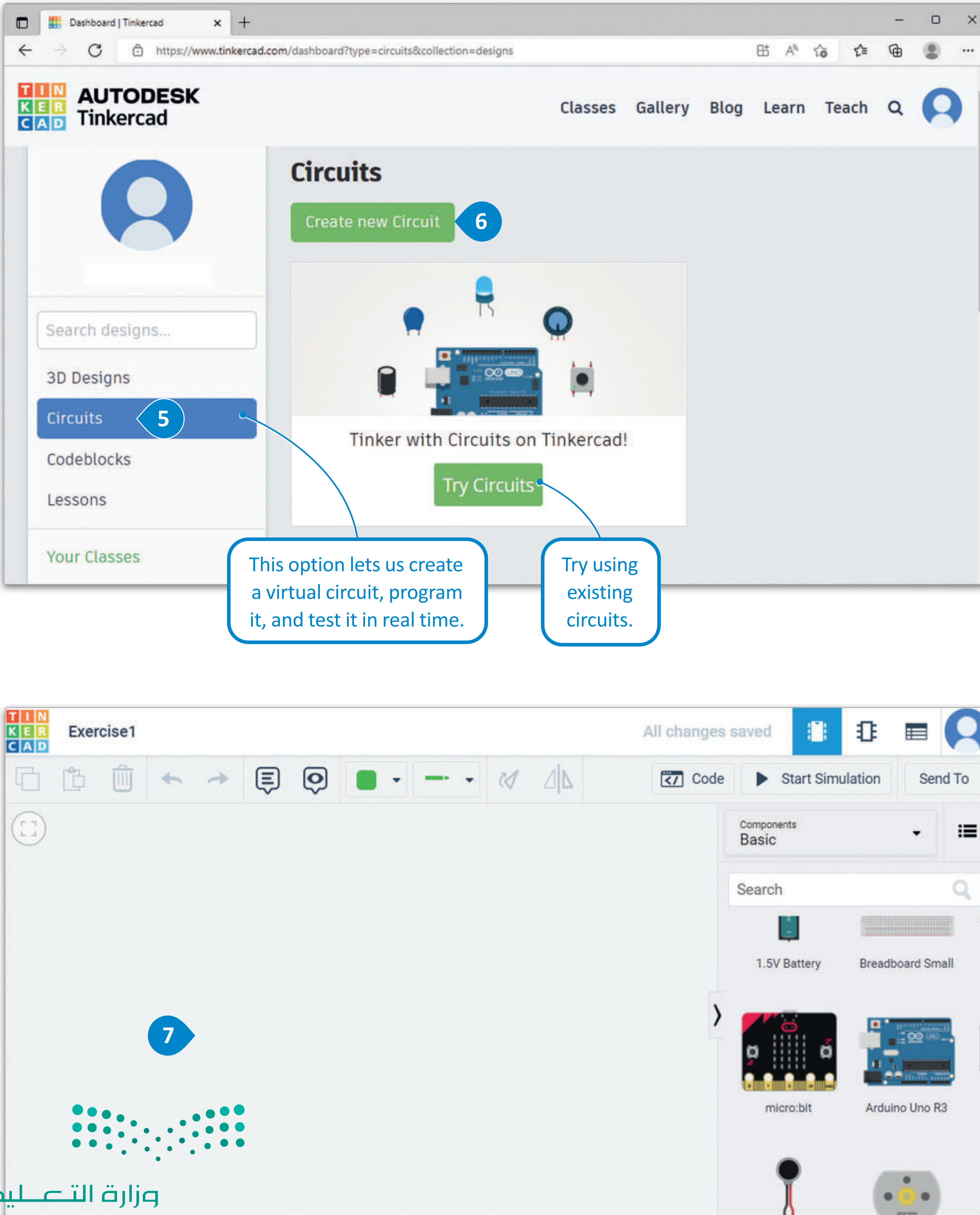


Figure 4.4: Create a circuit in Tinkercad Circuits

The Main Window of Tinkercad Circuits

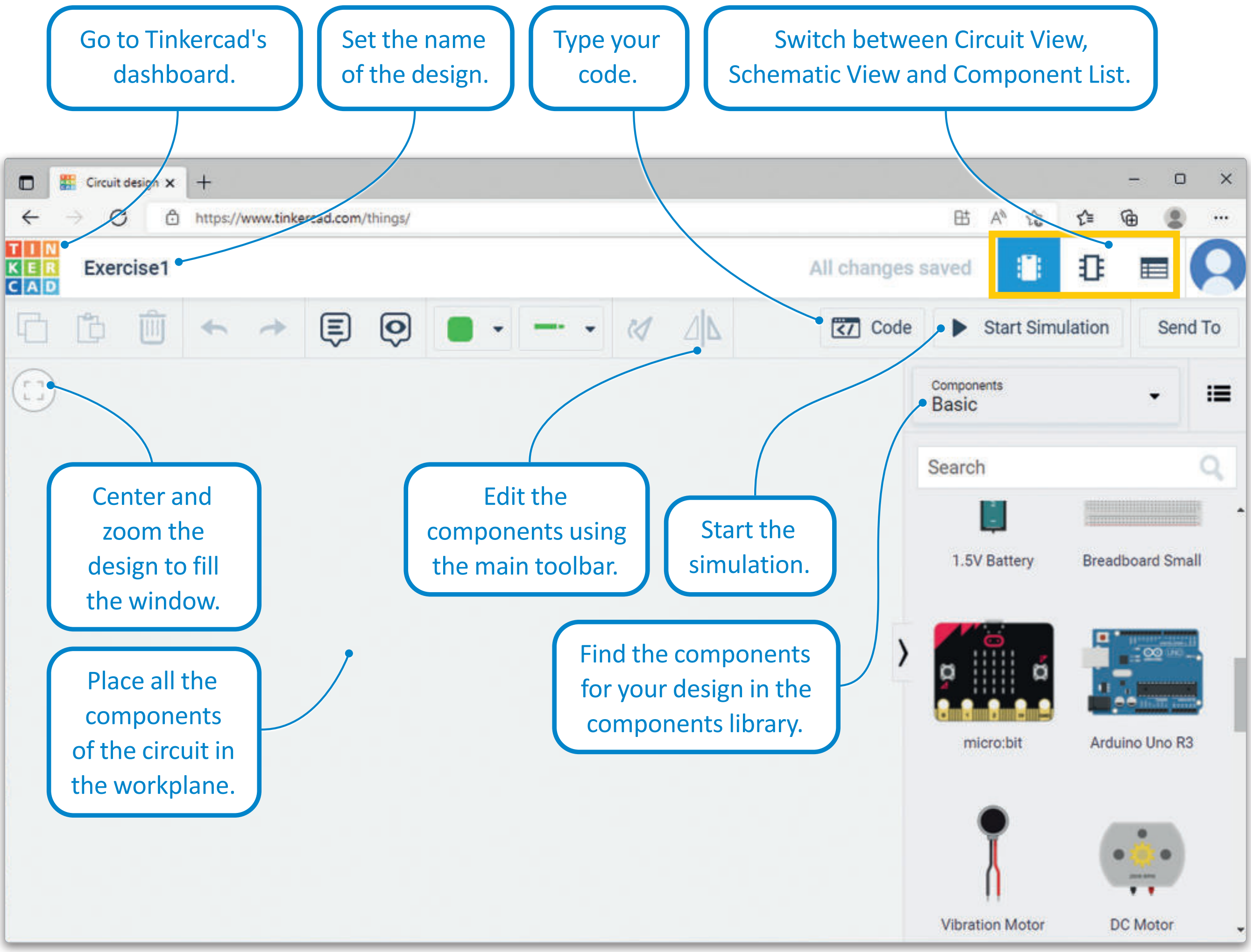


Figure 4.5: Tinkercad Circuits main window

Views

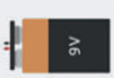
The Circuit View is the first view, and it's opened by default. The Schematic view contains an auto-generated schematic diagram of the design, and the Component List lets you export a BOM (Bill Of Materials) that lists all the components that have been added to the circuit.

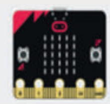
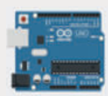
SMART TIP

Tinkercad Circuits has an automatic saving system. The system will update the save file every few minutes.

Core Components and Wiring

Electronic components such as LEDs, buttons, resistors, power sources can be used. These are the components available in the Basic option:

Resistor	
LED	
Pushbutton	
Potentiometer	
Capacitor	
Slideswitch	
9V Battery	
Coin Cell 3V Battery	

1.5V Battery	
Breadboard Small	
micro:bit	
Arduino Uno R3	
Vibration Motor	
DC Motor	
Micro Servo	
Hobby Gearmotor	

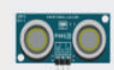
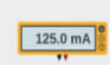
NPN Transistor (BJT)	
LED RGB	
Diode	
Photoresistor	
Soil Moisture Sensor	
Ultrasonic Distance Sensor	
PIR Sensor	
Piezo	
Temperature Sensor [TMP36]	
Multimeter	

Figure 4.6: Tinkercad Circuits core components

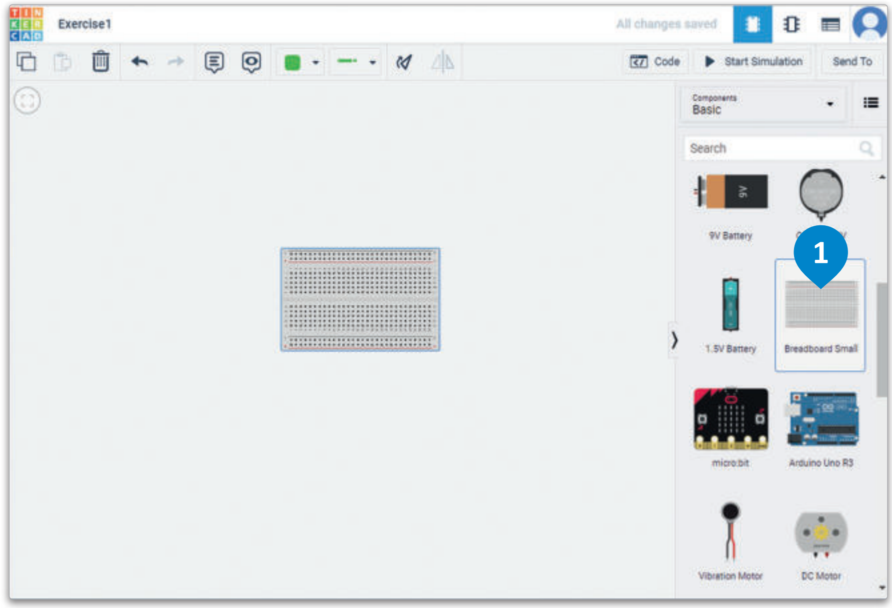
A breadboard is typically used to connect components. A breadboard is a piece of plastic with numerous holes. These holes are used to keep various components in place.

To add a component to the design:

> Click the base component you want to add to the design, for example, the **Breadboard Small**. 1

> The component is temporarily linked to the mouse pointer.

> Click in the workplane to place the component. 2



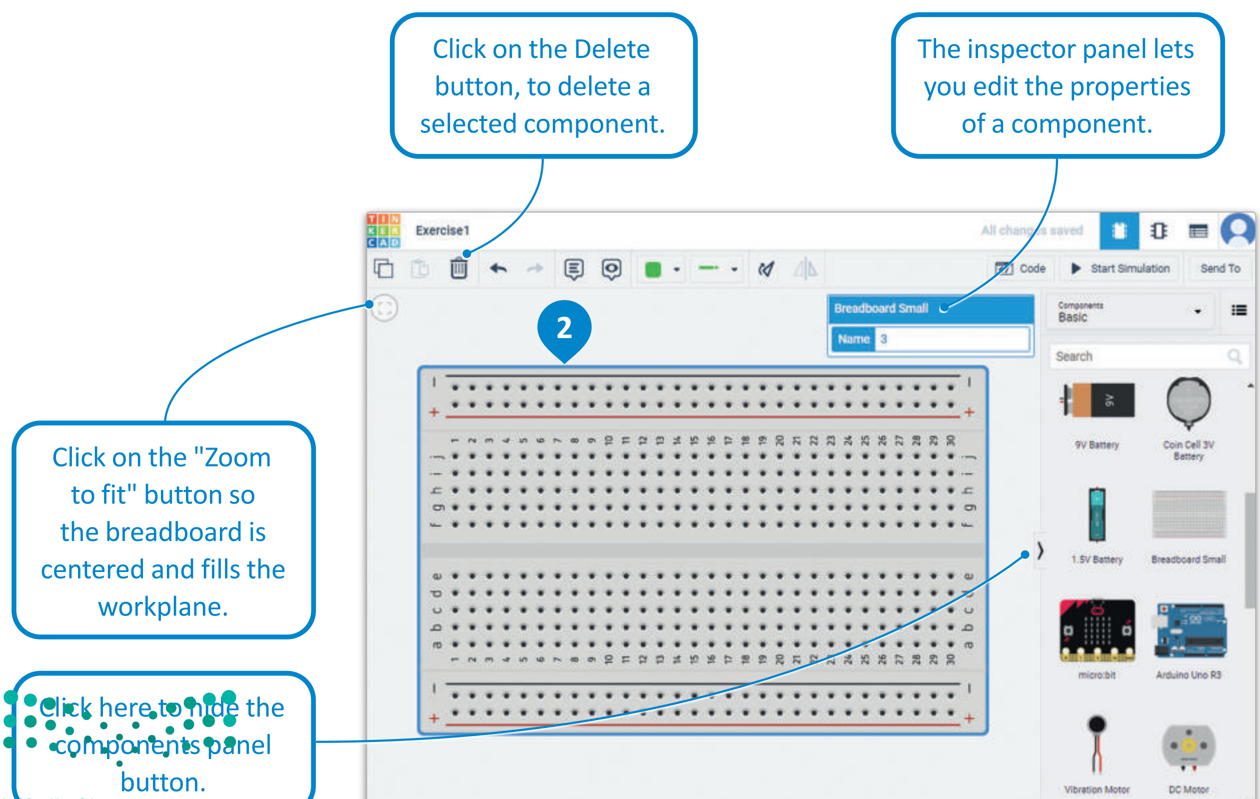


Figure 4.7: Add a component to the design

The Breadboard

In the main area of the breadboard, there is a grid of thirty by ten holes. The columns are labeled 1 through 30, and the rows are labeled a through j. A piece of plastic separates rows a through e from rows f through j.

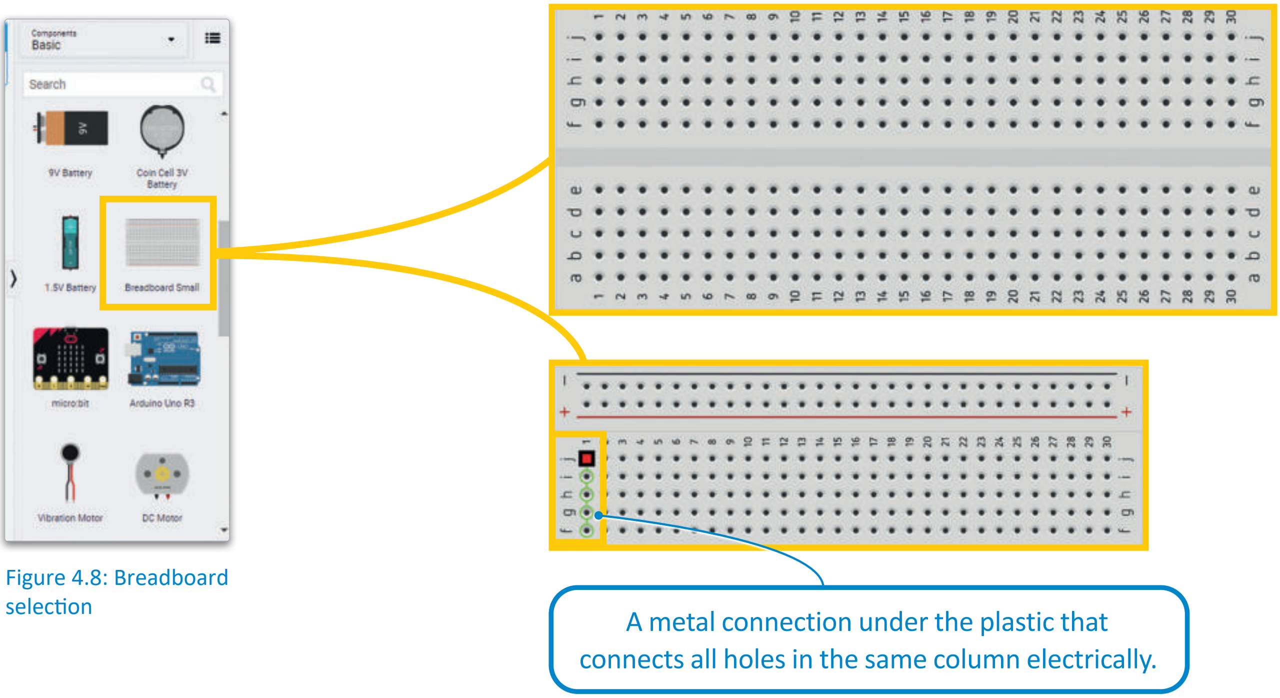
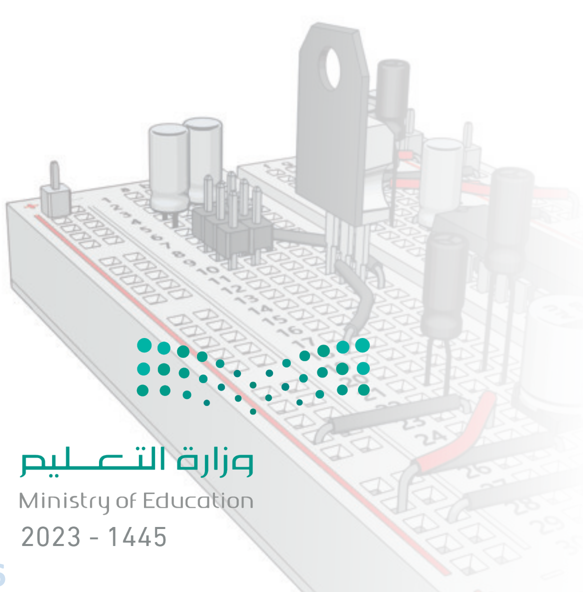
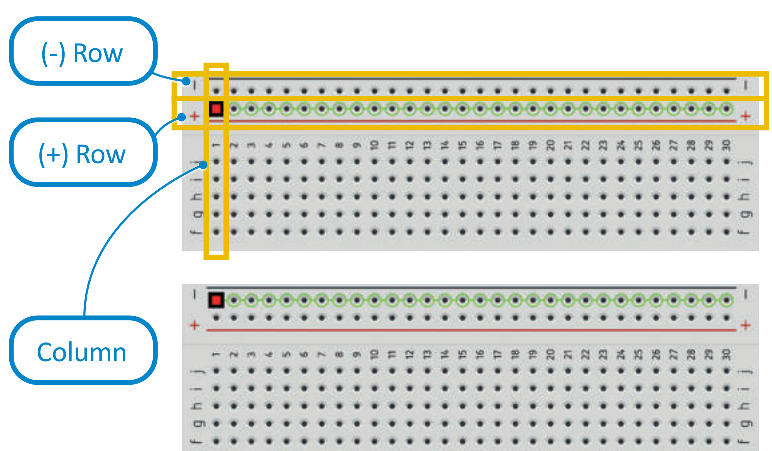


Figure 4.8: Breadboard selection

At the edge of the breadboard are two rows with the same number of columns. There are negative and positive symbols on these rows. These represent connections to the battery (main power source). To draw electric current, the components in the middle of the breadboard tap into these rows.





Closed Circuit with an LED

We will design a simple closed circuit with light. A Light Emitting Diode, or LED, will provide the light. Current can only flow in one direction through an LED. This is different from a regular light bulb, where current can flow in either direction. An LED has two connections, one for the cathode "negative" and one for the anode "positive". The lead of the anode is usually longer than the lead of the cathode. In Tinkercad Circuits, a bent lead identifies the LED anode. The positive voltage must connect there.

To place a component onto the breadboard:

> Click the component, for example the **LED**. 1

> Click to place the **LED** onto the breadboard so that each wire of the **LED** is in a hole. 2

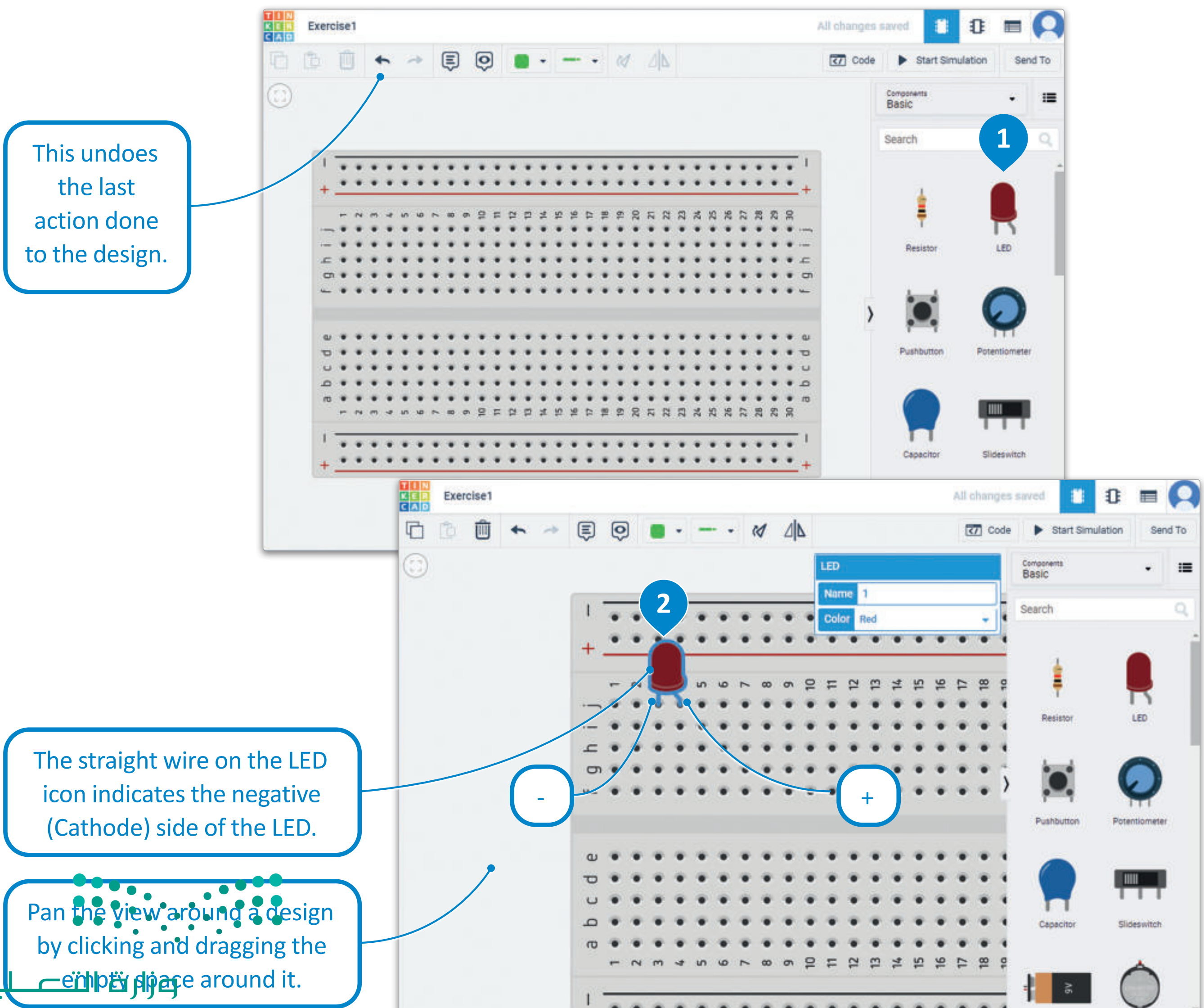


Figure 4.9: Place a component onto the breadboard

To add a power source to the circuit:

> On the components panel, click on a power source, for example the **1.5V Battery**. 1

> Click and place the battery along the left side of the breadboard. 2

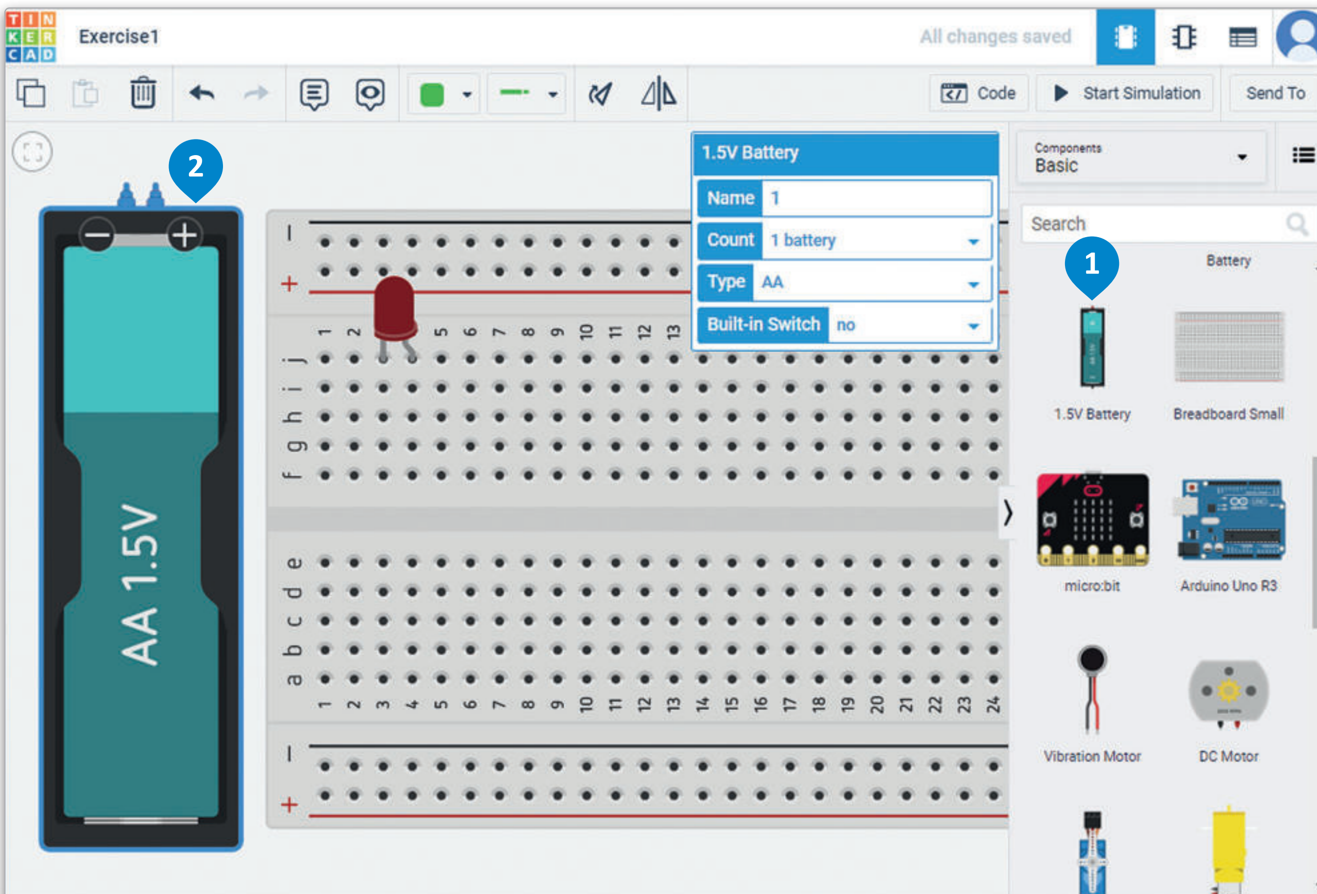


Figure 4.10: Add a power source to the circuit

SMART TIP

You can zoom in or out of a design by using the mouse wheel or the key combination Ctrl + + to zoom in and Ctrl + - to zoom out.

In electronic circuits, it is easier if the terminals are placed directly opposite the connectors.

To rotate a component:

> Click on the component to select it and make a blue frame appear around it, for example the **1.5V Battery**. 1

> Click the **Rotate** button on the main toolbar three times, as it rotates in small increments of approximately 30 degrees each time, to rotate the battery 90 degrees clockwise so that the terminals face the breadboard. 2

The Mirror button flips the selected component. This allows you to quickly design components with symmetry.

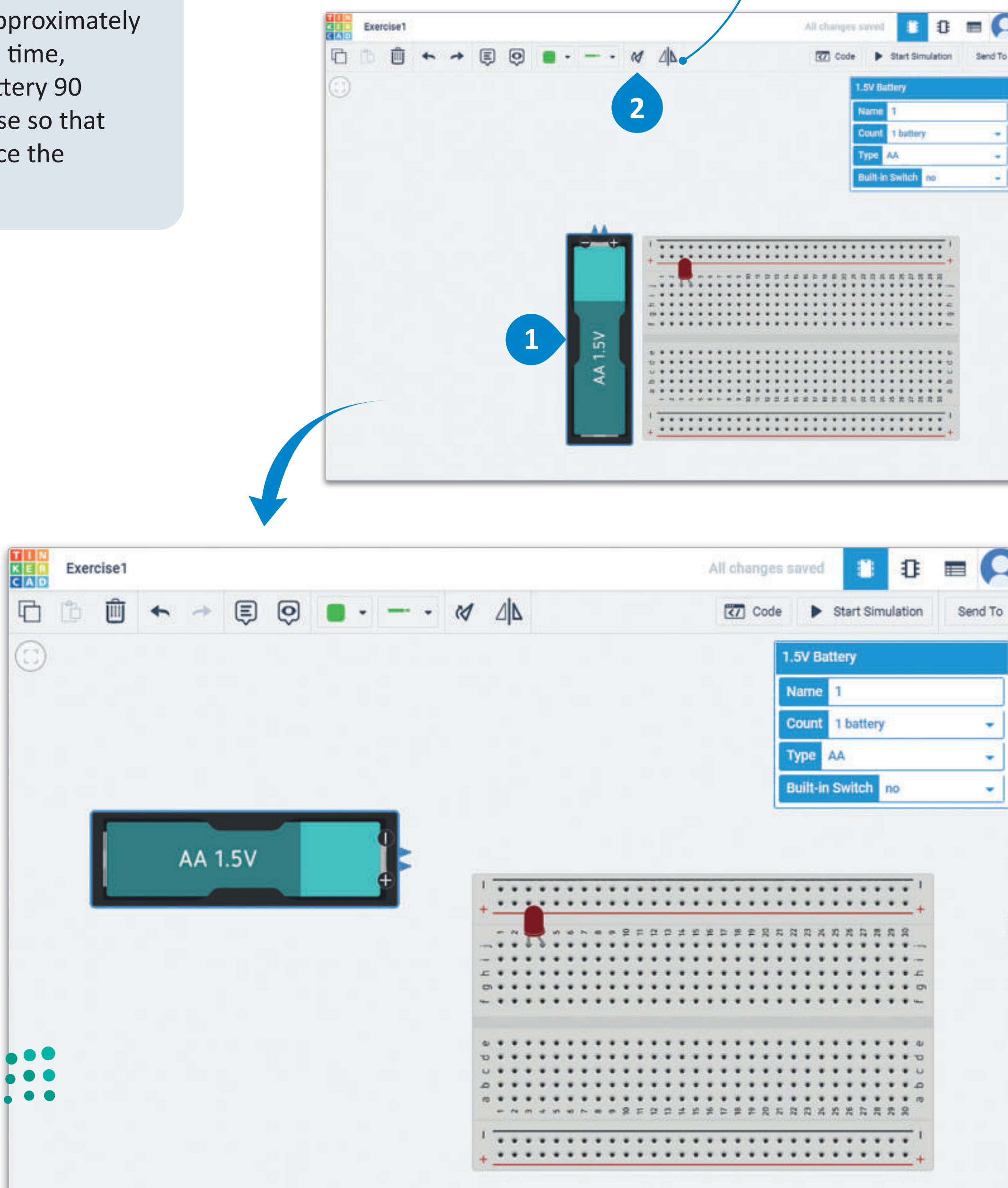


Figure 4.11: Rotate a component

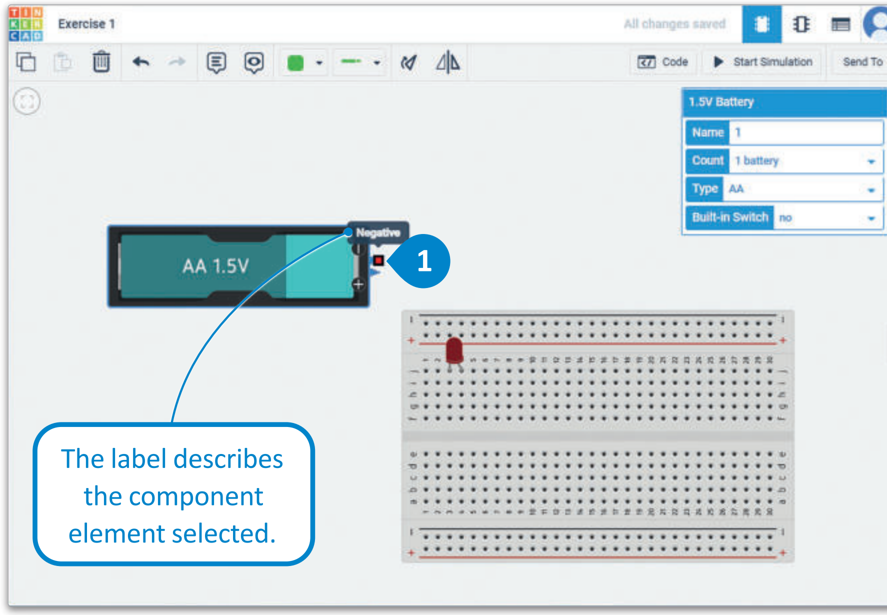
The battery must supply voltage to the LED of the circuit. Lead wires or Jumper wires are used to connect components that are not in the same row. These are plastic-covered wires with exposed ends that can be used to connect components. That is one of the reasons they are referred to as Jumper wires.

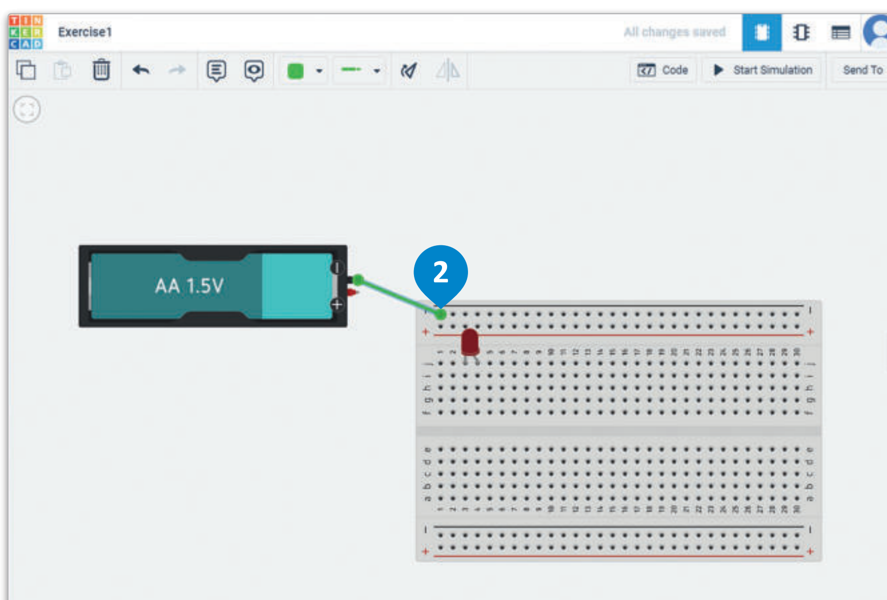
To wire a component:

> Click on the **negative terminal** of the component, for example that of the battery. 1

> Click on the **first hole in the negative column** to make the connection. 2

> Repeat the process with the **positive terminal**, placing the jumper wire on the positive hole on the breadboard. 3





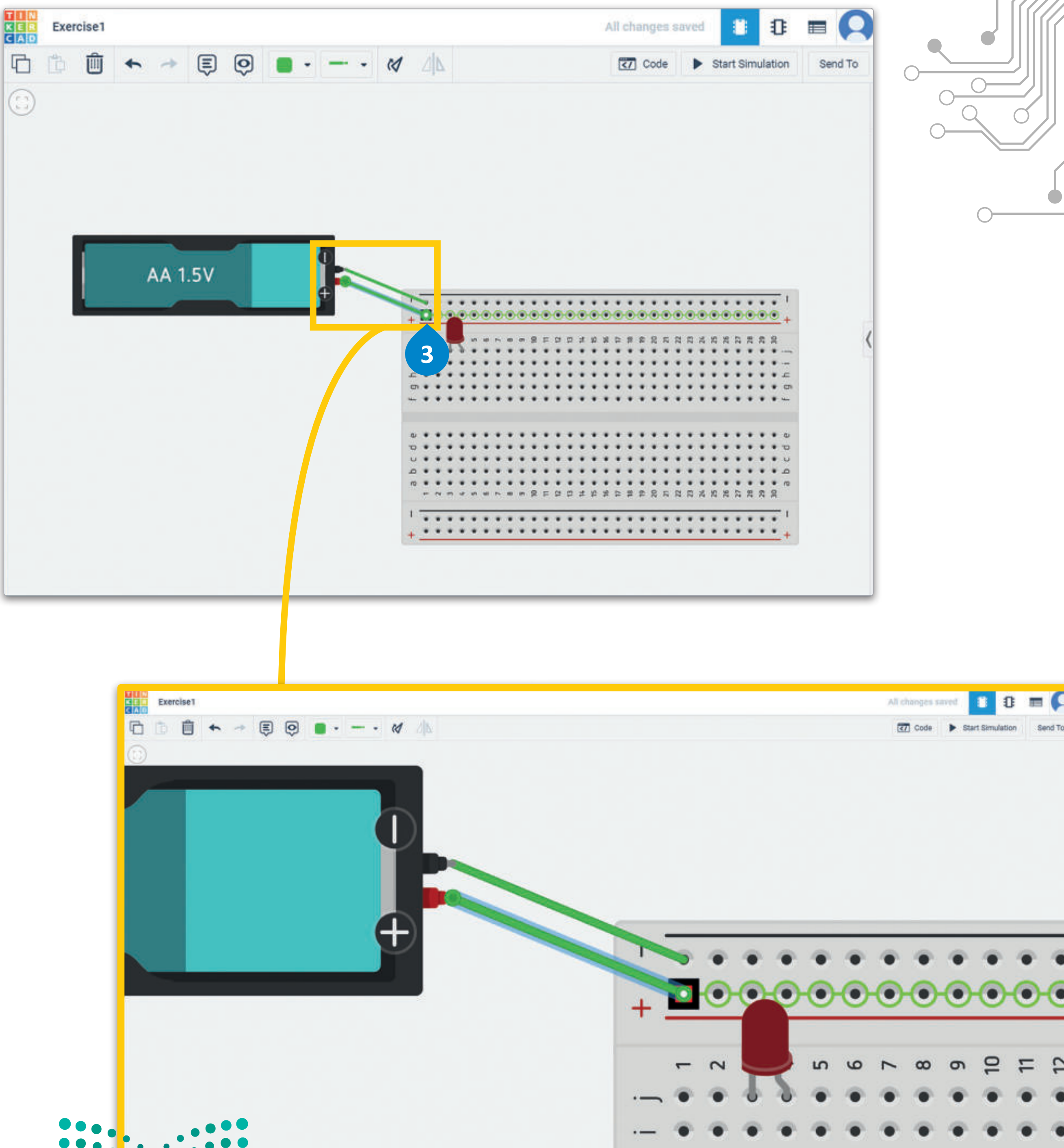


Figure 4.12: Wire a component

When many wires jump from one location to another, circuits can quickly become complicated. It is usually a good idea to color code the wires. In electronics, certain colors are commonly used. In DC circuits, red is typically used for positive connections and black for negative connections. Green is also used occasionally for ground.

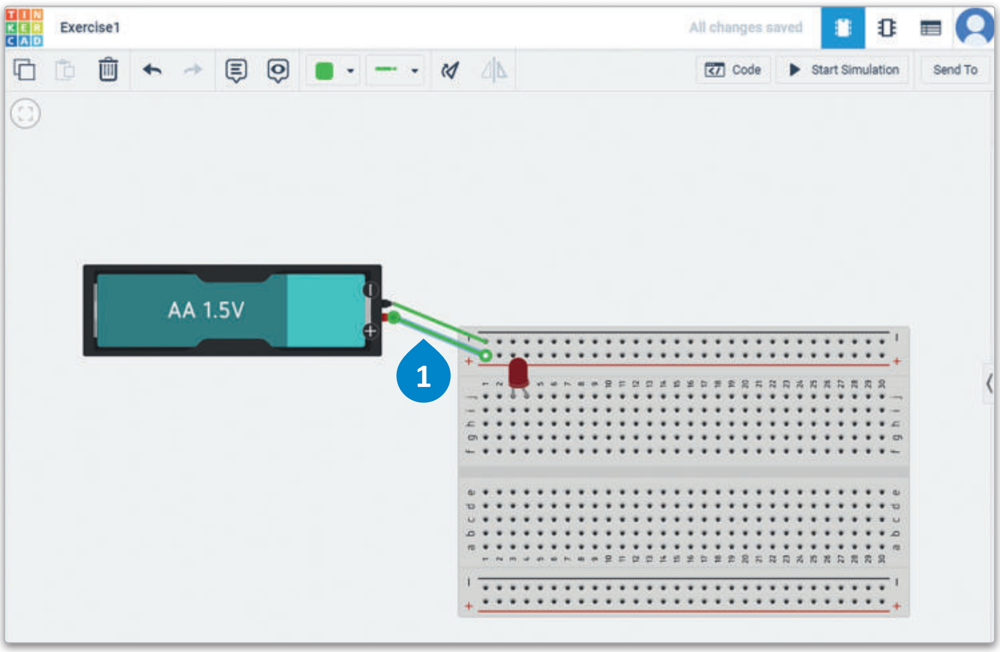
To edit a wire:

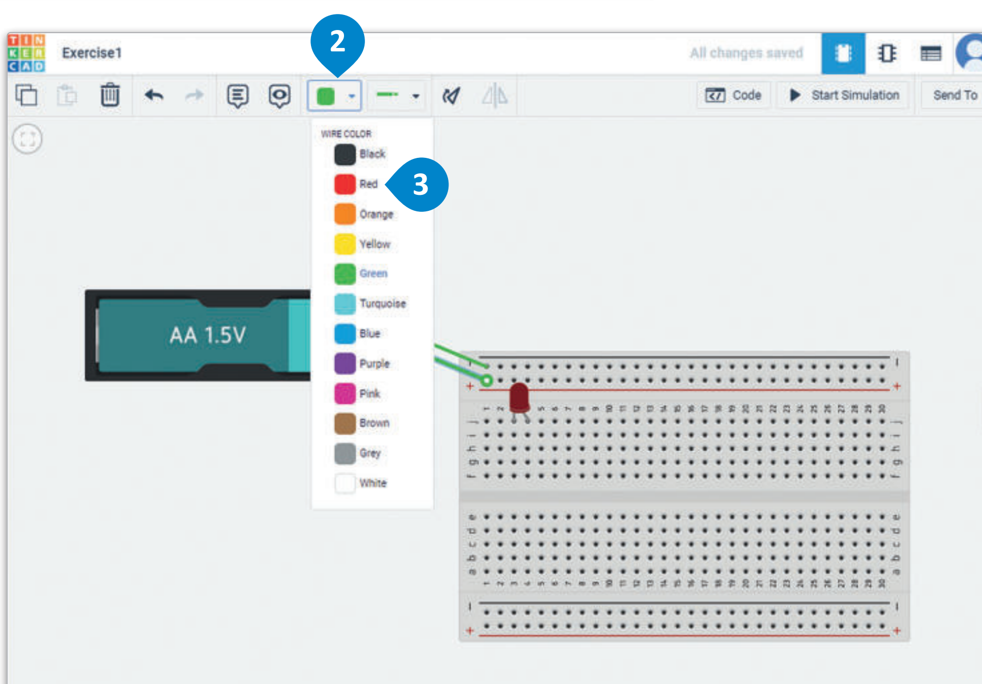
> Click on the **positive terminal**. 1

> In the main toolbar, click **Wire color**. 2

> Click on the color **Red**. 3

> Repeat the process for the **negative terminal** and change the **Wire color** to **Black**. 4





One of the advantages of using a breadboard is that the components can be easily moved to make new connections or to make room for other components.

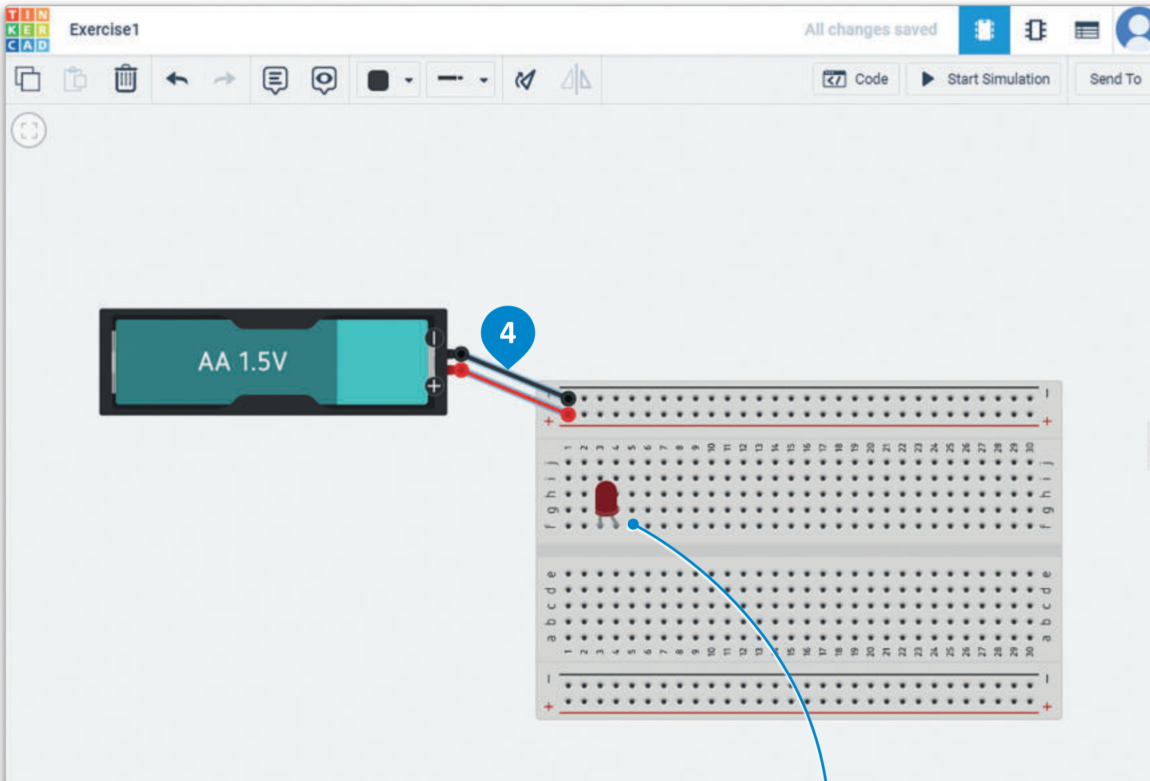


Figure 4.13: Edit a wire

In this case, for example, we drag and drop the LED to row f.

SMART TIP

When a wire is selected, you can change its color by typing any number on your keyboard. Typing 0 will, for example, result in a black wire.

The circuit is still open. To complete the circuit, two wires are required. One wire is for the positive terminal and one for the negative. The positive terminal must be connected to the anode of the LED.

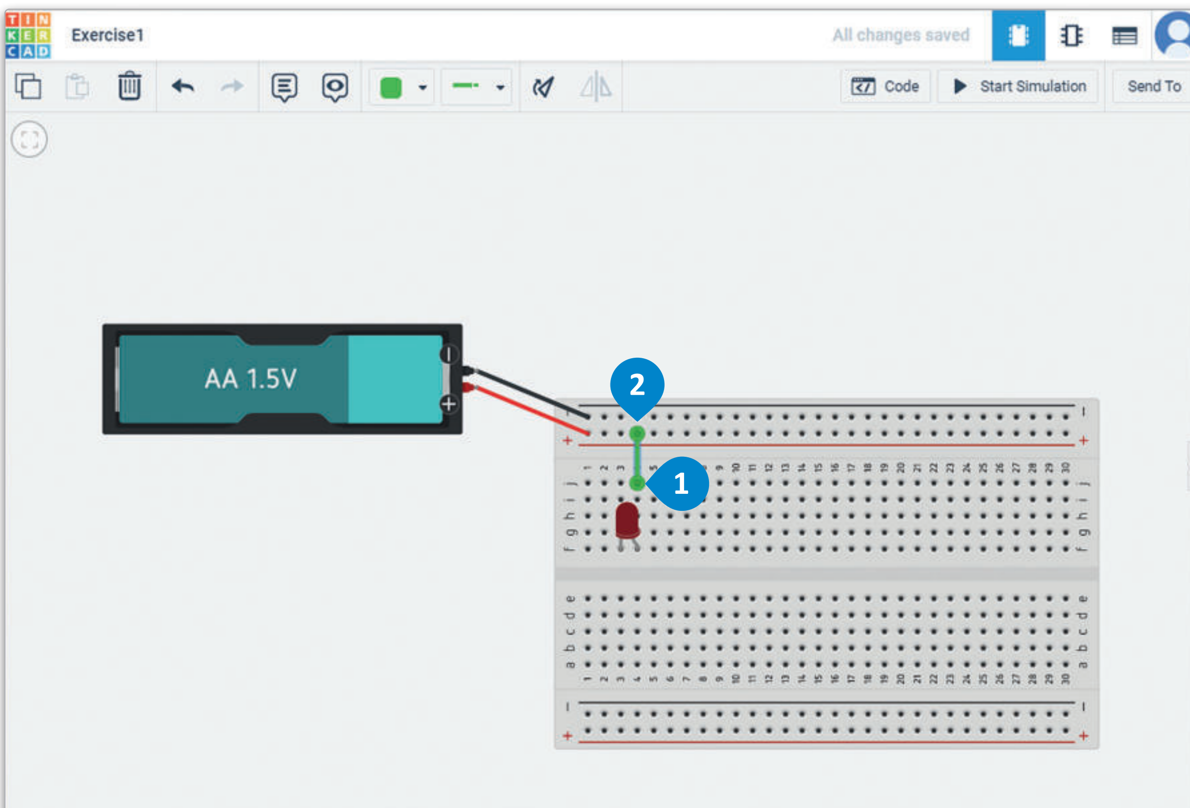
To close a circuit:

> Click on **Column 4 Row j** to begin a jumper wire. 1

> Connect the other end of the wire to the **positive column**. 2

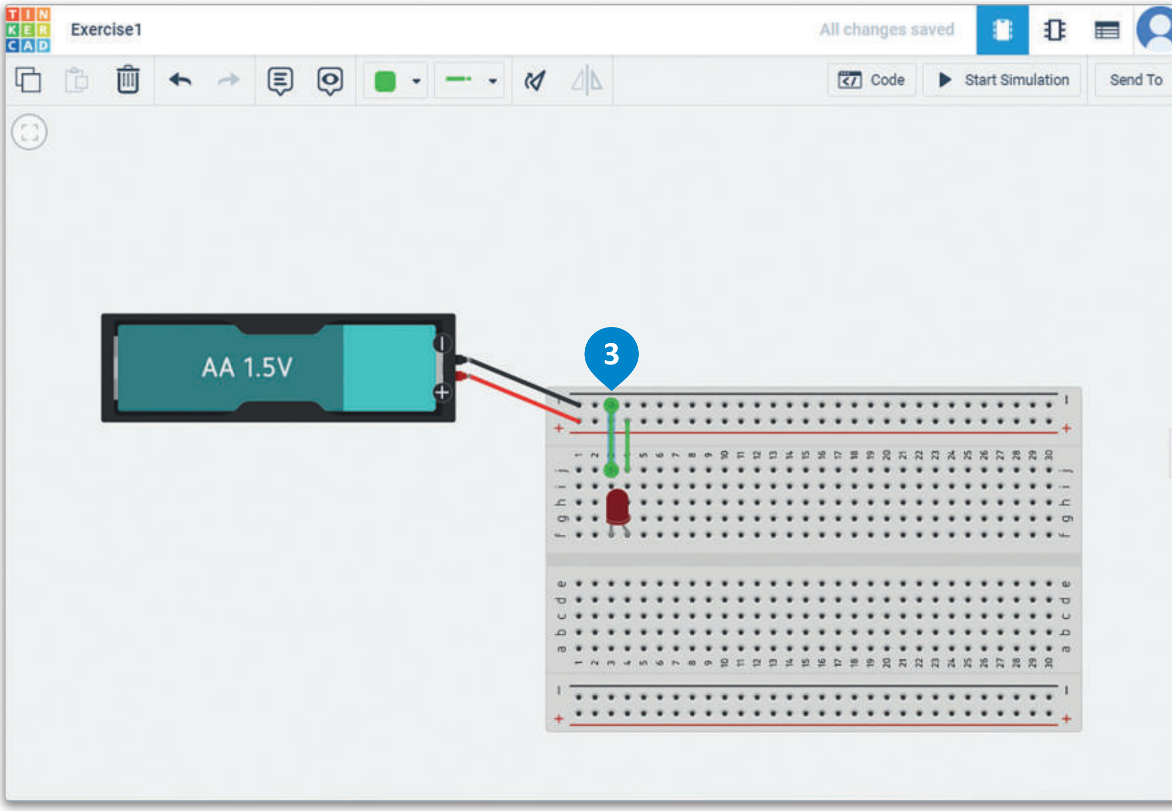
> Connect another wire from **Column 3 Row j**, to the **negative terminal column**. 3

> Change the color of the wires to match the polarities. 4



SMART TIP

The type of a selected wire can be changed to normal, alligator or hookup using the Wire type tool in the main toolbar.



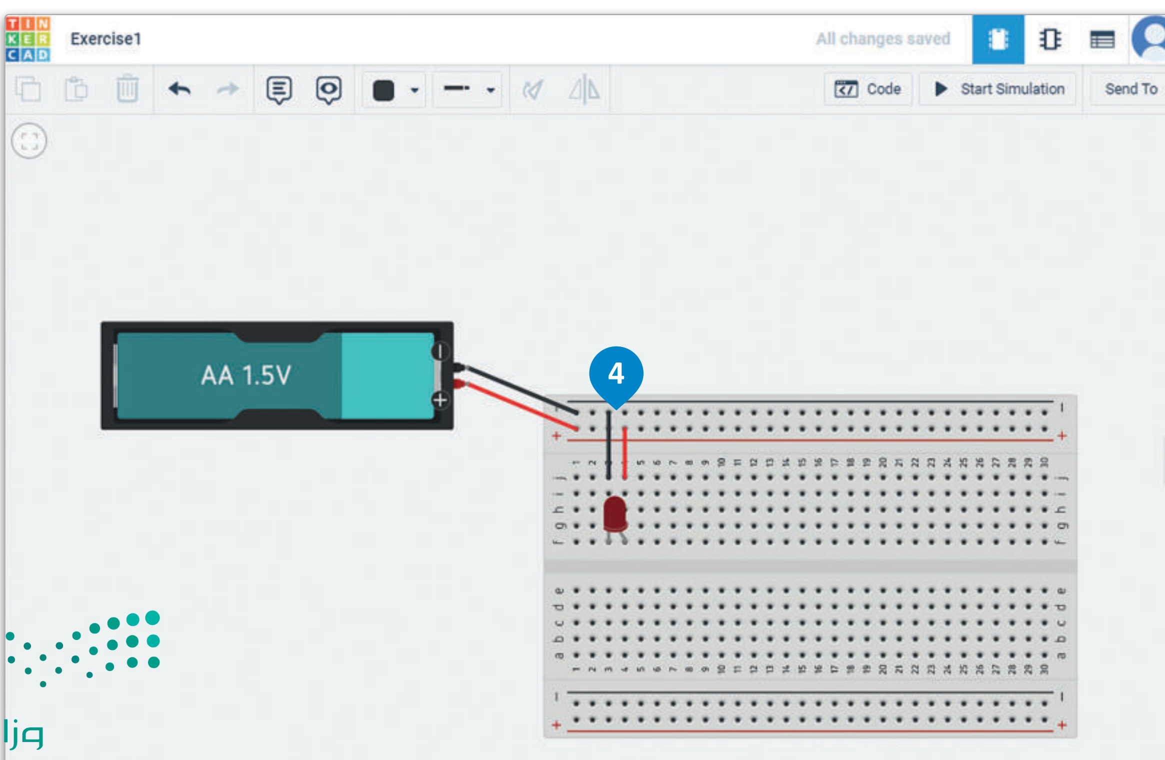


Figure 4.14: Close a circuit

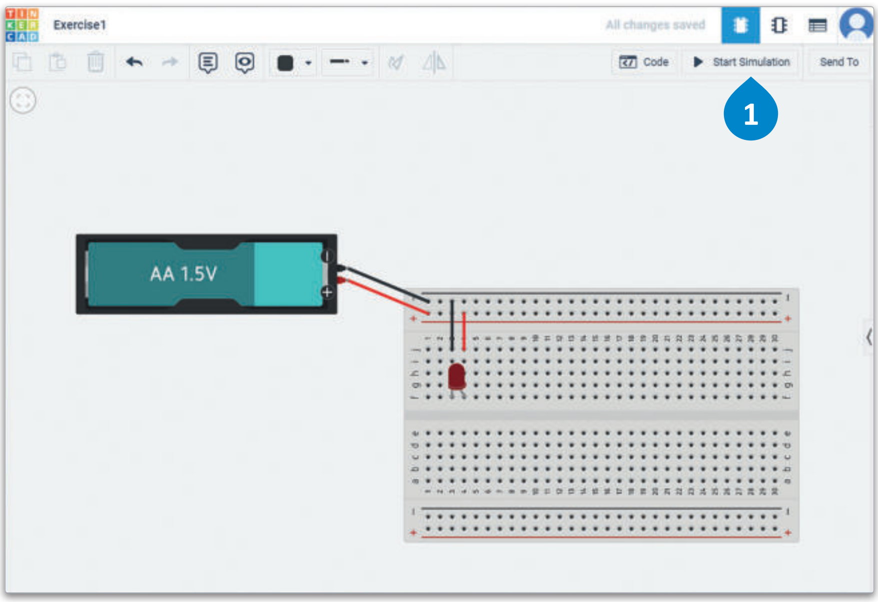
Nothing happens in the circuit editor until the simulation is executed. Simulation in Tinkercad Circuits simplifies the learning process. It is free, works on any computer with an Internet connection, and is suitable for any class size.

To run a simulation:

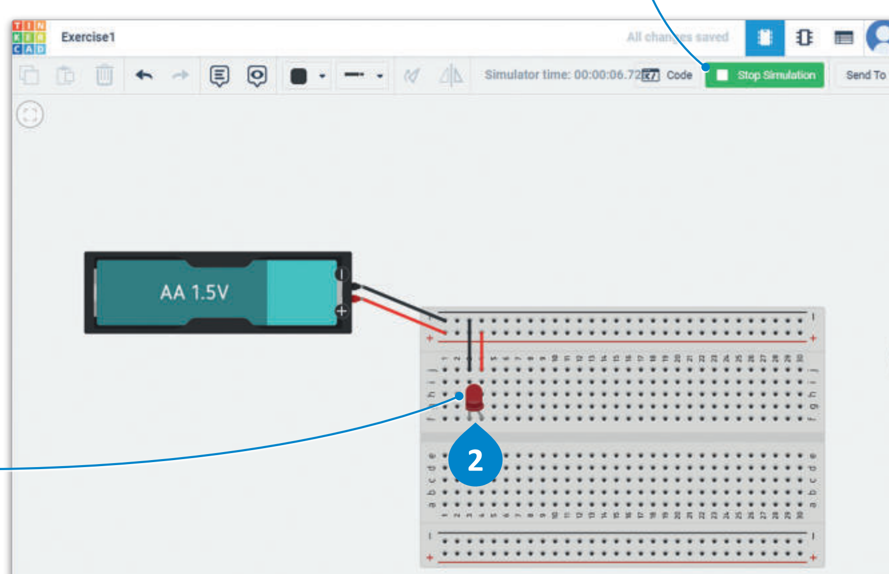
> In the Circuit View, click on **Start Simulation**. 1

> The LED on the breadboard will change to a lighter color to simulate that the LED has turned **ON**. 2

LEDs have a voltage limit. If the voltage is too high, the LED will burn out and stop working. In this case, a simulator is extremely helpful. We don't want the LED to burn out in a real-world application.



The Stop Simulation button stops the simulation so that the circuit can be edited.



The LED does not seem particularly bright. This is not due to the program but the voltage supplied to the LED. This battery supplies a low voltage.

Figure 4.15: Run a simulation

Simulations allow us to experiment with circuit development. In this case, we will edit the power source to test the circuit.

To edit and test a circuit:

> Click the **battery** once to select it. 1

> Go to the inspector panel and click **Count**. 2

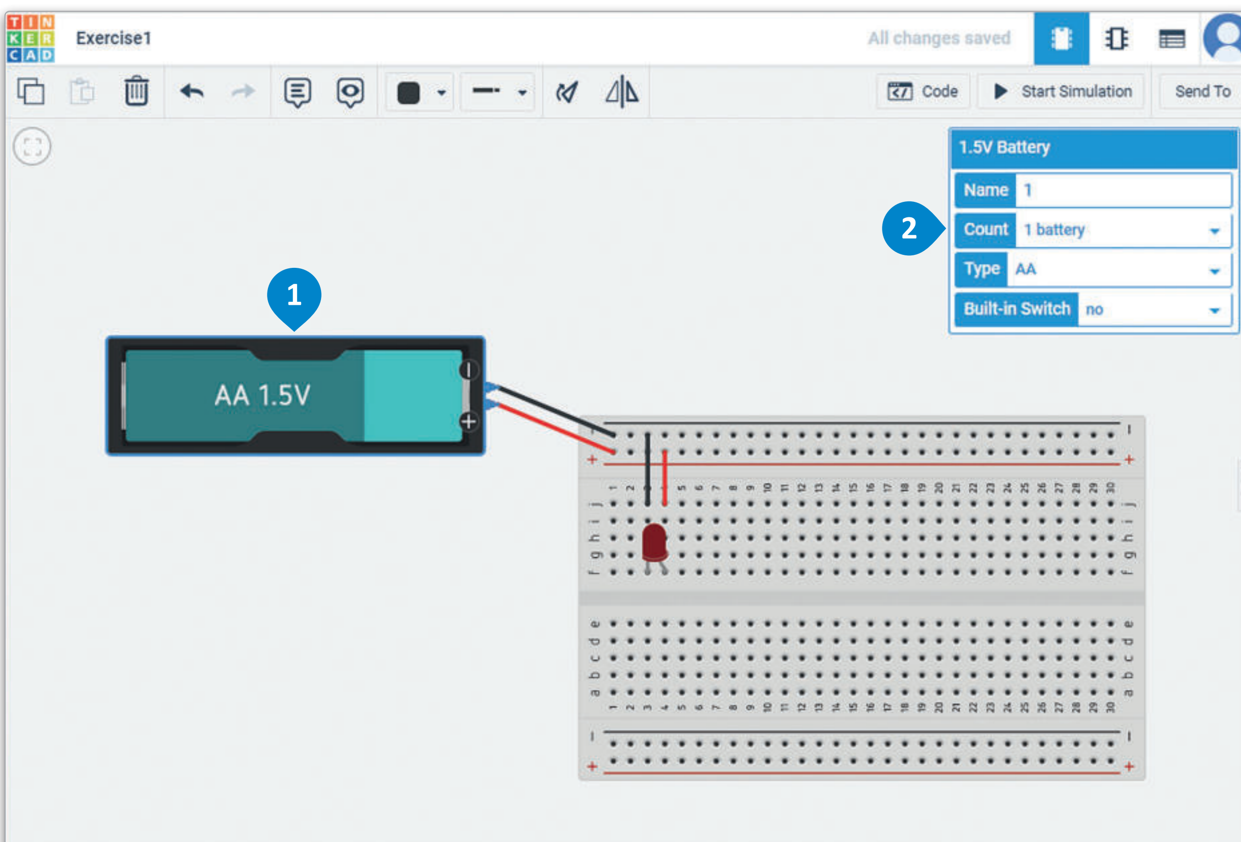
> Click **2 batteries**. 3

> Click **Start Simulation**. 4

> The **star** over the LED indicates that the LED blew out. 5

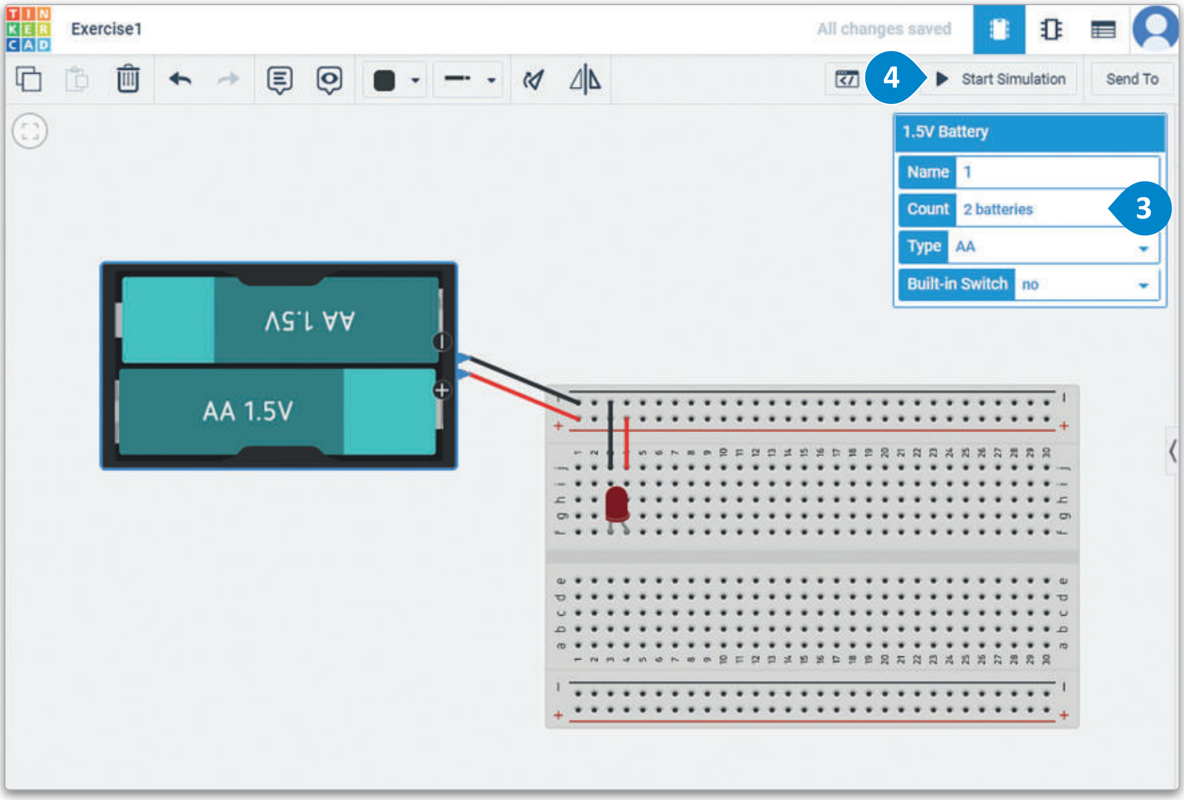
> Click **Stop Simulation**, 6 and change the number of batteries to **1 battery**. 7

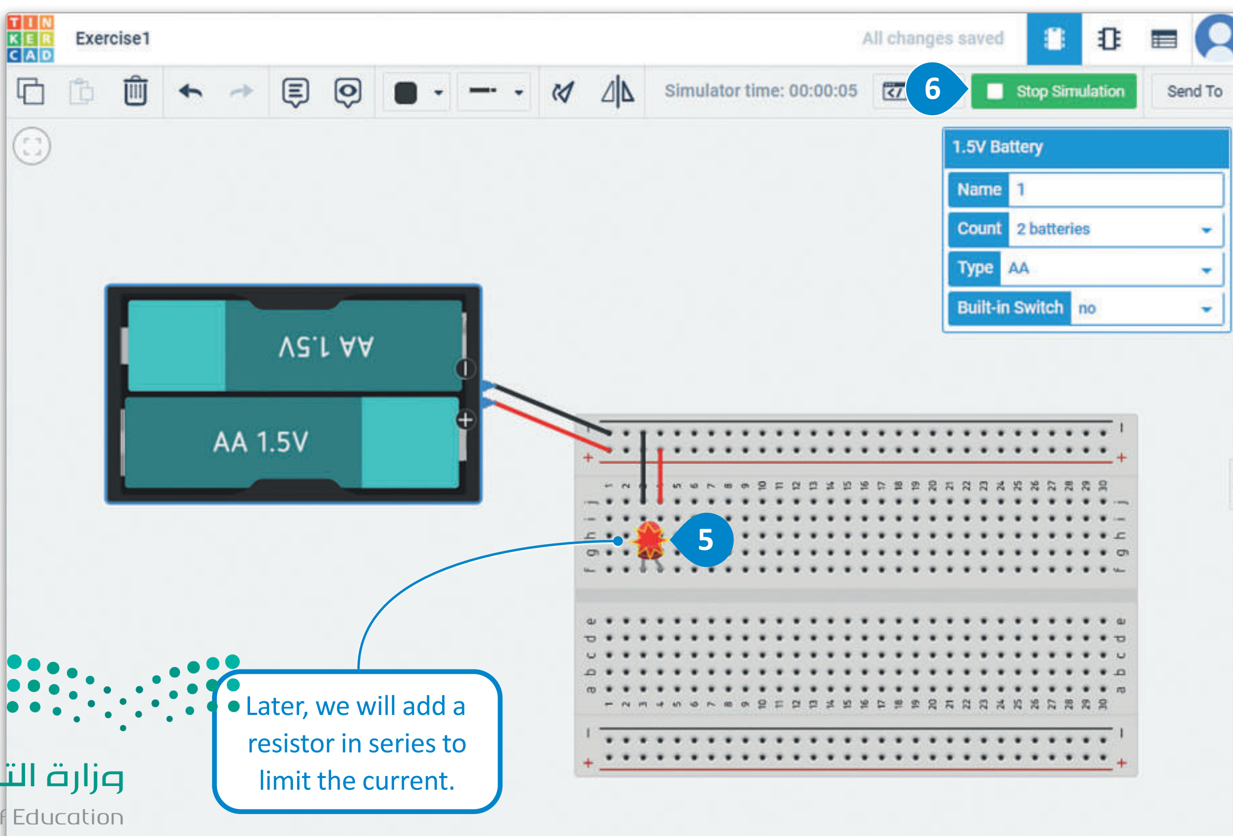
> Click **Start Simulation** again, 8 to verify that the circuit is functioning normally.



SMART TIP

You can activate the commands Start Simulation and Stop Simulation with the **S** key on your keyboard.


Exercise1
All changes saved
4
Start Simulation
Send To
1.5V Battery
Name 1
Count 2 batteries
3
Type AA
Built-in Switch no
AA 1.5V
AA 1.5V


Exercise1
All changes saved
Simulator time: 00:00:05
6
Stop Simulation
Send To
1.5V Battery
Name 1
Count 2 batteries
Type AA
Built-in Switch no
AA 1.5V
AA 1.5V
5
Later, we will add a resistor in series to limit the current.

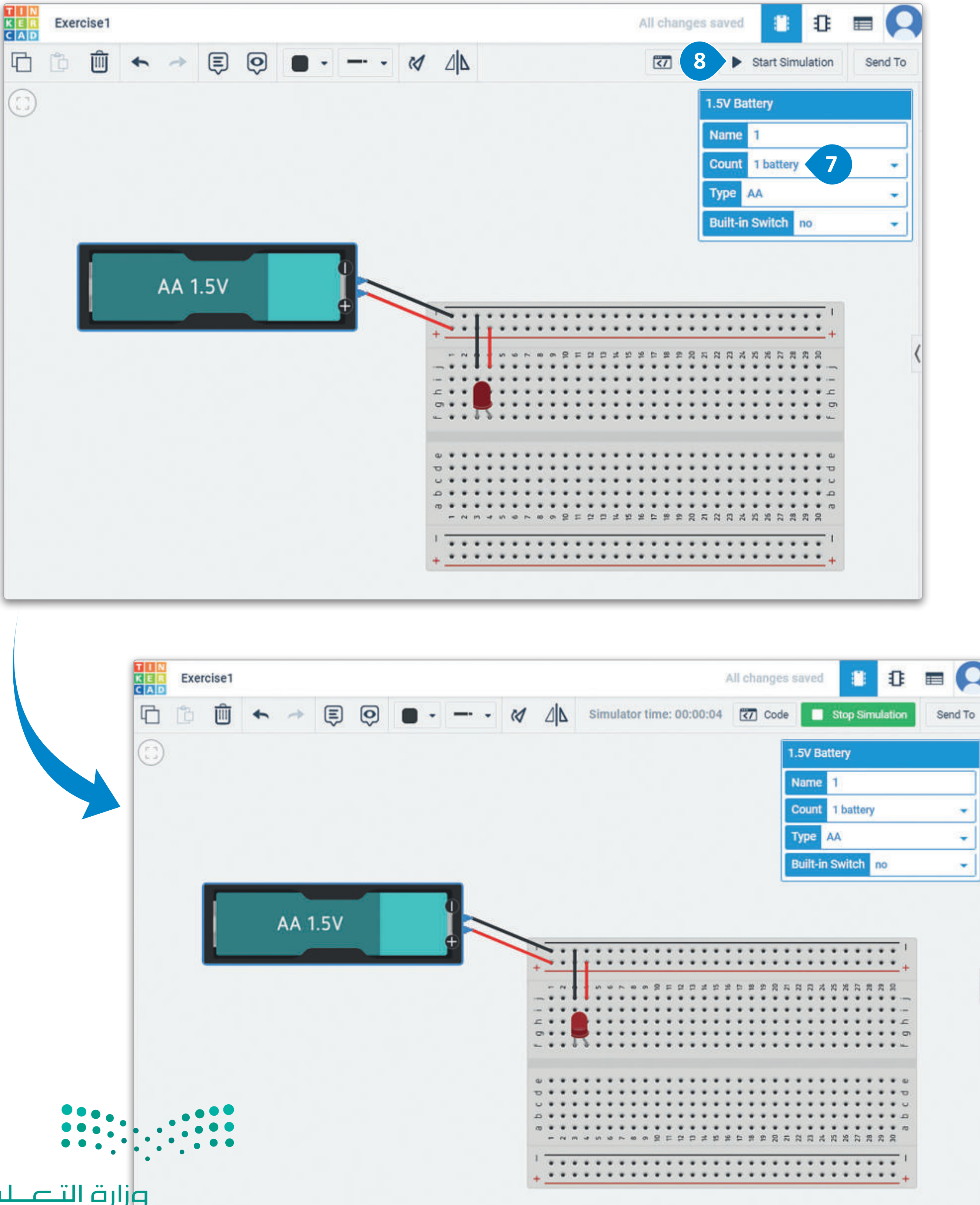


Figure 4.16: Edit and test a circuit

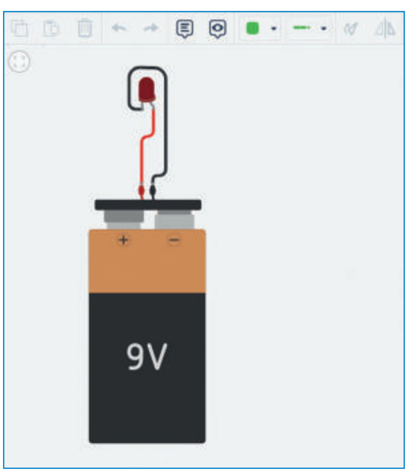
Exercises

1

Read the sentences and tick ✓ True or False.	True	False
1. Tinkercad Circuits is a web-based simulator.		
2. You can build and simulate an electrical circuit with Tinkercad Circuits.		
3. Tinkercad Circuits is used by engineers to build advanced computer designs.		
4. Resistors, power sources and LEDs are the only components you can use in Tinkercad Circuits.		
5. The Component List displays all the components of the designed circuit.		
6. It is better to use the same color for all wire connections.		
7. Power rails are columns along the left and right sides of the breadboard marked with [+] and [-] labels.		
8. The black wire (Ground Wire) carries the return current back to the energy supply.		
9. The red wire (Live Wire) carries the current from the power source.		

2 Briefly explain what prototyping is.

3 Design the following circuit using Tinkercad Circuits. Run the simulation. Note if it works correctly and if not, what corrections need to be made. Fix the circuit in the application. Which basic principle does the circuit describe?



4 Search the Internet for applications similar to Tinkercad Circuits. Compare them and write down your conclusions.

5 What are the advantages of Tinkercad Circuits? Justify your answer.

6 What limitations do you observe when using Tinkercad Circuits?

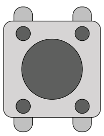
Troubleshooting and Measurements

Link to digital lesson

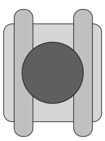
www.ien.edu.sa

To begin, we will build a circuit that includes a power source, an LED, and a pushbutton. Let us examine how the pushbutton works.

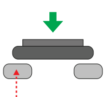
The Pushbutton



The pushbutton serves as a temporary connection. It has a large circle in the center that closes the circuit. There are four connectors on the pushbutton. Each corner of the button has a connector.

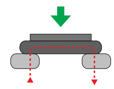


Looking at the underside, we can see that the left and right connectors are actually two wires. There is one wire on each side of the button.

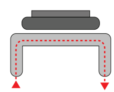


Looking at the pushbutton from the front, we can see that it hovers over the two wires with a spring.

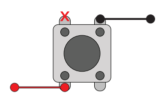
The spring is not visible in the illustration. Electric current cannot flow through the circuit when the pushbutton is above the wires. In the illustration, the electric current is represented by the red dashed arrow pointing up.



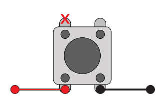
The circuit closes when the pushbutton is pressed, and current flows from one side of the pushbutton to the other.



Looking from the side, when we connect a circuit to the ends of one wire on one side of the switch, that wire inside the switch allows current to flow even when the button is not pressed.



When connecting components, we must ensure that they are connected to opposing sides of the switch. As shown in the illustration on the right, a connection can be made at diagonally opposite ends.



A connection can also be made at neighboring opposite ends, as shown in the image on the left.

It is critical to connect the correct ends of the pushbutton to ensure that the circuit works properly.

A pushbutton on a circuit is typically used to open and close the circuit. We will use the same circuit as in the previous lesson, but this time we will add a pushbutton. This is the previous lesson's circuit:

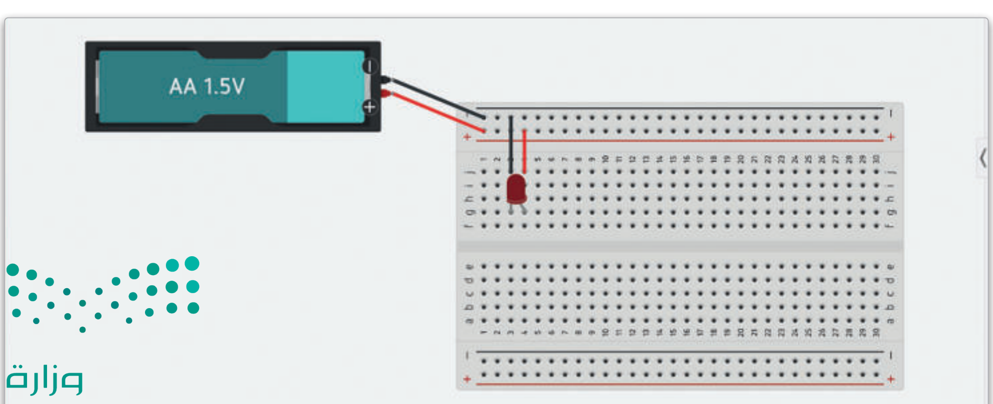


Figure 4.17: Circuit with battery and LED

To add a pushbutton to the circuit:

> On the components panel, click **Pushbutton**. 1

> Click and place the pushbutton on the breadboard so that one end is in **Row f**, and the other end is in **Row e**. 2

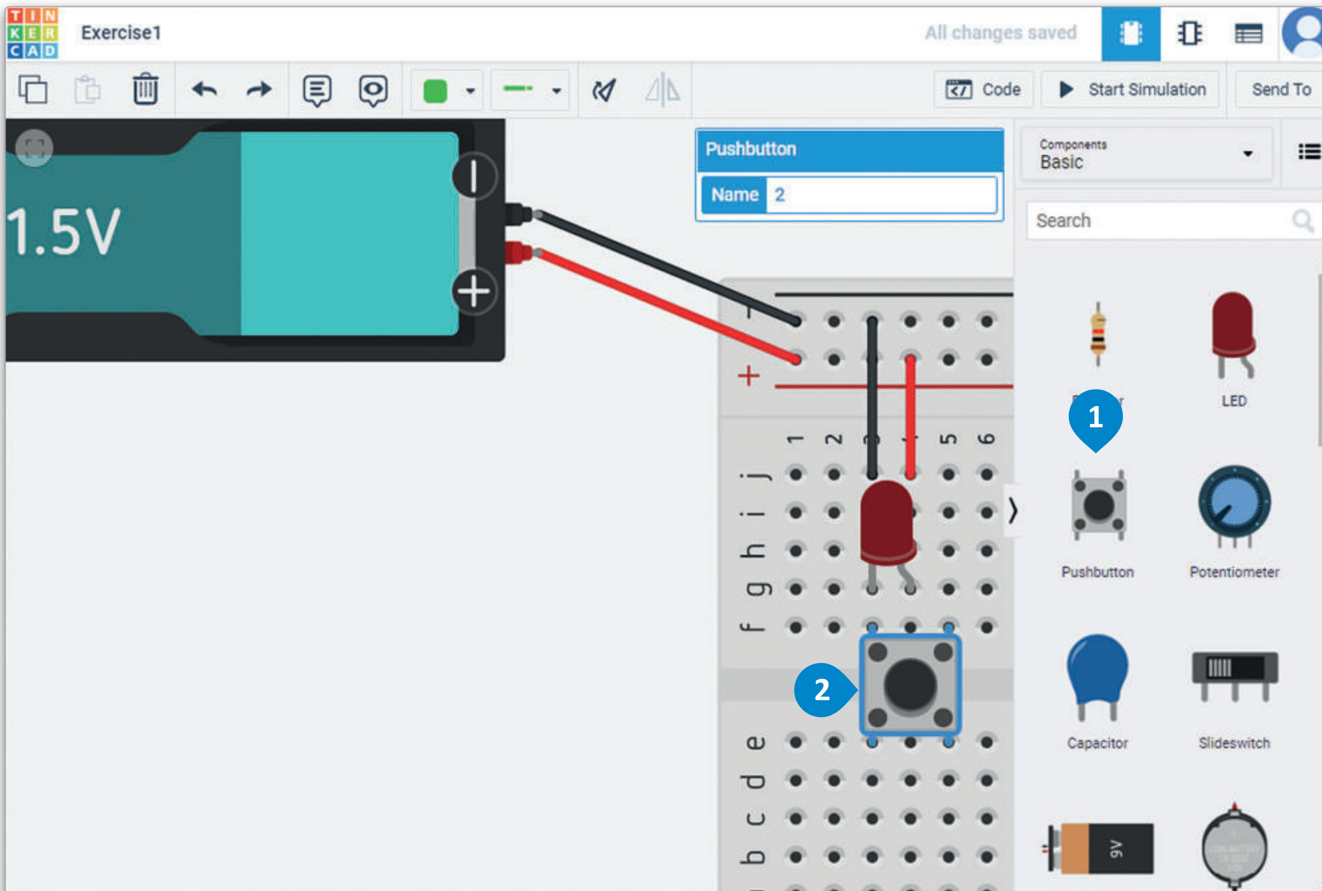


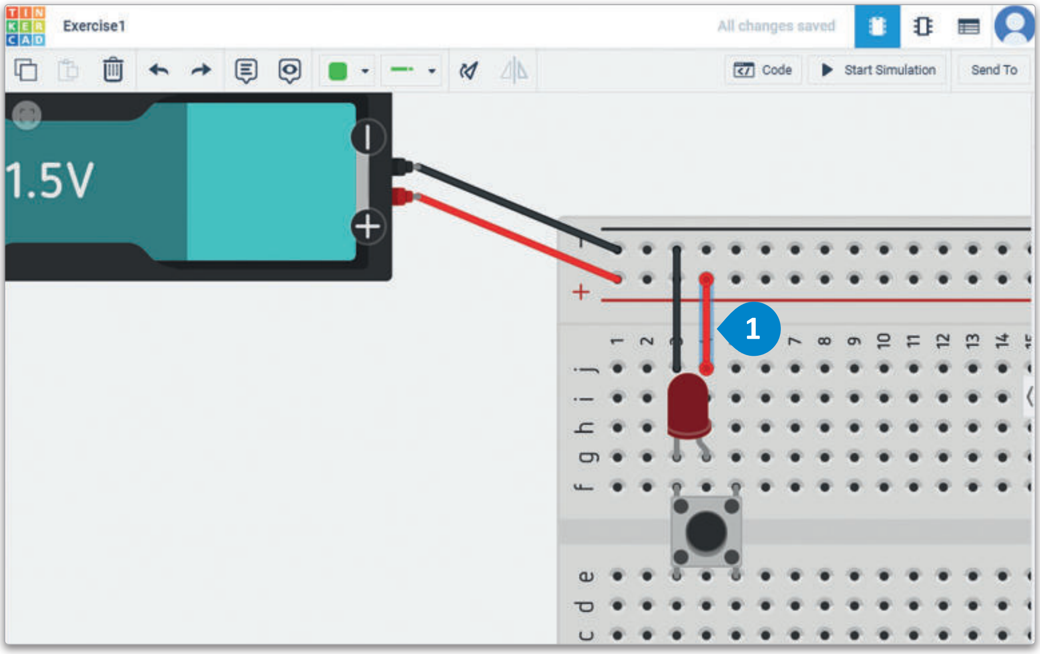
Figure 4.18: Add a pushbutton to the circuit

The diagonal terminals in this switch represent the switch's opposite ends. This indicates that current will flow from e5 to f3. The pushbutton will be included in the closed circuit. Placing the pushbutton on f3, one end of the connector forms part of our closed circuit. Keep in mind that everything in a numbered column is linked. This means that the pushbutton is wired to one end of the LED and the jumper wire running from j3 is wired to the negative rail. We must move the jumper wire from the positive terminal to the opposite side of the pushbutton. This will complete the circuit.

To delete a wire using the keyboard:

> Click on the **positive terminal jump wire** to select it. 1

> Press **Delete** or **Backspace ⟵** and the wire will be deleted. 2



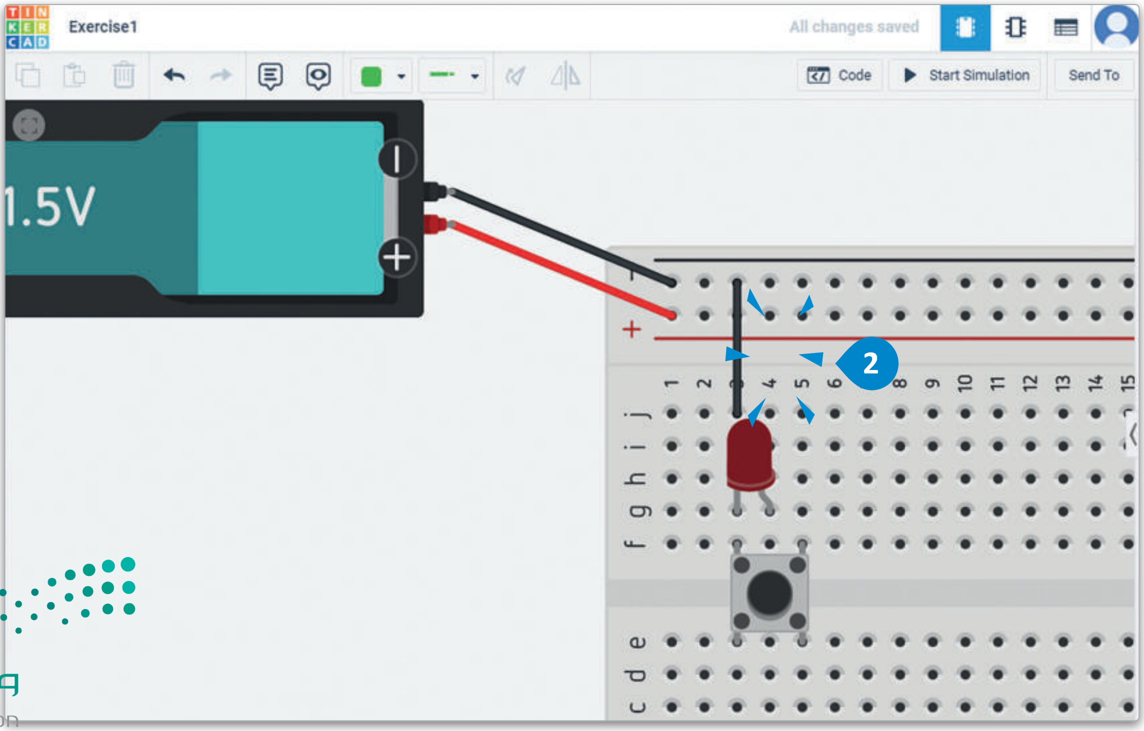


Figure 4.19: Delete a wire using the keyboard

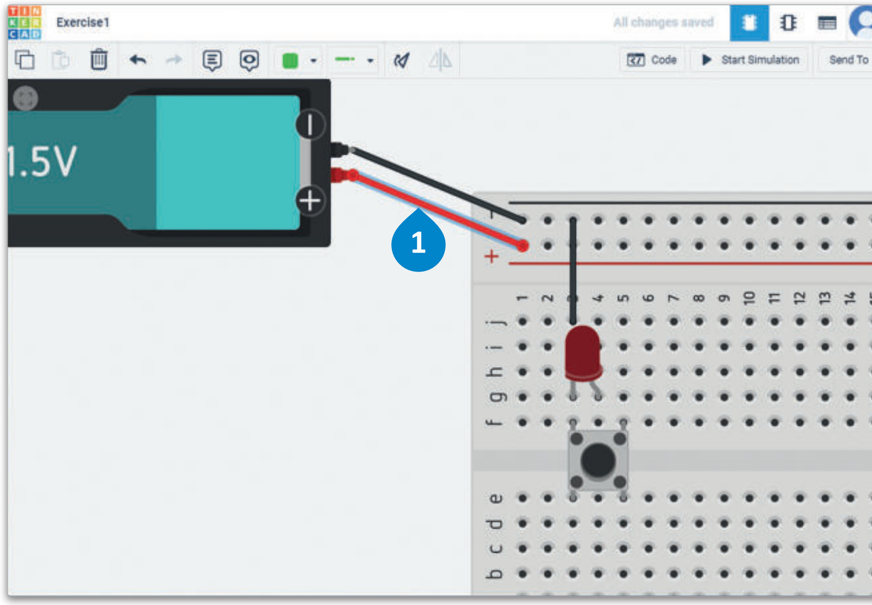
The positive connection has to be made on the other side of the button. Both sides of the breadboard have positive and negative rails. We will connect the positive end of our battery to the other side of the breadboard.

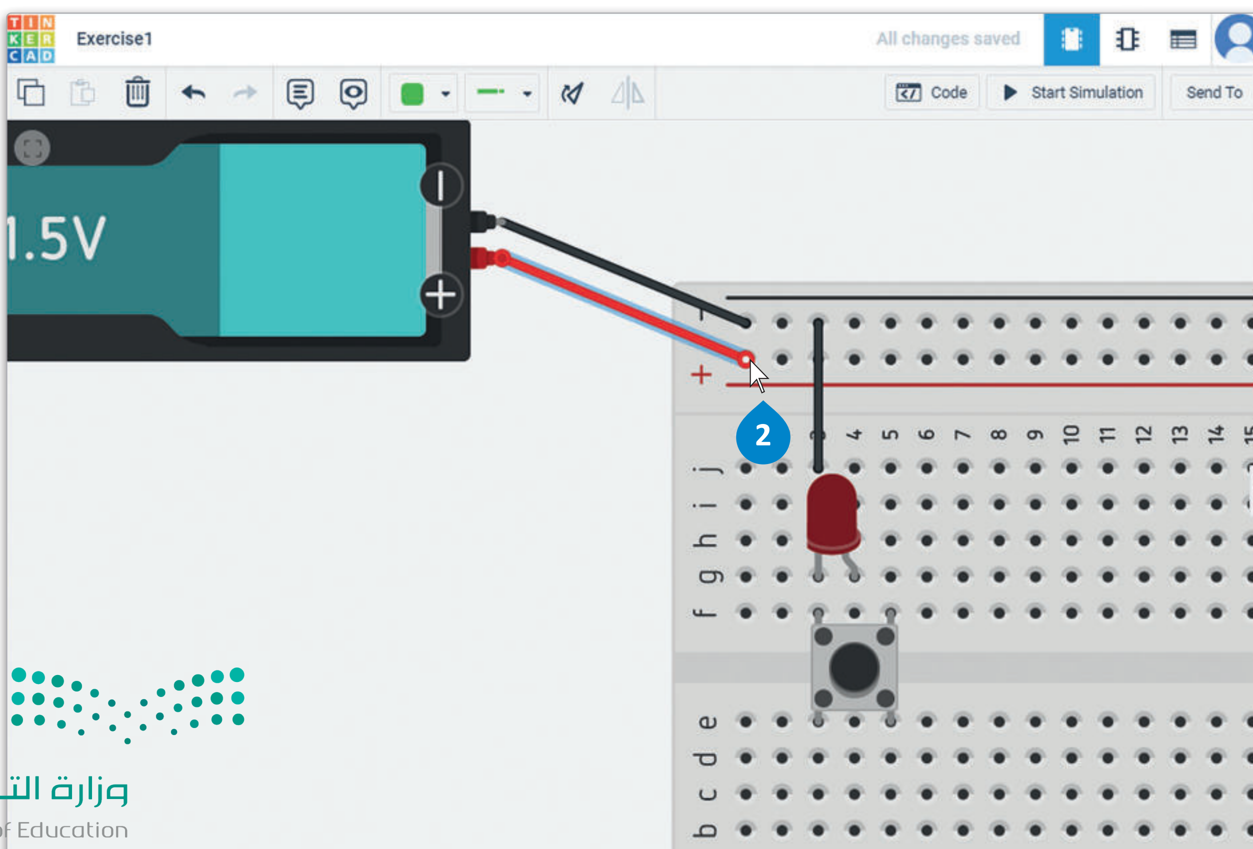
To detach and move a wire:

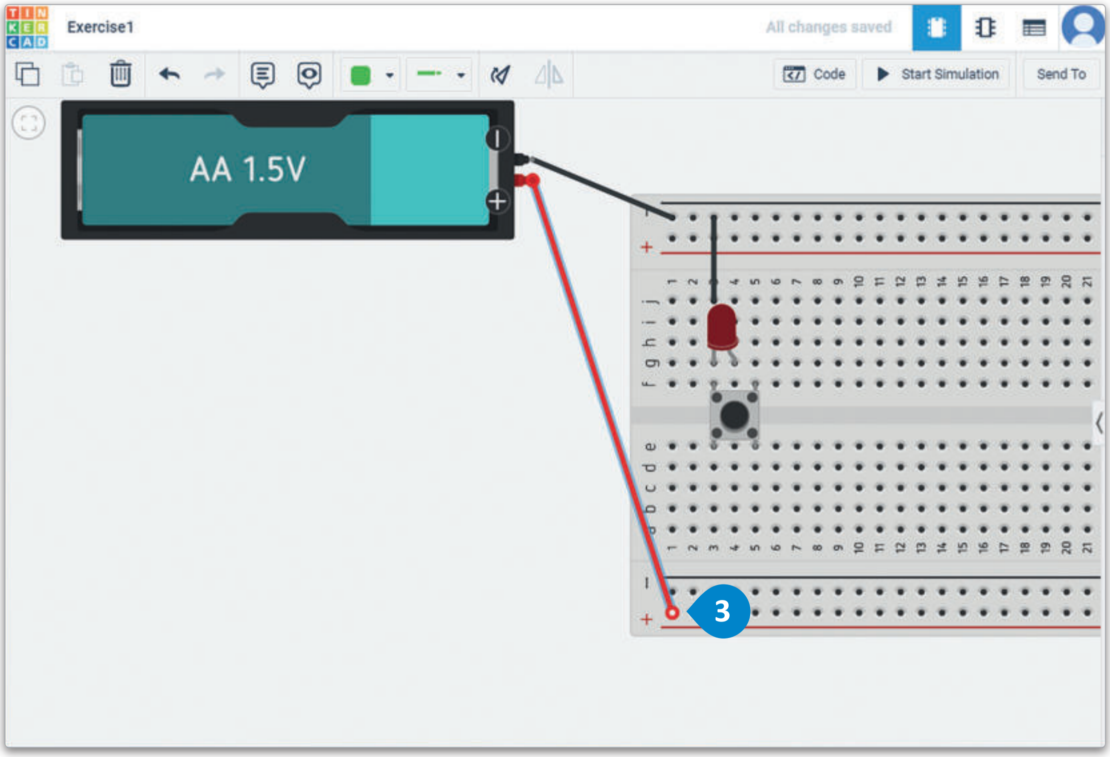
> Click on the **positive terminal wire** to select it. 1

> Move the mouse pointer to the end of the wire that is connected to the breadboard and when a **white dot** appears, click on it to **detach the wire**. 2

> Click and drag to place the end of the wire on the other side of the breadboard and connect it to the positive rail. 3







Next we have to connect the anode on the LED with the positive connection of the electric current flow, so that the LED turns ON.

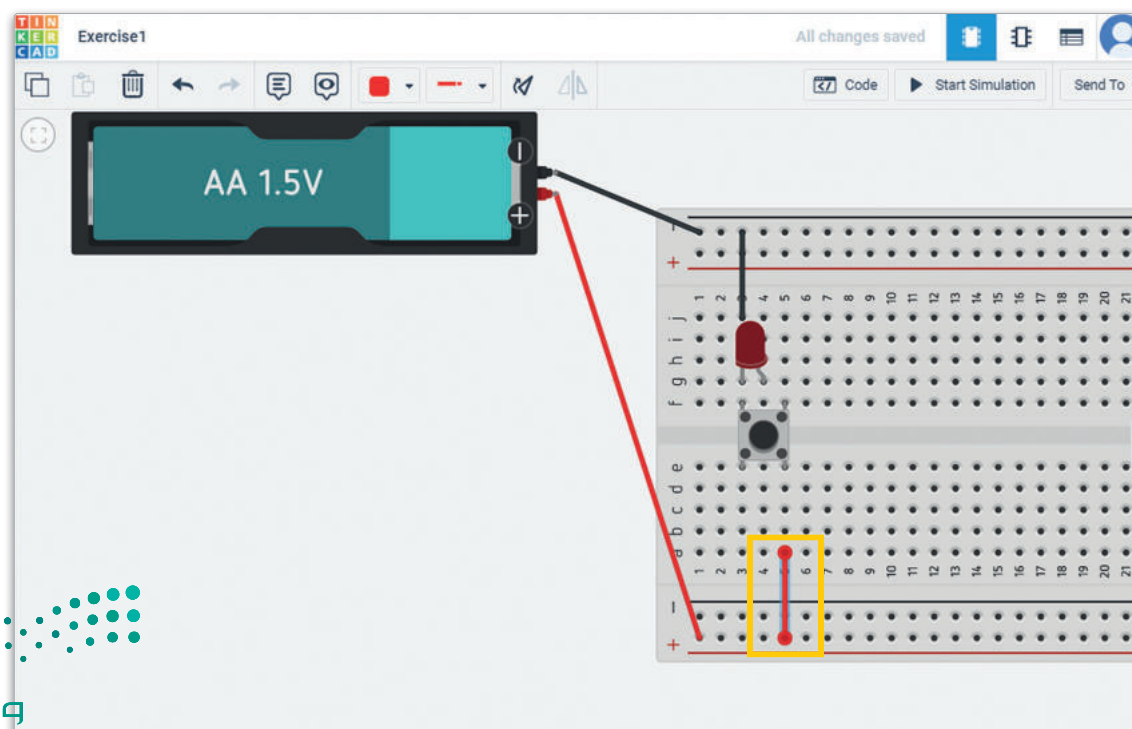


Figure 4.20: Detach and move a wire

Troubleshooting

Circuit simulation is a technique where we simulate the behavior of an electronic circuit or a whole system with the assistance of a software application. New designs can be tested, evaluated and diagnosed without physically constructing the circuit. Through simulation, we can also troubleshoot and gather data before building a real prototype with electronic components. This allows the engineer to determine the correctness and efficiency of a design beforehand. The engineer may also explore alternative designs without using any physical components, at no cost and much faster than with a real prototype. There is an infinite quantity of simulated components available to build and test alternative designs.

Like other electronic circuits, LED circuits are very sensitive to current. An LED burns out if more current flows than its rated current, for example 20mA. An appropriate resistor must be used to protect the LEDs, or the whole circuit, from burning out. Tinkercad Circuits shows you if more than the rated current flows through the circuit elements when you run the simulation. The program alerts you by showing a red star on top of the component that has a problem.

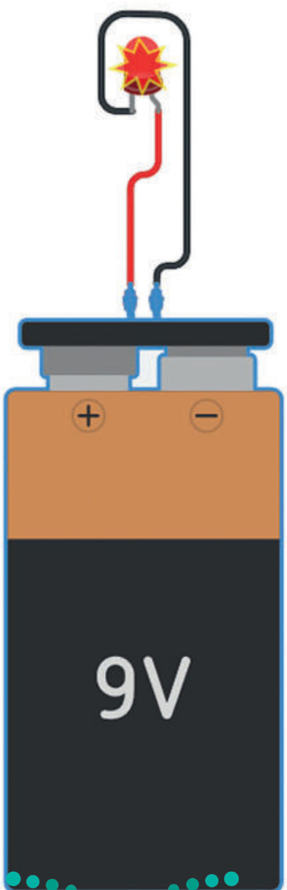
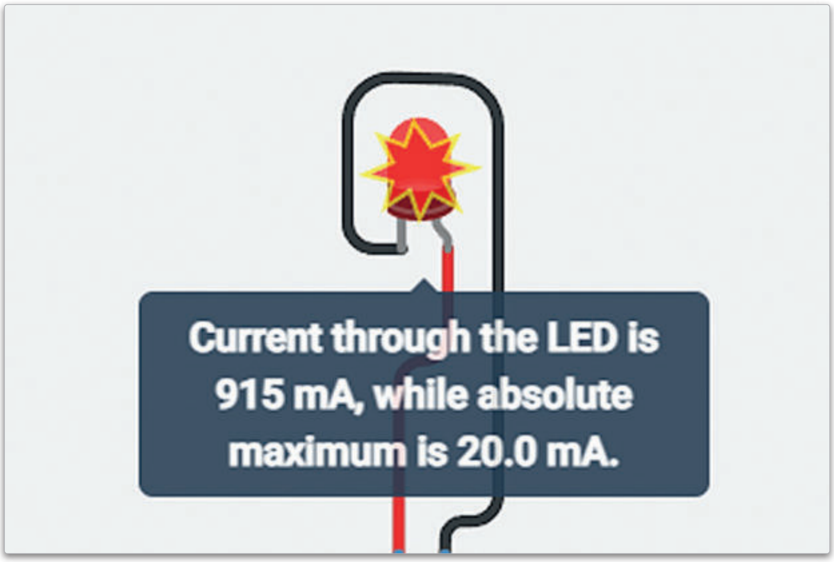
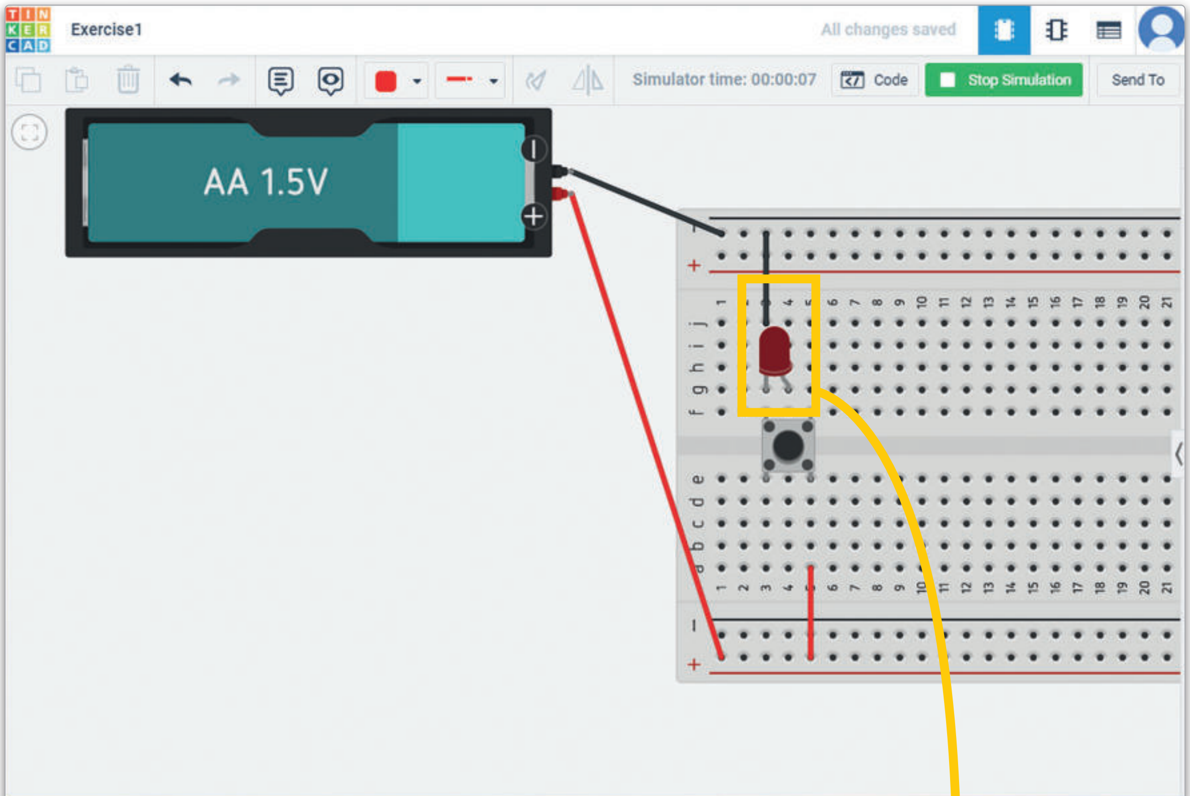


Figure 4.21: Simulation with a current issue

Hover over the red star for an explanation of the problem.



Now let's go back to the electronic circuit that we have constructed with a battery, an LED and a pushbutton. We want to test if the circuit works properly. When we simulate the circuit and press the pushbutton, we observe that the LED does not light up.



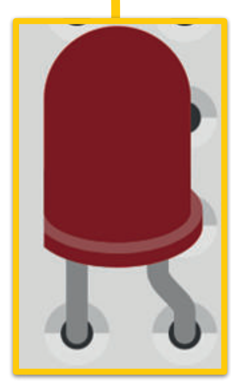
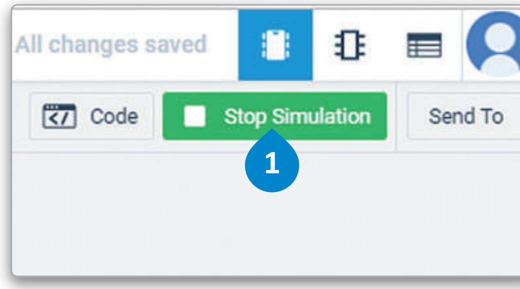


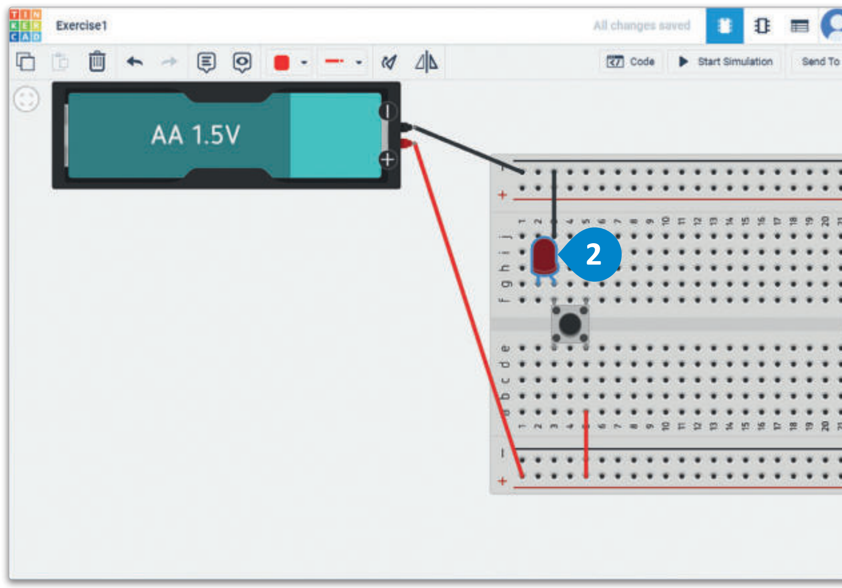
Figure 4.22: Circuit with a component connected inaccurately

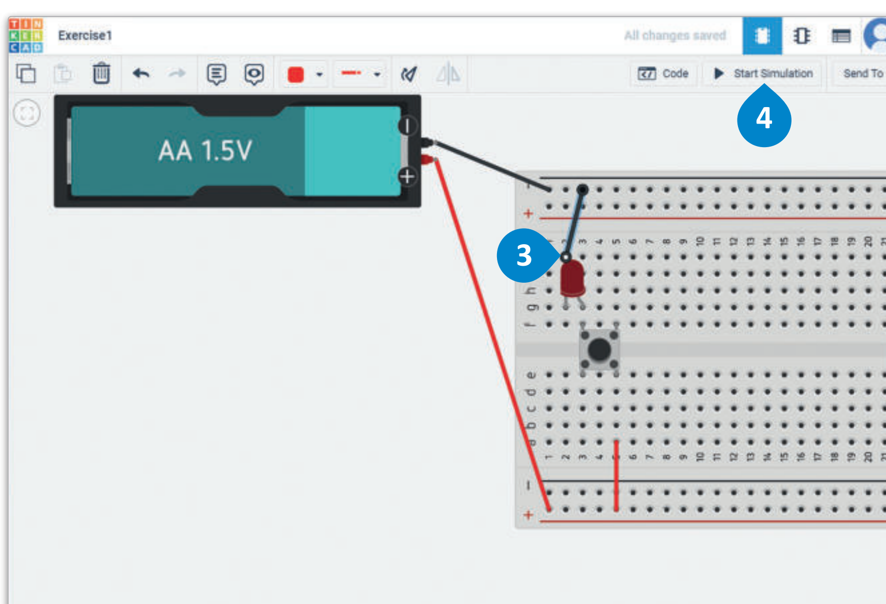
The circuit is not working properly. We have to connect the anode on the LED to the positive connection of the electric current flow. We cannot move components while the simulation is running.

To modify and test the operation of a circuit:

> Click **Stop Simulation.** 1
> Move the **LED** to **Column 2.** 2
> Click once on the **jumper wire** and move one end so it connects to the **cathode of the LED.** 3
> Click **Start Simulation.** 4
> Press the **pushbutton.** 5
> Check that **the LED** remains lit while the pushbutton is pressed. 6
> Release the **pushbutton** and the LED will turn **OFF.** 7







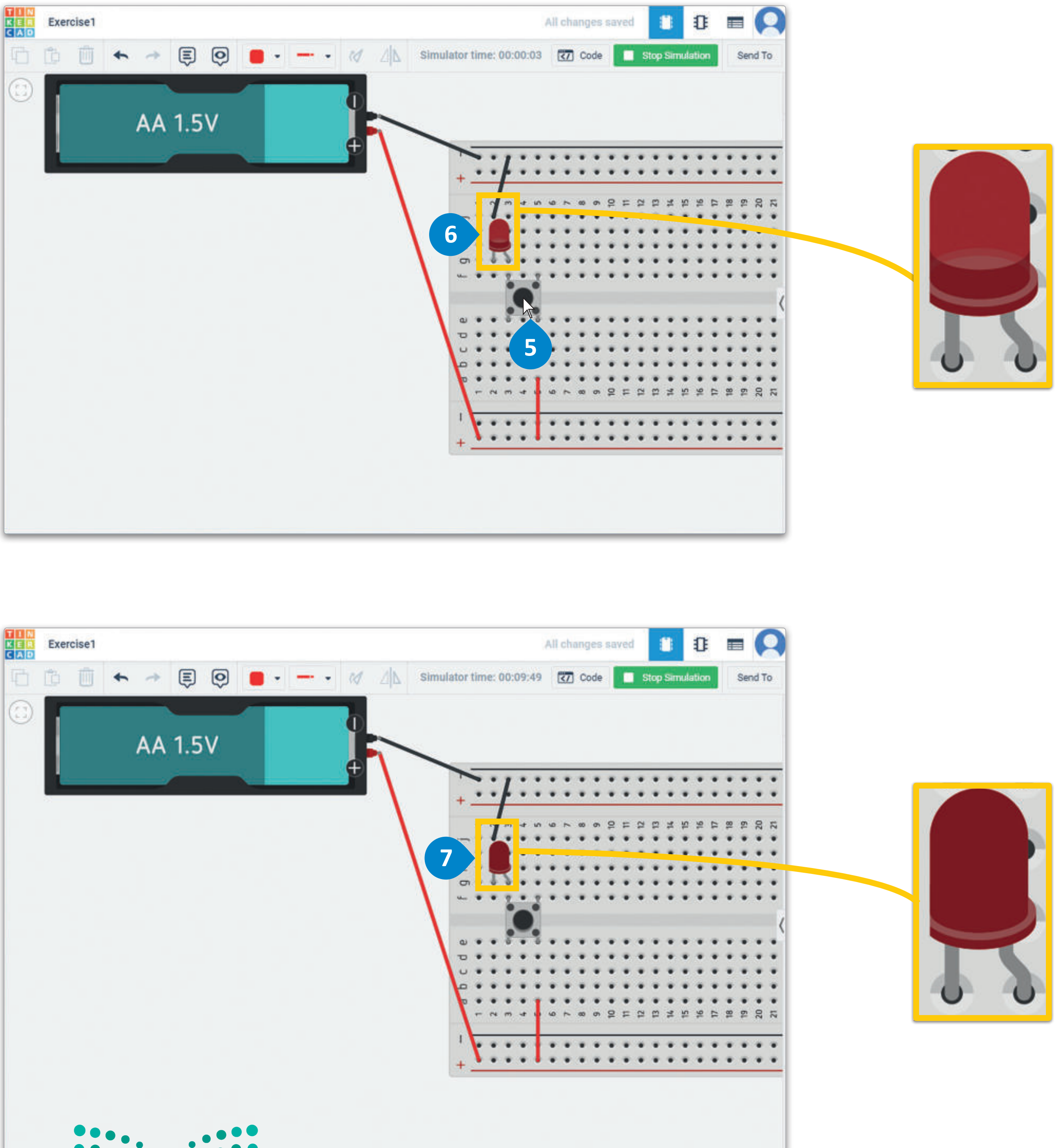


Figure 4.23: Modify and test the operation of a circuit

Circuits with Resistors

In this part of the lesson, we will create two identical circuits in the same workspace of Tinkercad Circuits: one without the breadboard and one with the breadboard. We will use these circuits later in the lesson to gain a better understanding of current, resistance and voltage. In both cases, we will build a simple LED circuit with a battery, an LED and a resistor. First we will design an LED circuit without the breadboard. We have to go to the Tinkercad dashboard by clicking on the Tinkercad logo, and create a new circuit.

Create a new circuit:

> From the components panel, click on **Resistor**, 1 and place it on the workplane. 2

> From the inspector panel of the resistor set the **Resistance** to **47Ω**. 3

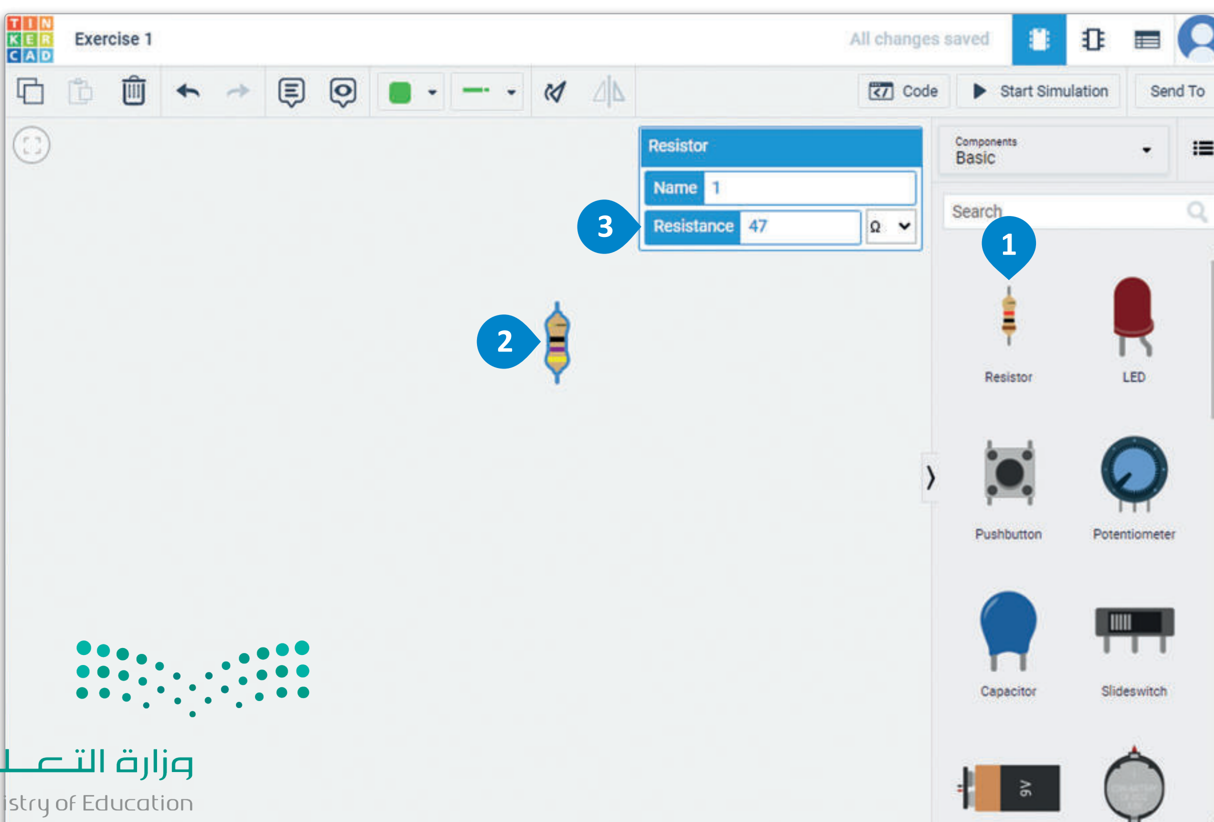
> Click on the **LED**, 4 and place it on the workplane. 5

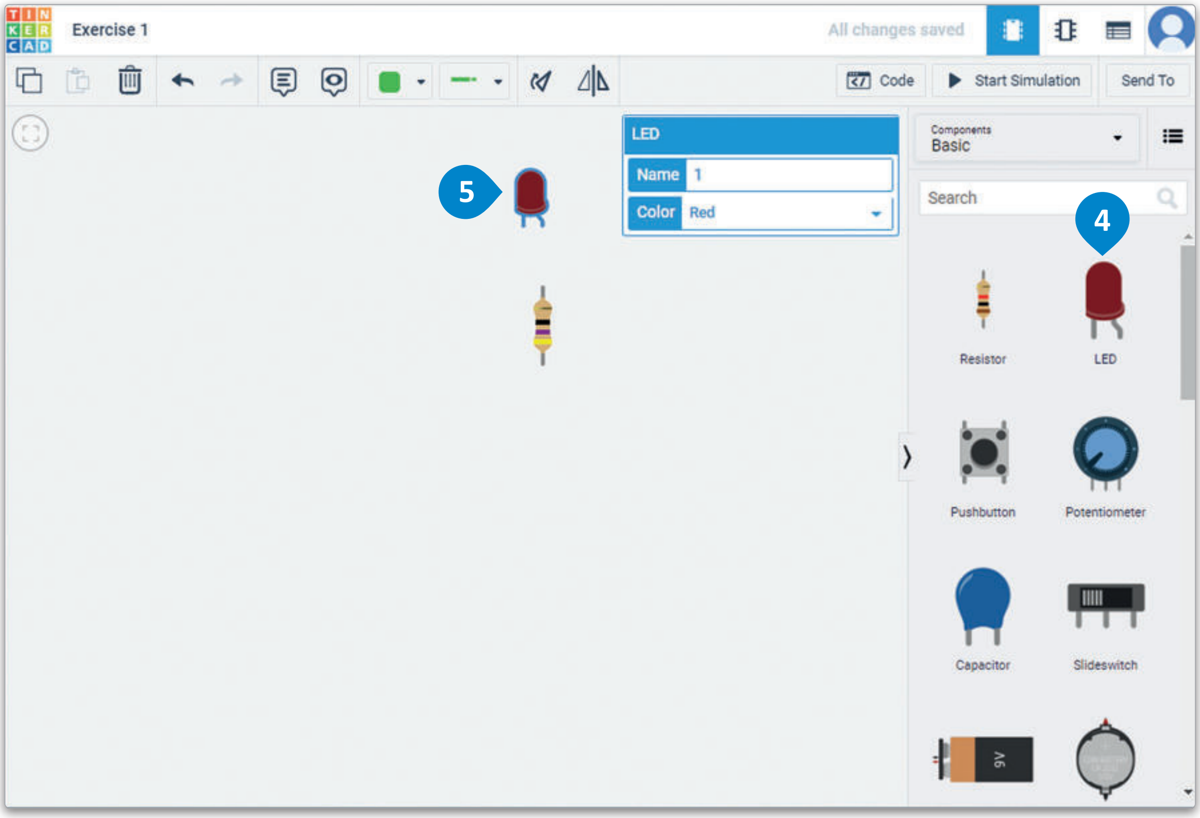
> Click on the **1.5V Battery**, 6 and place it on the workplane. 7

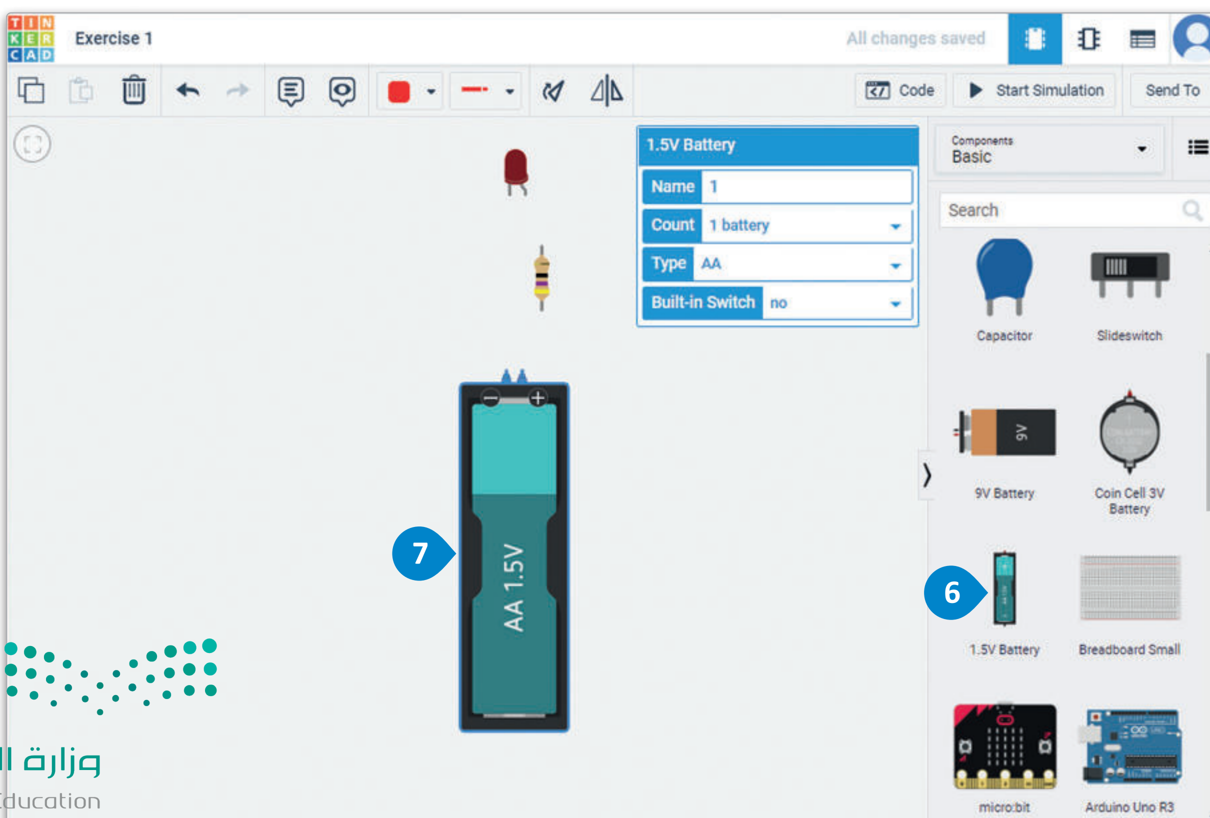
> From the **inspector** panel, of the **1.5V Battery**, set the **Count** to **2 batteries** to supply the circuit with 3V. 8

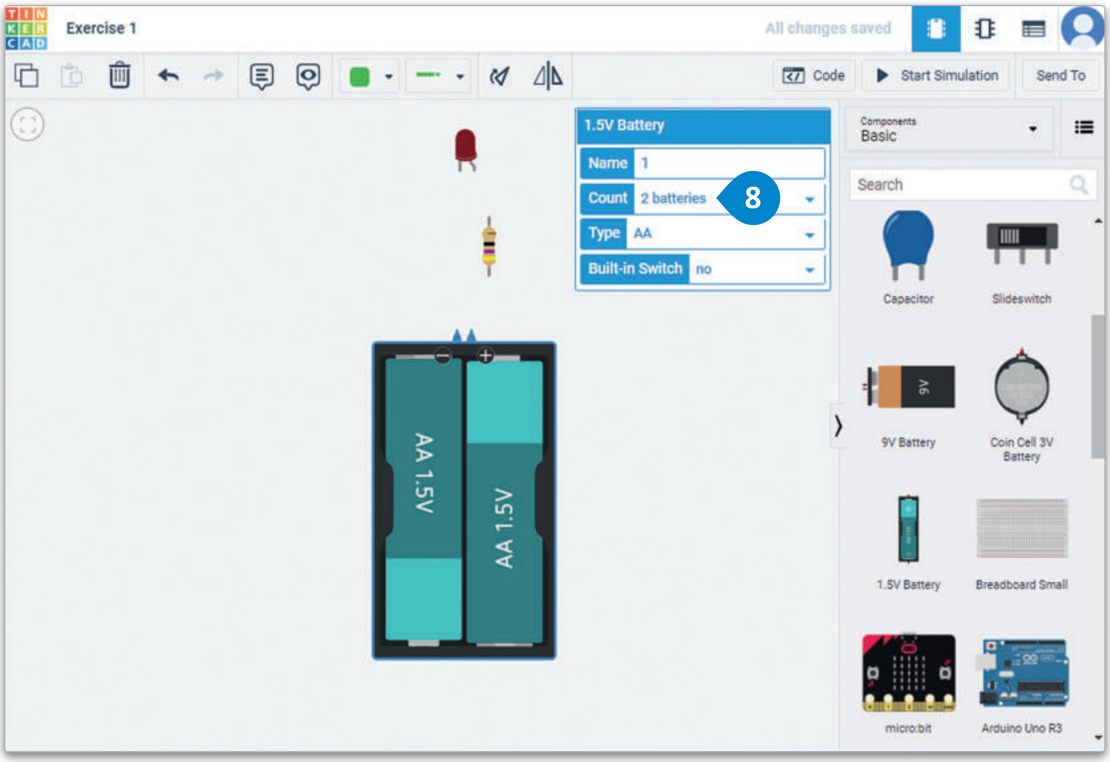
> Wire up the circuit, 9 and start the simulation.

The circuit has a 3V battery, and an LED with a forward voltage (voltage drop) of approximately 2.06V. The LED's ideal forward current is 20mA. To calculate the resistor value in Ohms, we use the formula R = (Vsource - Vdrop) / Iforward which tell us that the resistance has to be 47Ω.




Exercise 1
All changes saved
Code
Start Simulation
Send To
LED
Name 1
Color Red
Components
Basic
Search
5
4
Resistor
LED
Pushbutton
Potentiometer
Capacitor
Slideswitch


Exercise 1
All changes saved
Code
Start Simulation
Send To
1.5V Battery
Name 1
Count 1 battery
Type AA
Built-in Switch no
Components
Basic
Search
AA 1.5V
7
6
Capacitor
Slideswitch
9V Battery
Coin Cell 3V Battery
1.5V Battery
Breadboard Small
micro:bit
Arduino Uno R3



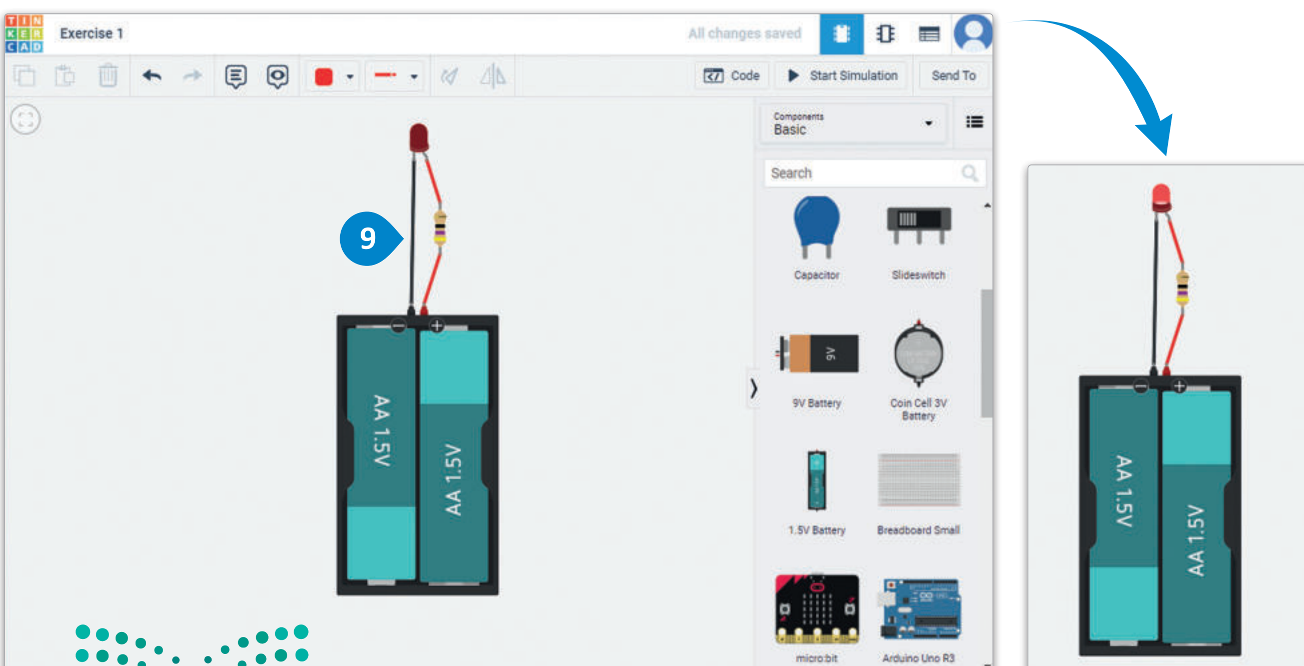


Figure 4.25: Create a new circuit

To continue, we will design an LED circuit on a breadboard. Go to the Tinkercad dashboard by clicking on the Tinkercad logo, and create a new circuit.

Create a new circuit:

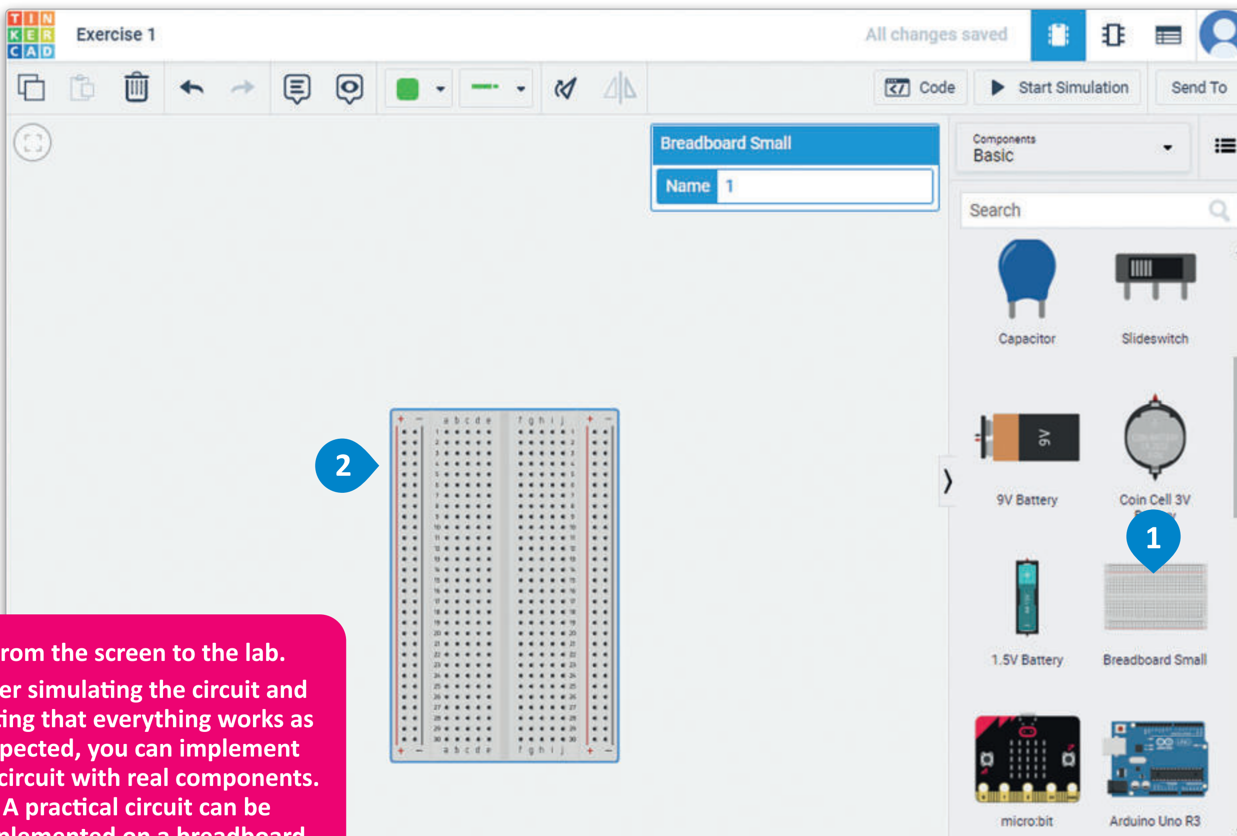
> From the components panel, click on **Breadboard Small**, 1 place it on the workplane and rotate it. 2

> Click on **Resistor**, 3 place it on the breadboard and rotate it. 4

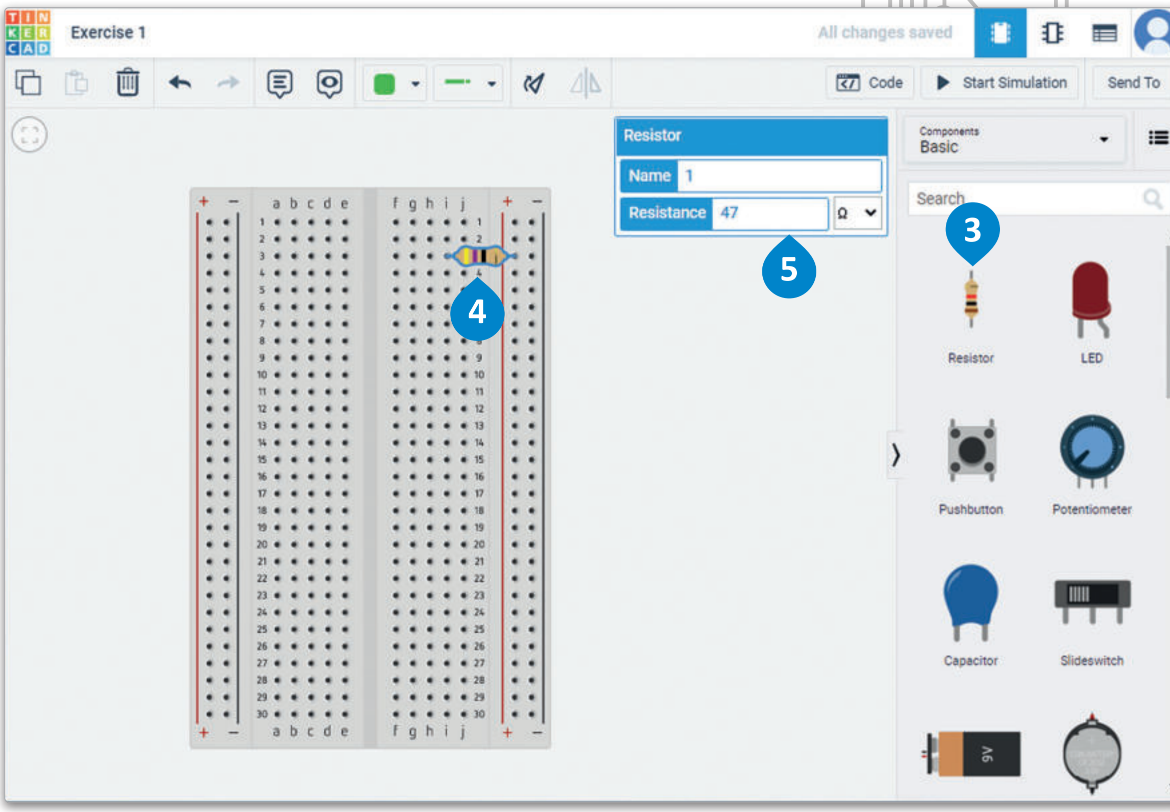
> From the inspector panel of the resistor set the **Resistance** to **47Ω**. 5

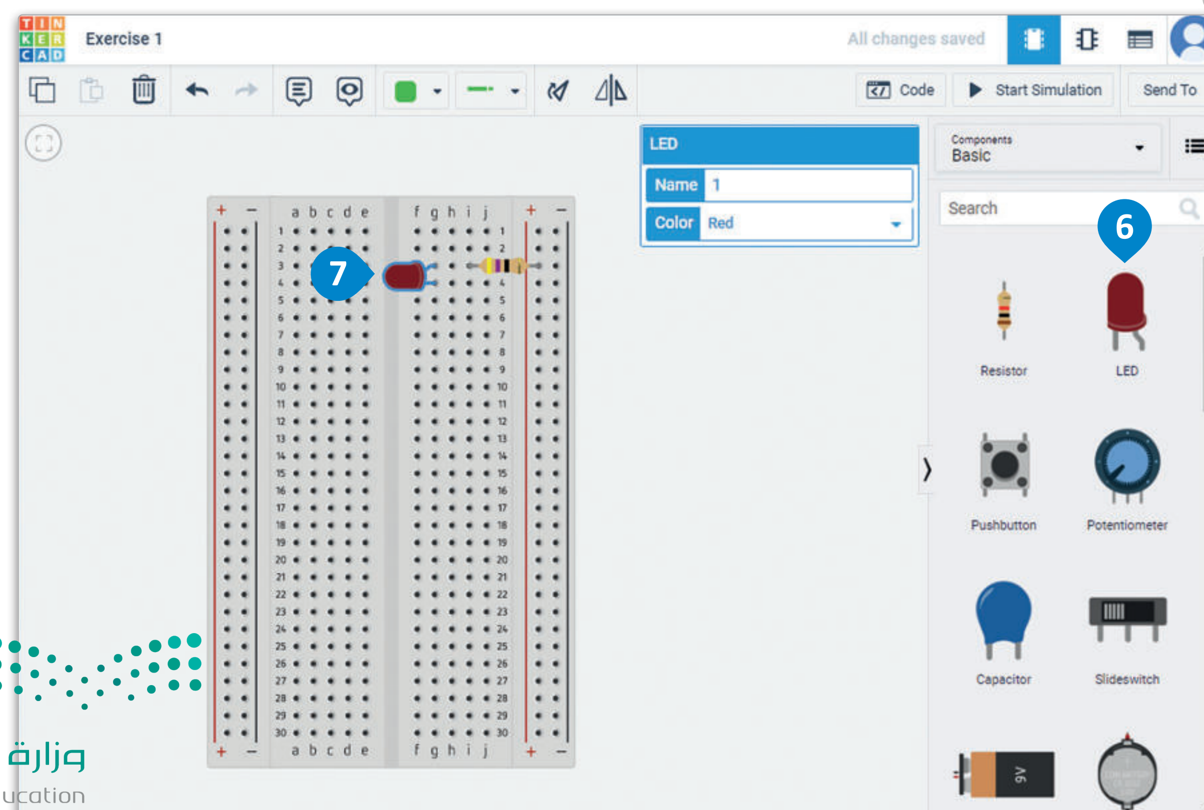
> Click on the **LED**, 6 place it on the breadboard and rotate it. 7

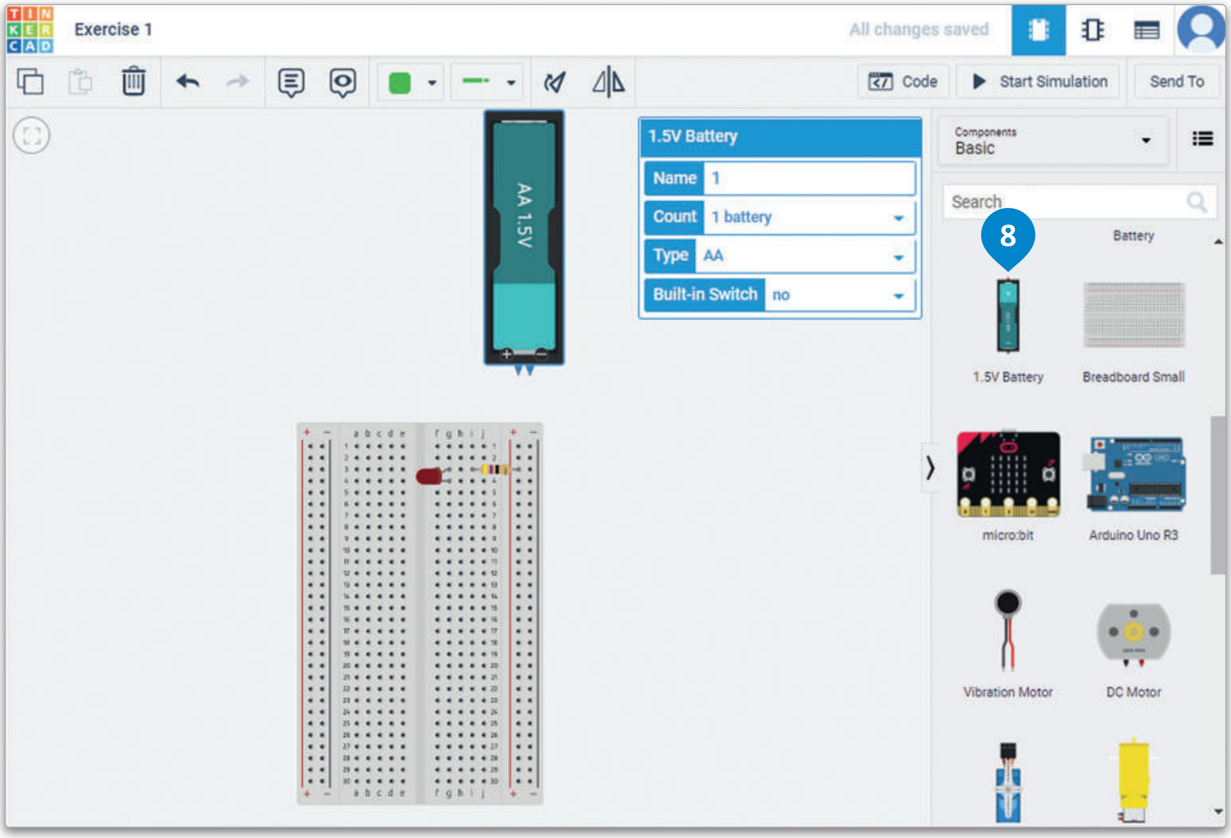
> Click on the **1.5V Battery**, 8 place it on the workplane, rotate it and from the **inspector** panel of the 1.5V Battery, set the **Count** to **2 batteries** to supply the circuit with 3V. 9

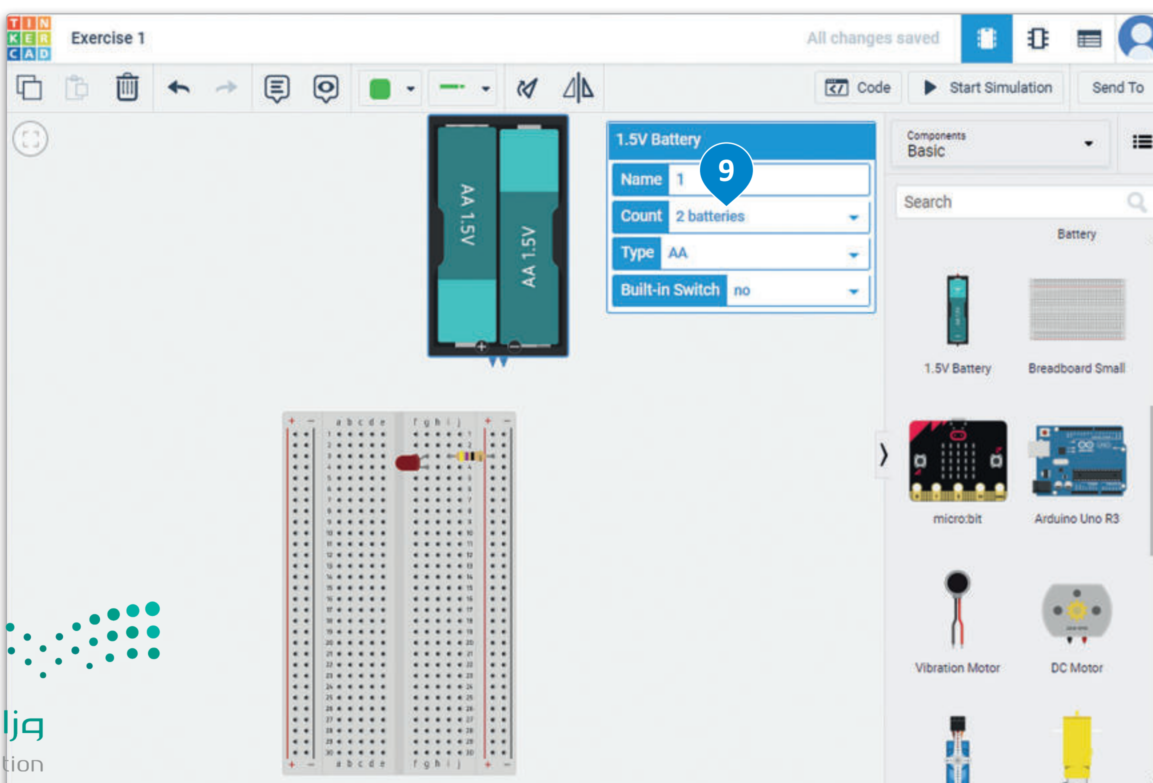


From the screen to the lab.
After simulating the circuit and testing that everything works as expected, you can implement the circuit with real components. A practical circuit can be implemented on a breadboard to make a prototype for display. The main advantage of the breadboard circuit is that you can easily make modifications, and no soldering is required. However, breadboard connections can become loose very easily, and it is very hard to identify loose connections in a complex circuit.

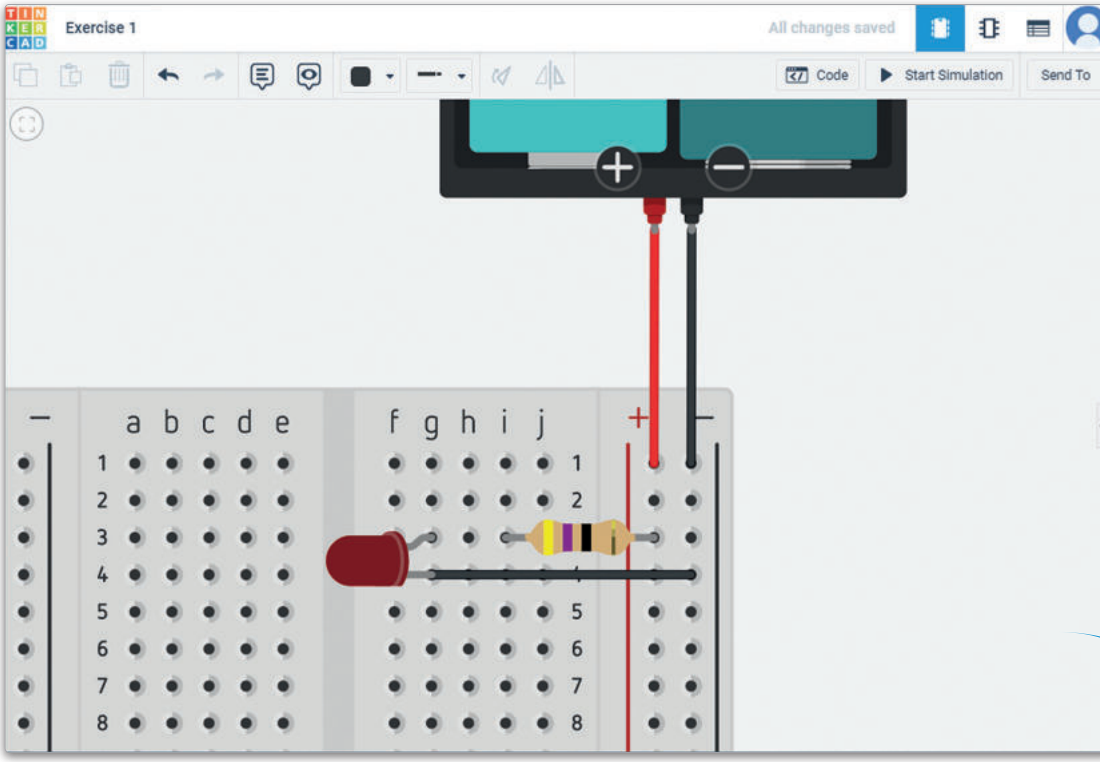

Exercise 1
All changes saved
Code
Start Simulation
Send To
Resistor
Name 1
Resistance 47 Ω
Components
Basic
Search
3
4
5
Resistor
LED
Pushbutton
Potentiometer
Capacitor
Slideswitch


Exercise 1
All changes saved
Code
Start Simulation
Send To
LED
Name 1
Color Red
Components
Basic
Search
6
7
Resistor
LED
Pushbutton
Potentiometer
Capacitor
Slideswitch


Exercise 1
All changes saved
Code
Start Simulation
Send To
1.5V Battery
Name 1
Count 1 battery
Type AA
Built-in Switch no
AA 1.5V
Components
Basic
Search
Battery
8
1.5V Battery
Breadboard Small
micro:bit
Arduino Uno R3
Vibration Motor
DC Motor


Exercise 1
All changes saved
Code
Start Simulation
Send To
1.5V Battery
Name 1
Count 2 batteries
Type AA
Built-in Switch no
9
AA 1.5V
AA 1.5V
Components
Basic
Search
Battery
1.5V Battery
Breadboard Small
micro:bit
Arduino Uno R3
Vibration Motor
DC Motor

Now, connect the components of the circuit and start the simulation.



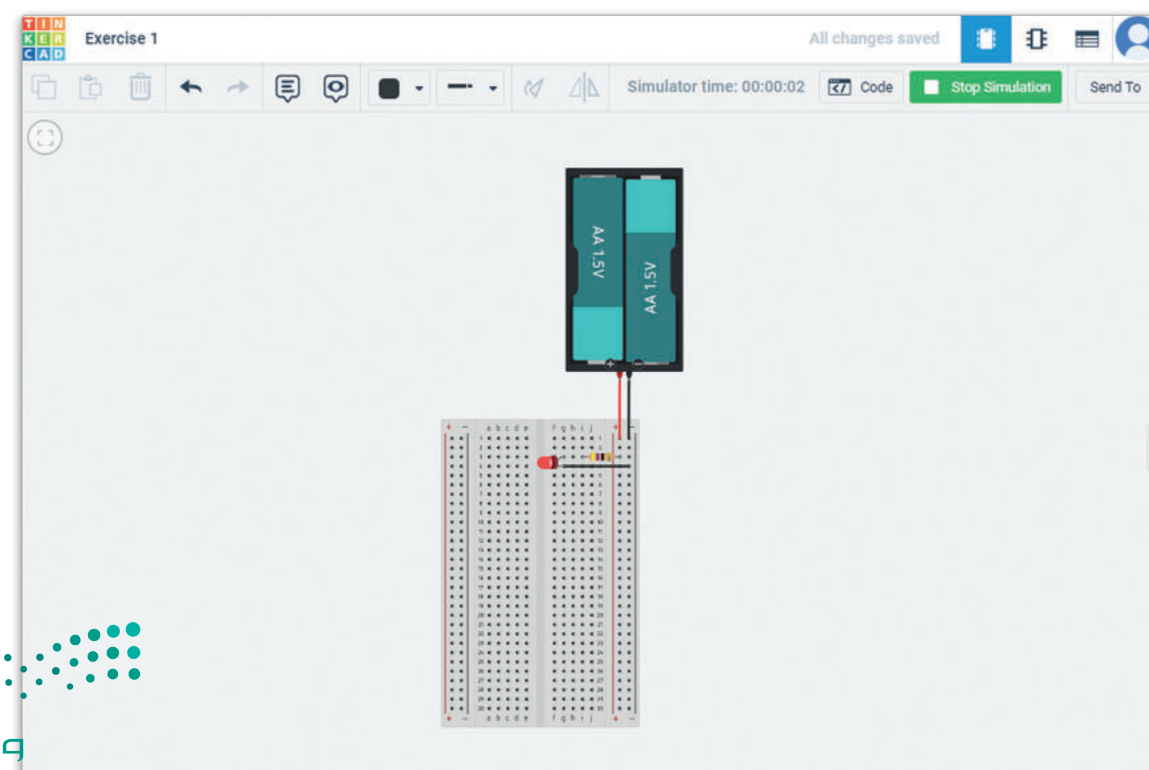


Figure 4.25: Create a new circuit

Using a Multimeter

Now that we have a working circuit, we can take some measurements with the virtual multimeter of Tinkercad Circuits. Note that the multimeter has three modes. By default, it functions as a voltmeter in voltage mode, which allows us to read the voltages across different components in our circuit. We can easily change the mode of the multimeter by clicking on it to open the inspector panel and selecting a different mode. In current mode it functions as an ammeter, allowing us to read the current flowing through certain points in our circuit. In resistance mode it functions as an ohmmeter, allowing us to read the resistance between certain points in our circuit.

To read voltages:

> From the components panel, click on the **1.5V Battery**, 1 and place it on the workplane. 2

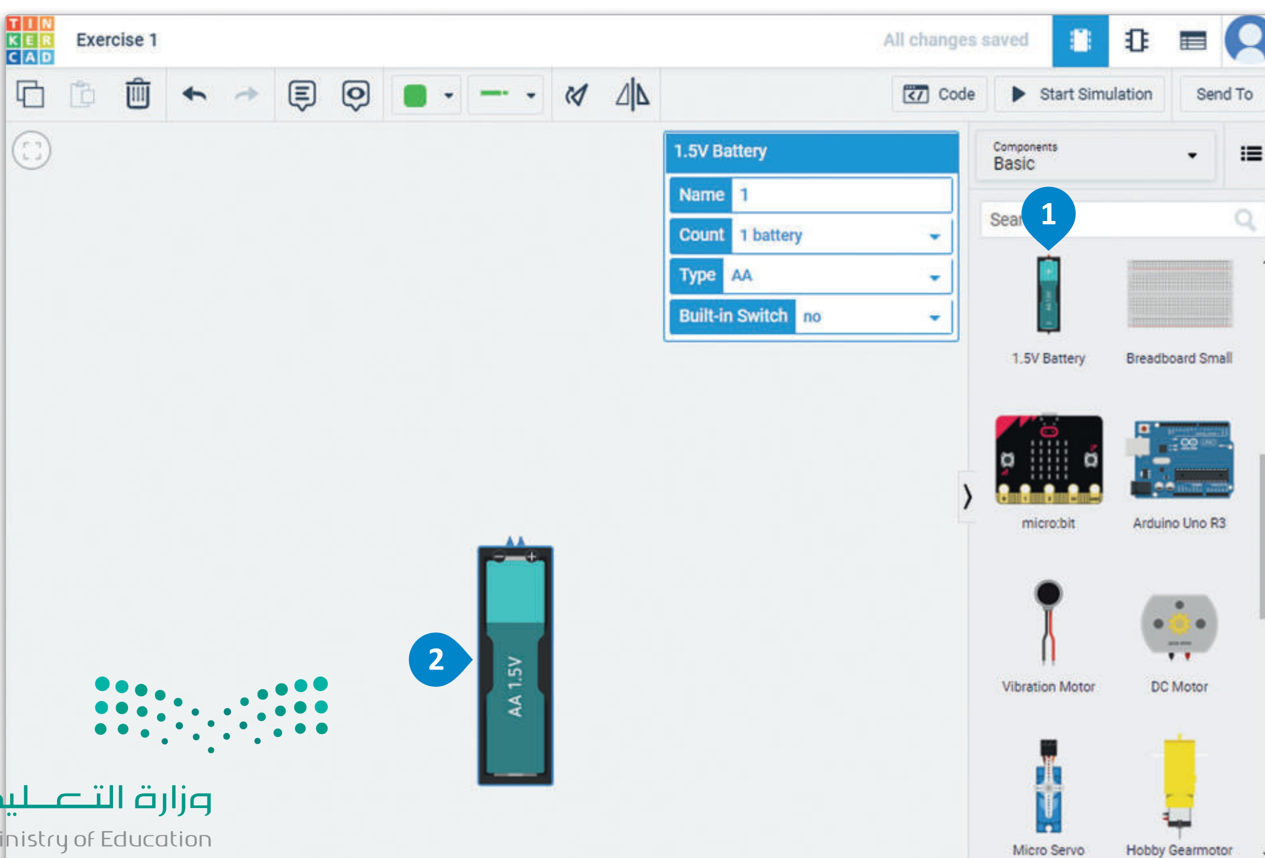
> From the inspector panel of the **1.5V Battery** set the **Count** to **2 batteries** to supply the circuit with 3V. 3

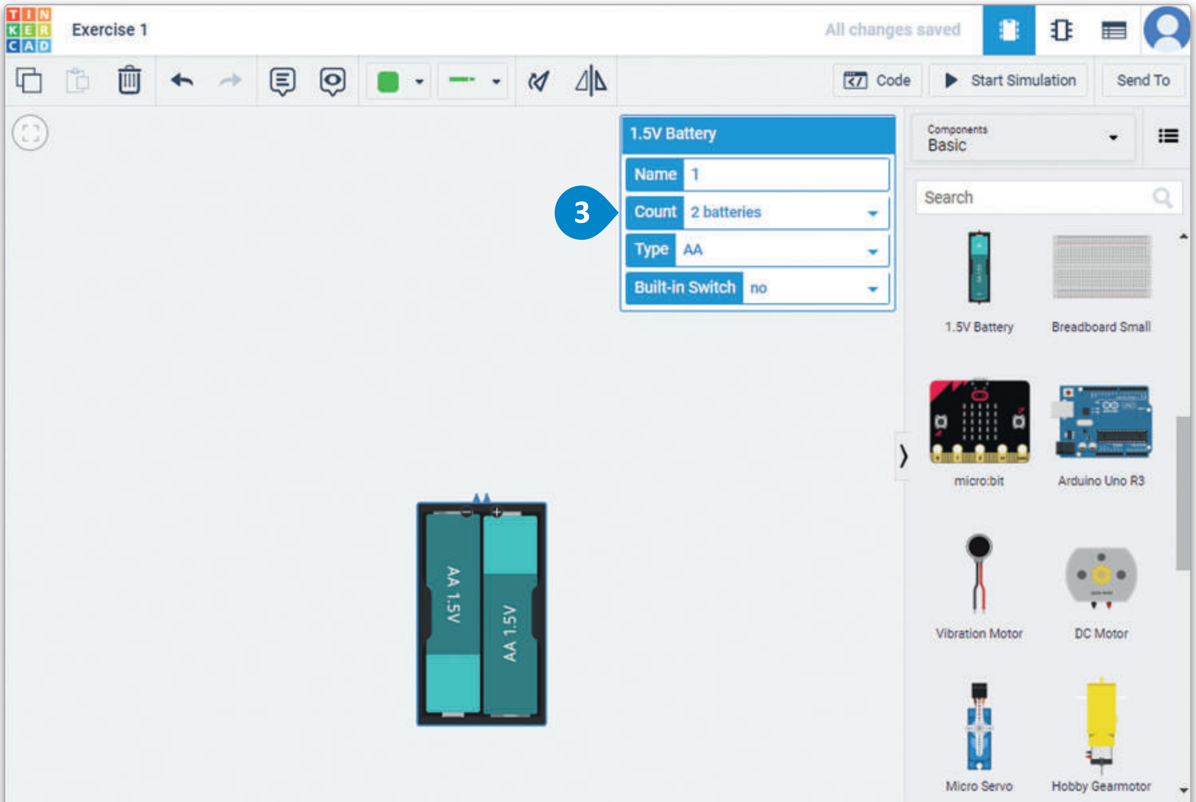
> From the components panel, click on the **Multimeter**, 4 and place it on the workplane. 5

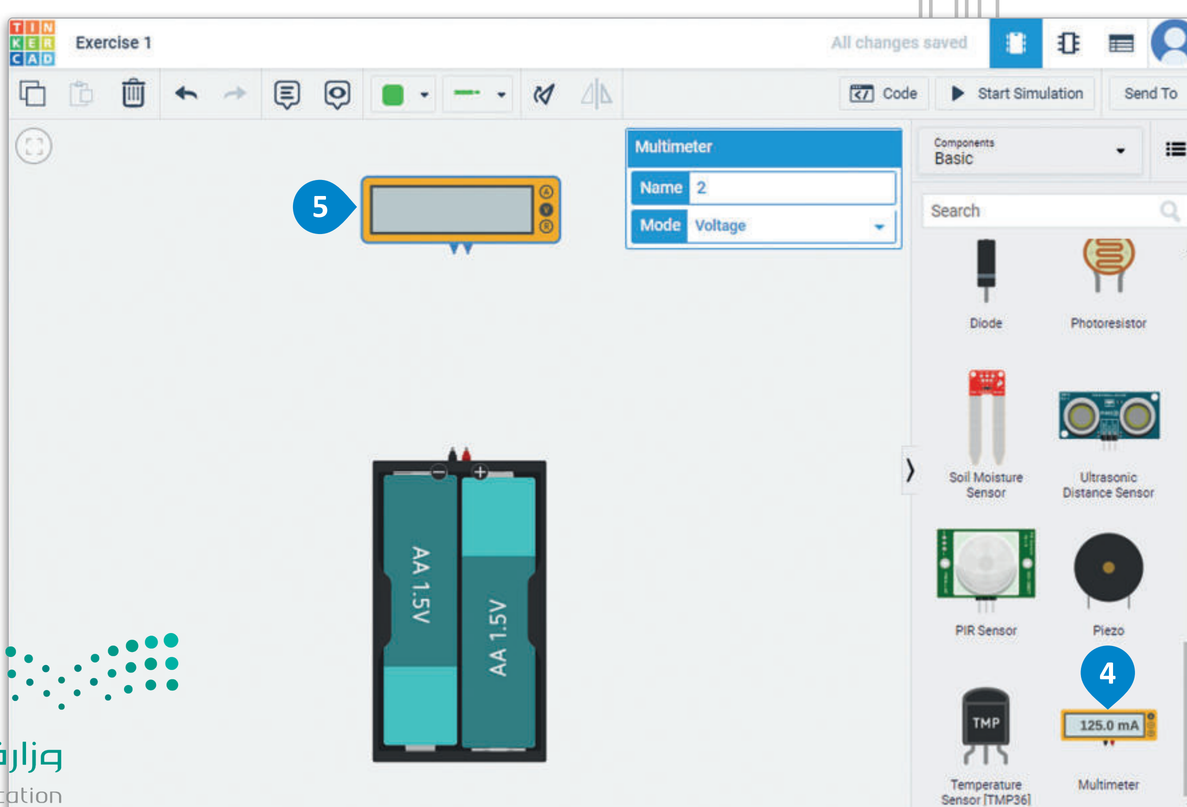
> Wire up the circuit. 6

> Click **Start Simulation**. 7

Use the Notes tool from the main toolbar to add annotations to a design. The same icon appears in the design and you can drag and drop it onto a component you want to annotate. When you click on the design element, the annotation is anchored and you are prompted to type your note.




Exercise 1
All changes saved
Code
Start Simulation
Send To
1.5V Battery
Name 1
3
Count 2 batteries
Type AA
Built-in Switch no
Components
Basic
Search
1.5V Battery
Breadboard Small
micro:bit
Arduino Uno R3
Vibration Motor
DC Motor
Micro Servo
Hobby Gearmotor
AA 1.5V
AA 1.5V


Exercise 1
All changes saved
Code
Start Simulation
Send To
Multimeter
Name 2
Mode Voltage
5
Components
Basic
Search
Diode
Photoresistor
Soil Moisture Sensor
Ultrasonic Distance Sensor
PIR Sensor
Piezo
4
TMP
Temperature Sensor [TMP36]
125.0 mA
Multimeter
AA 1.5V
AA 1.5V

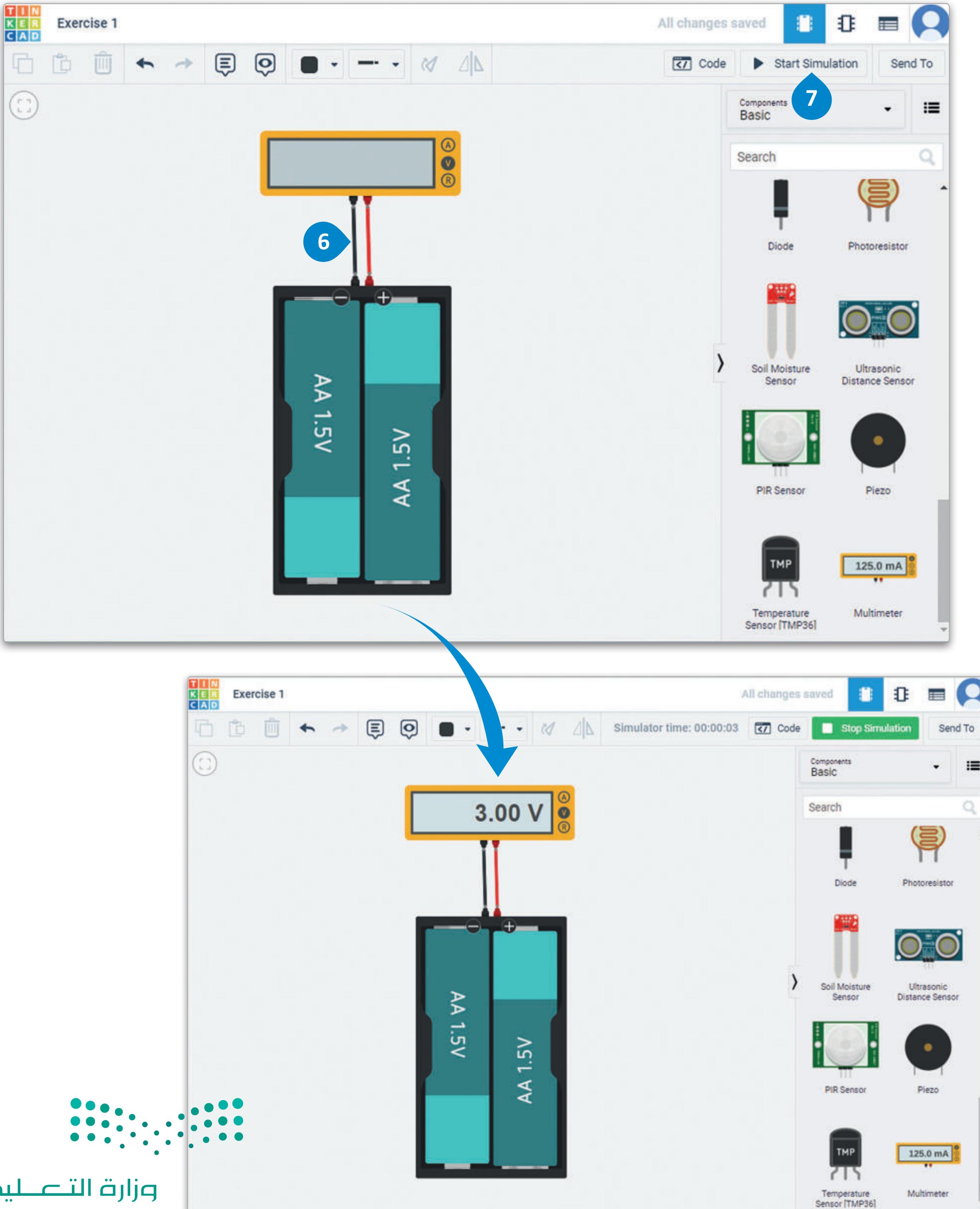
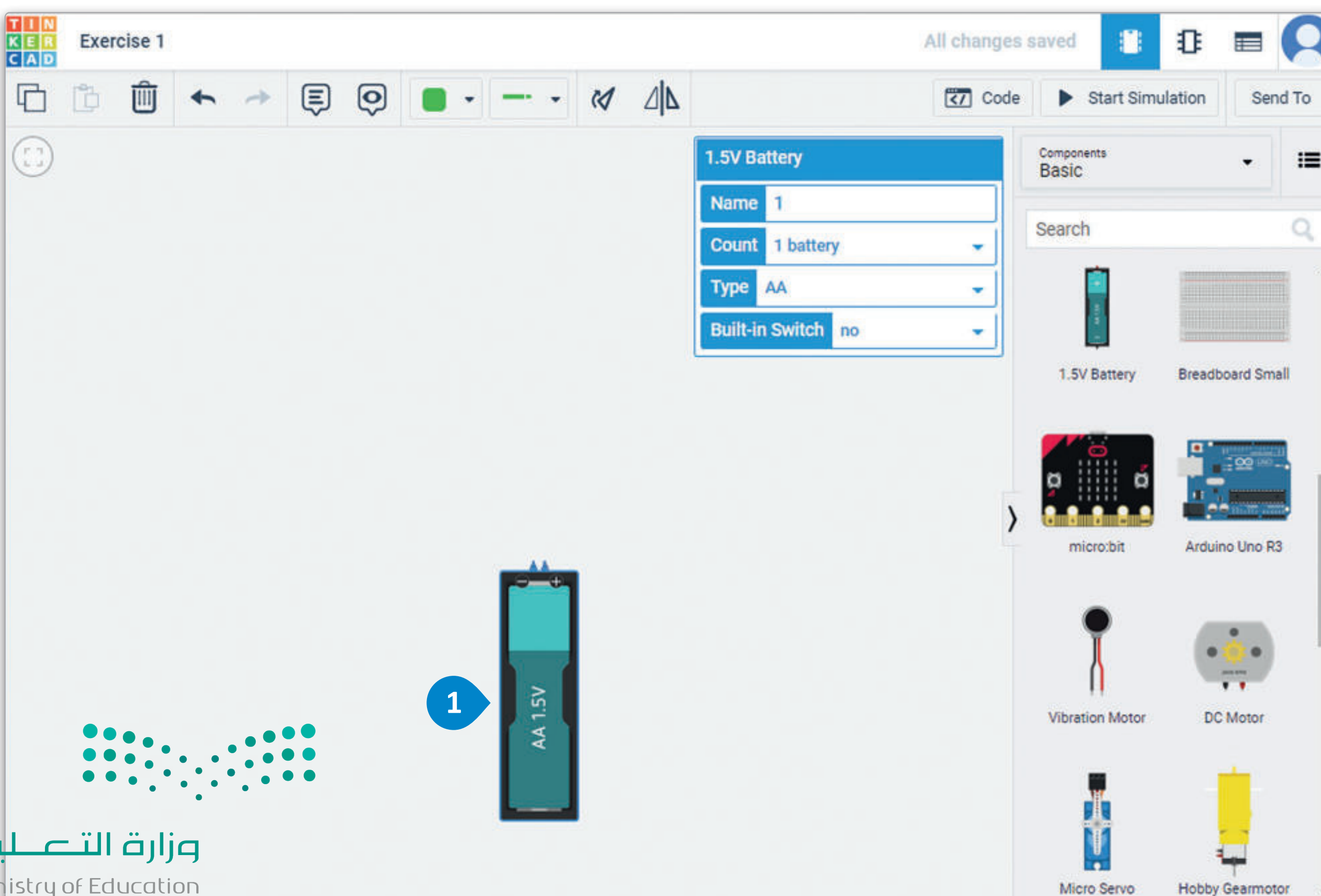


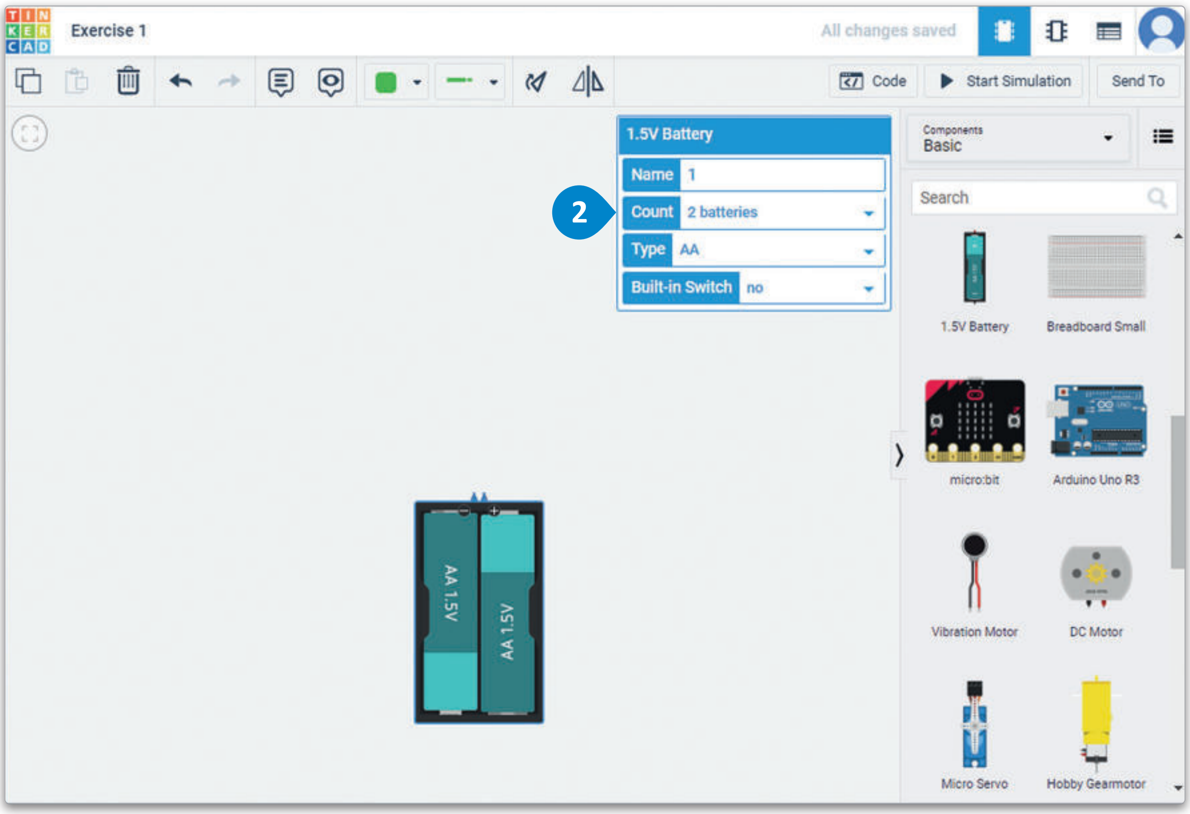
Figure 4.26: Read voltages

We will now read the voltages across various points in our circuit. Let's start by measuring the voltage between the two sides of the resistor.

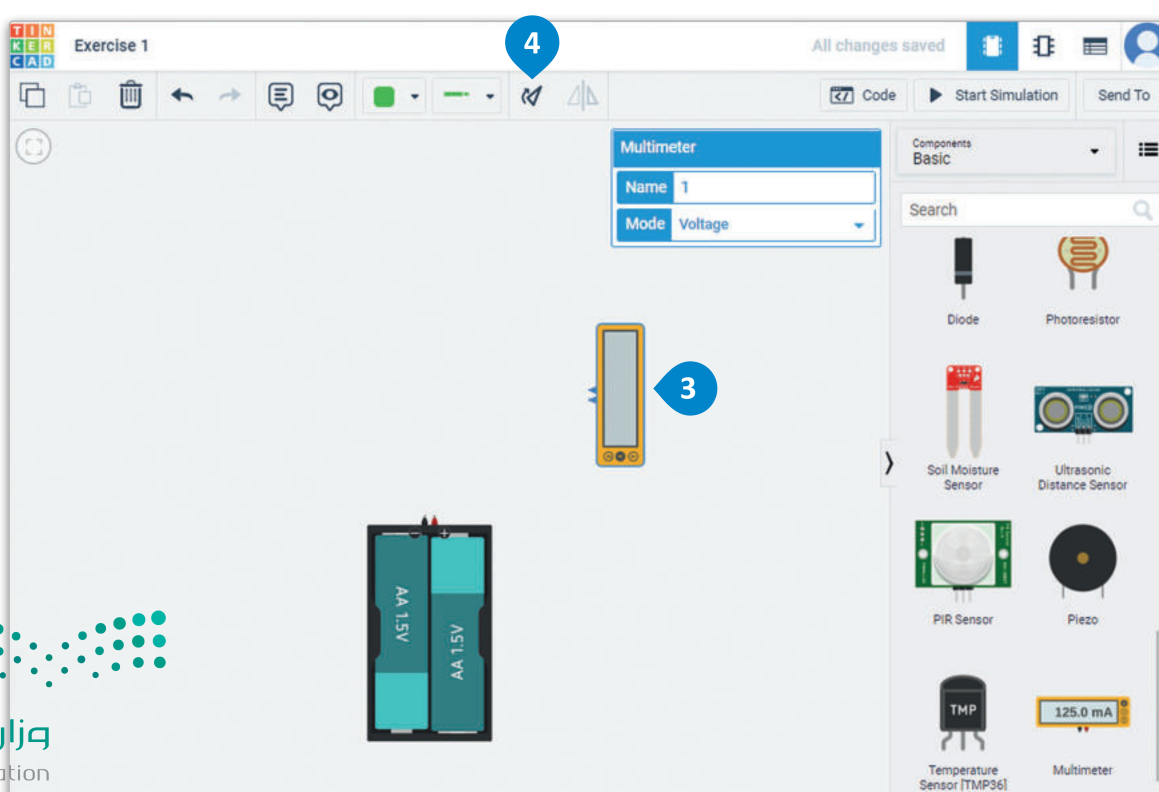
Voltage measurement across the ends of a resistor:

> From the components panel, place a **1.5V Battery** on the workplane. 1
> From the inspector panel of the **1.5V Battery**, set the **Count** to **2 batteries** to supply the circuit with 3V. 2
> From the components panel, place a **Multimeter** on the workplane 3 and rotate it. 4
> From the components panel, place a **Resistor** on the workplane. 5
> From the inspector panel of the resistor, set the **Resistance** to **47Ω**. 6
> From the components panel, place an **LED** on the workplane. 7
> Wire up the circuit. 8
> Click **Start Simulation**. 9

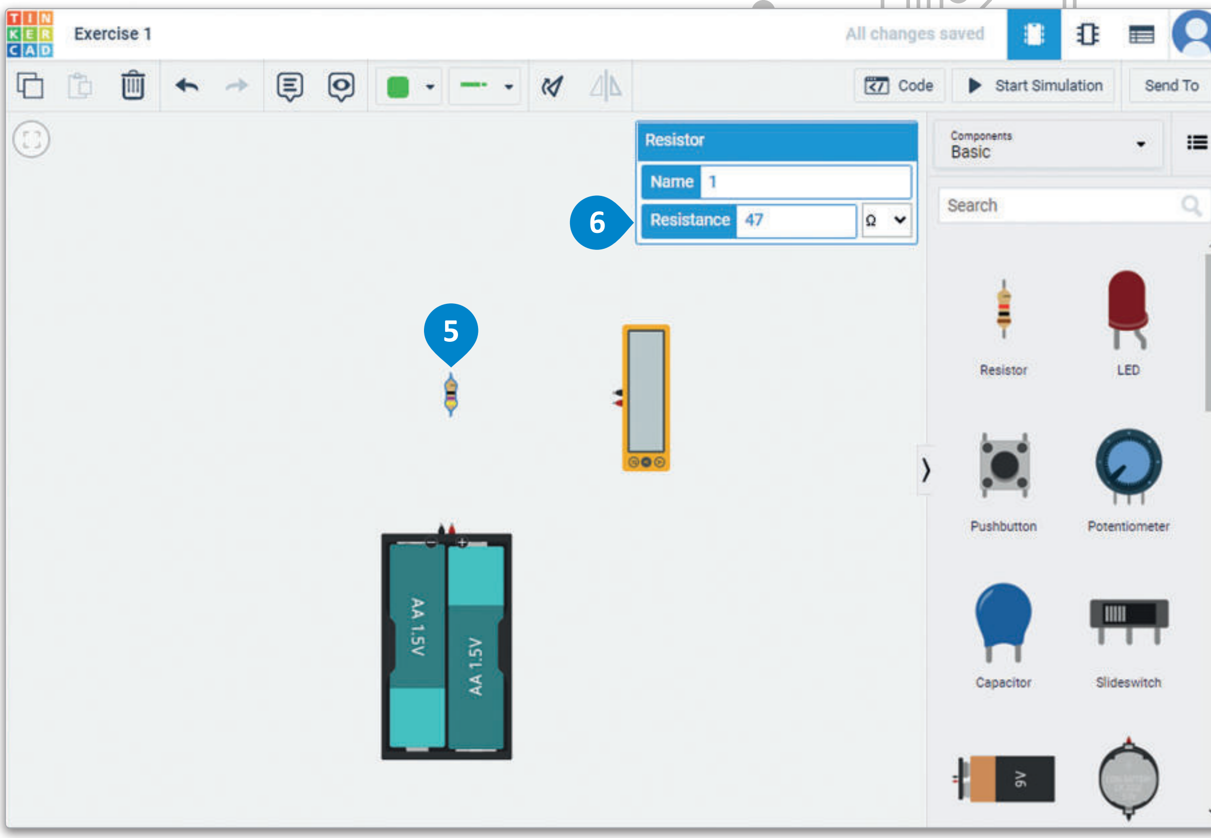


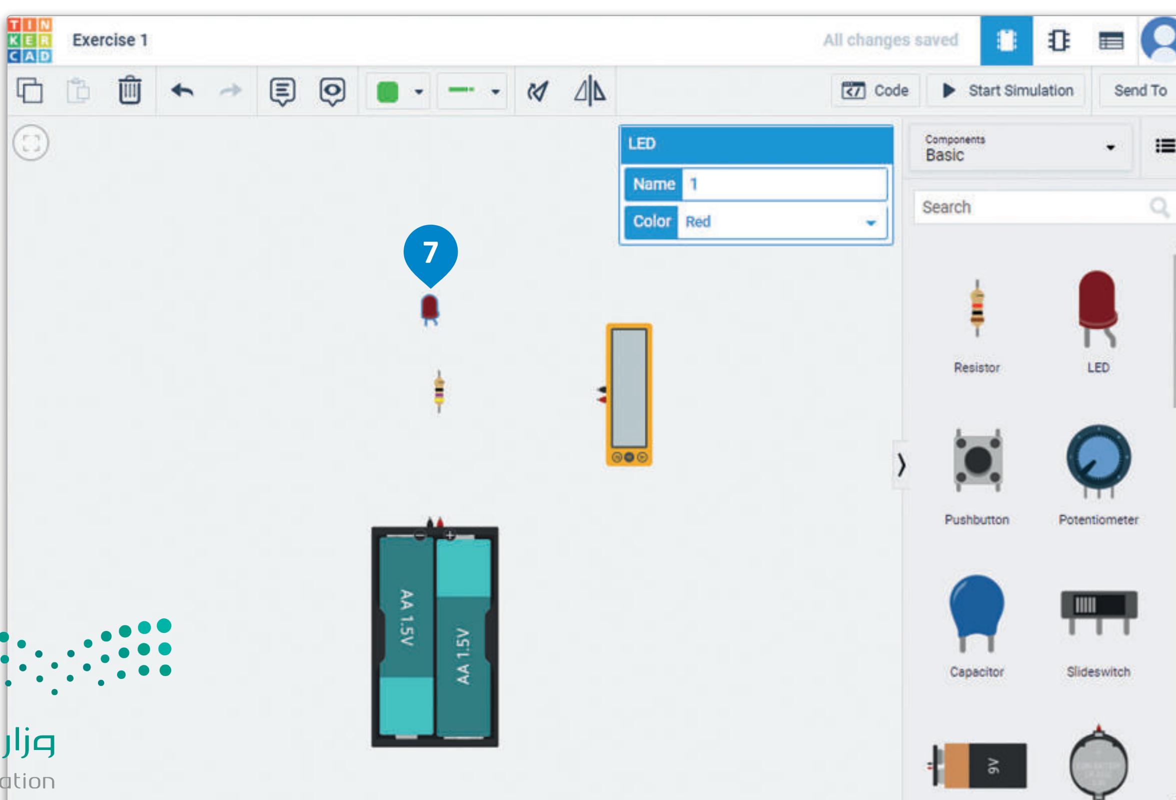


Exercise 1
All changes saved
Code
Start Simulation
Send To
1.5V Battery
Name
1
Count
2 batteries
Type
AA
Built-in Switch
no
2
Components
Basic
Search
1.5V Battery
Breadboard Small
micro:bit
Arduino Uno R3
Vibration Motor
DC Motor
Micro Servo
Hobby Gearmotor
AA 1.5V
AA 1.5V



Exercise 1
4
All changes saved
Code
Start Simulation
Send To
Multimeter
Name
1
Mode
Voltage
3
Components
Basic
Search
Diode
Photoresistor
Soil Moisture Sensor
Ultrasonic Distance Sensor
PIR Sensor
Piezo
TMP
Temperature Sensor [TMP36]
125.0 mA
Multimeter
AA 1.5V
AA 1.5V


Exercise 1
All changes saved
Code
Start Simulation
Send To
Resistor
Name 1
Resistance 47 Ω
6
5
Components
Basic
Search
Resistor
LED
Pushbutton
Potentiometer
Capacitor
Slideswitch
AA 1.5V
AA 1.5V
9V


Exercise 1
All changes saved
Code
Start Simulation
Send To
LED
Name 1
Color Red
7
Components
Basic
Search
Resistor
LED
Pushbutton
Potentiometer
Capacitor
Slideswitch
AA 1.5V
AA 1.5V
9V

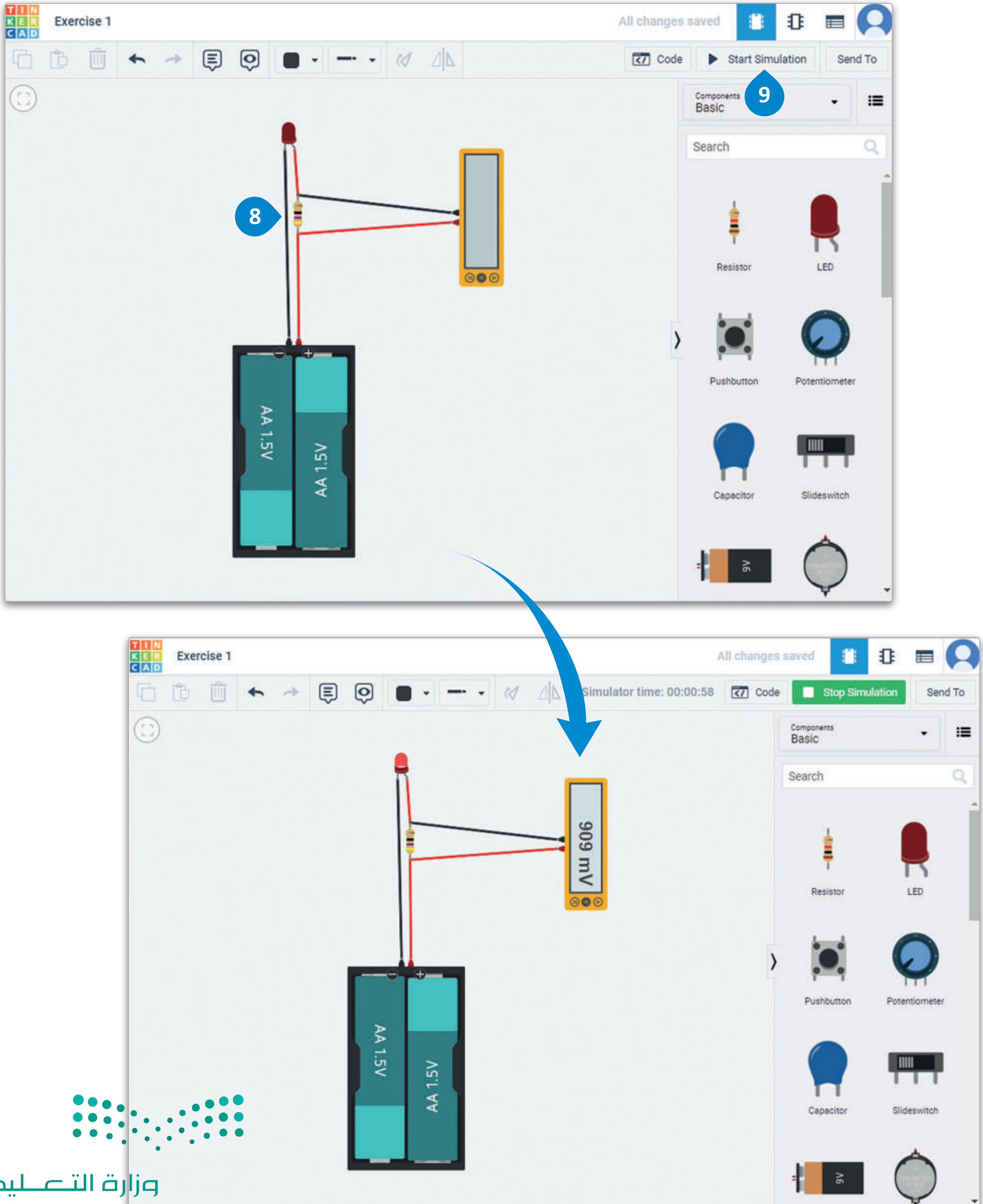
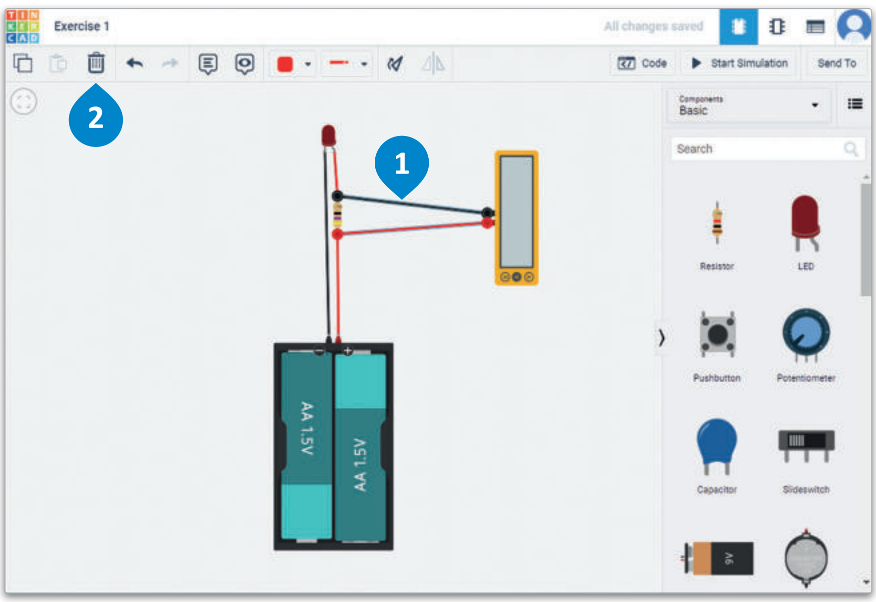
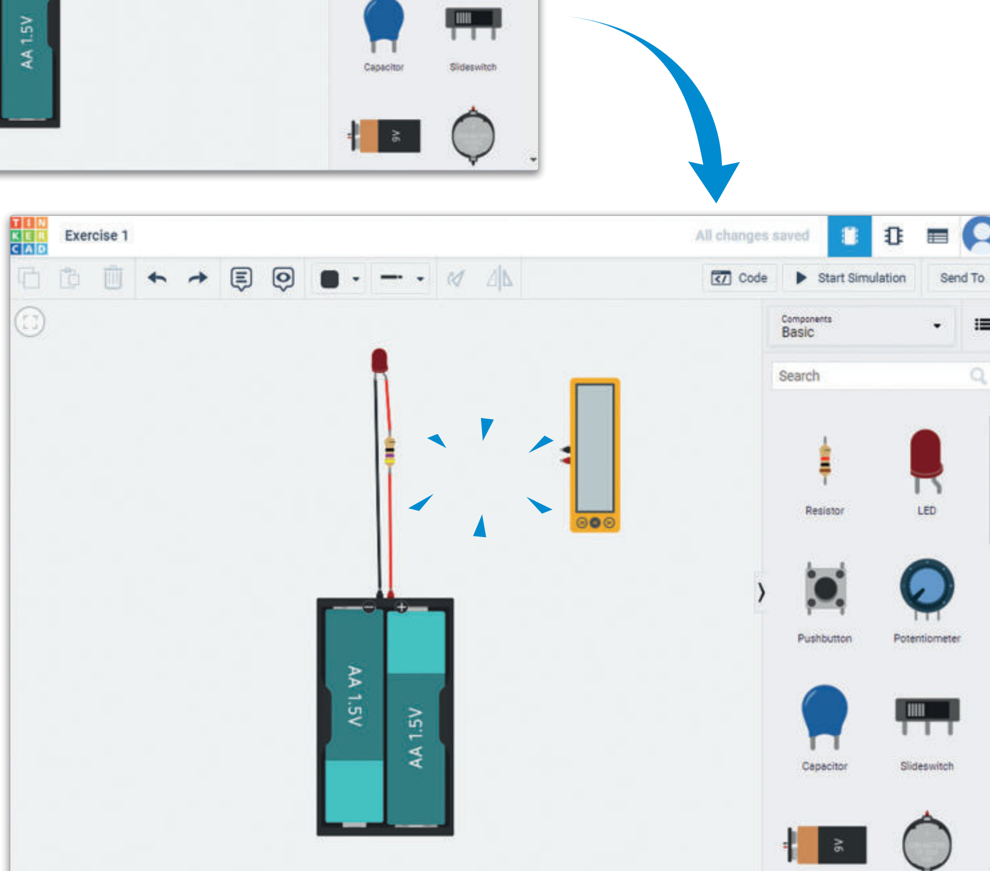


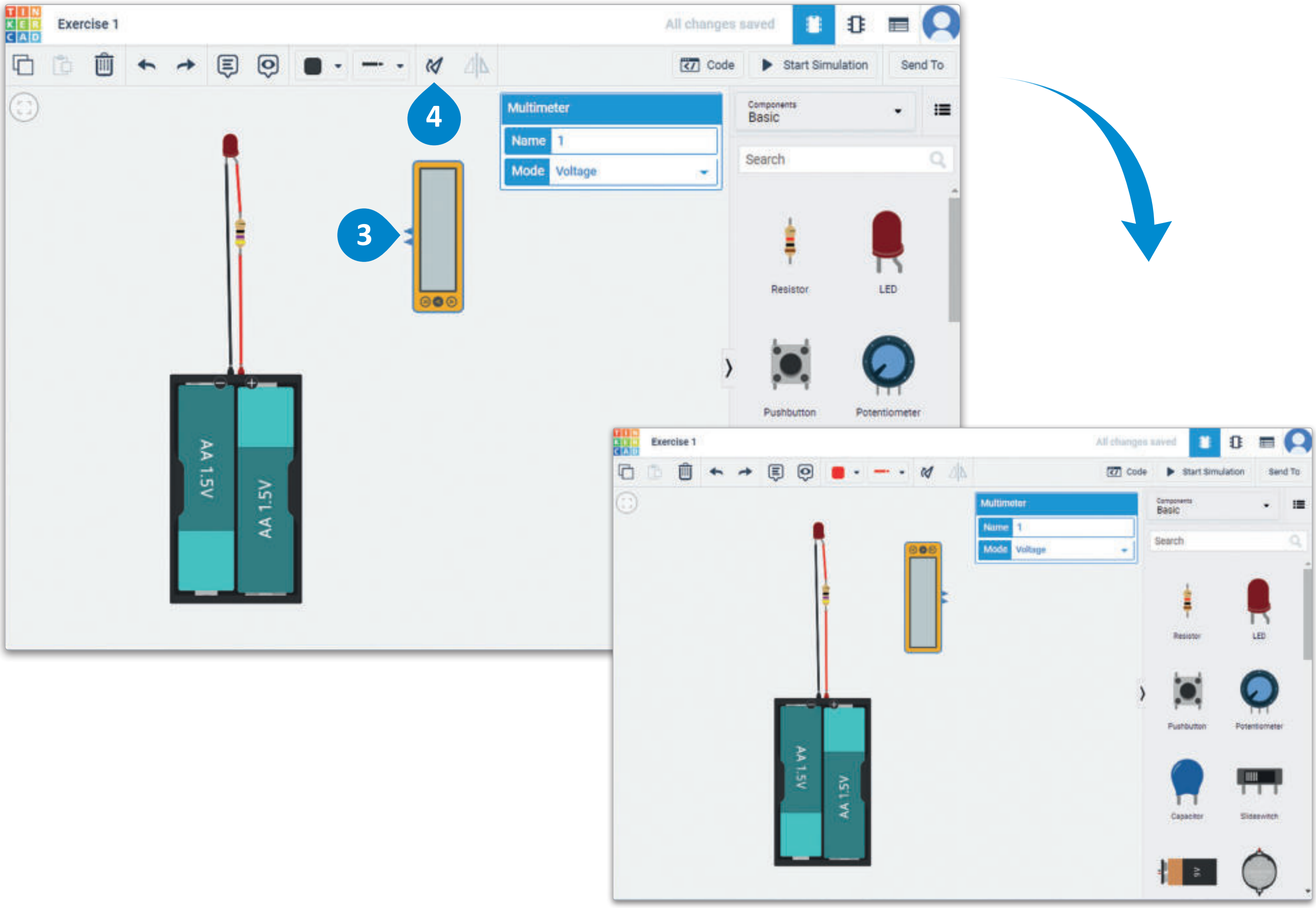
Figure 4.27: Voltage measurement across the ends of a resistor

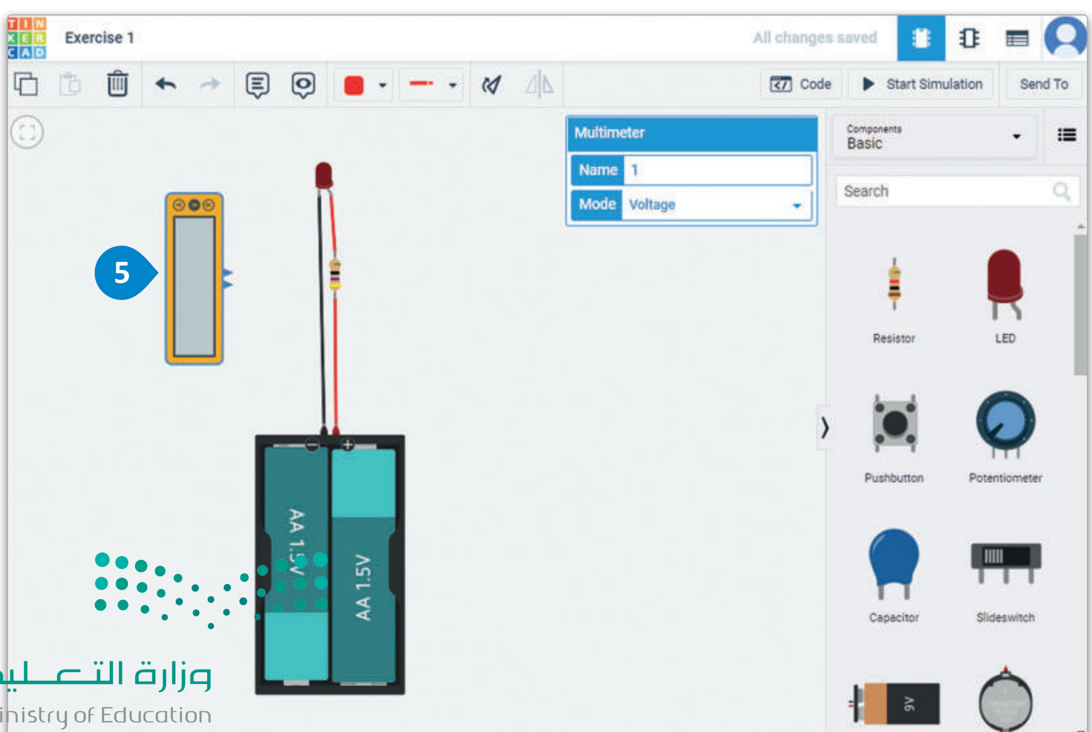
Voltage measurement across the anode and cathode of an LED:

> Select the **wiring** of the multimeter by using Shift and click, 1 and click **Delete**. 2
> Click on the **Multimeter** to select it, 3 and click **Rotate** six times. 4
> Move the **Multimeter** by dragging and dropping. 5
> Wire the **Multimeter** across the anode and the cathode of the **LED**. 6
> Click **Start Simulation**. 7






Exercise 1
All changes saved
Code
Start Simulation
Send To
4
3
Multimeter
Name 1
Mode Voltage
Components
Basic
Search
Resistor
LED
Pushbutton
Potentiometer
AA 1.5V
AA 1.5V
Capacitor
Slideswitch


Exercise 1
All changes saved
Code
Start Simulation
Send To
5
Multimeter
Name 1
Mode Voltage
Components
Basic
Search
Resistor
LED
Pushbutton
Potentiometer
Capacitor
Slideswitch
AA 1.5V
AA 1.5V

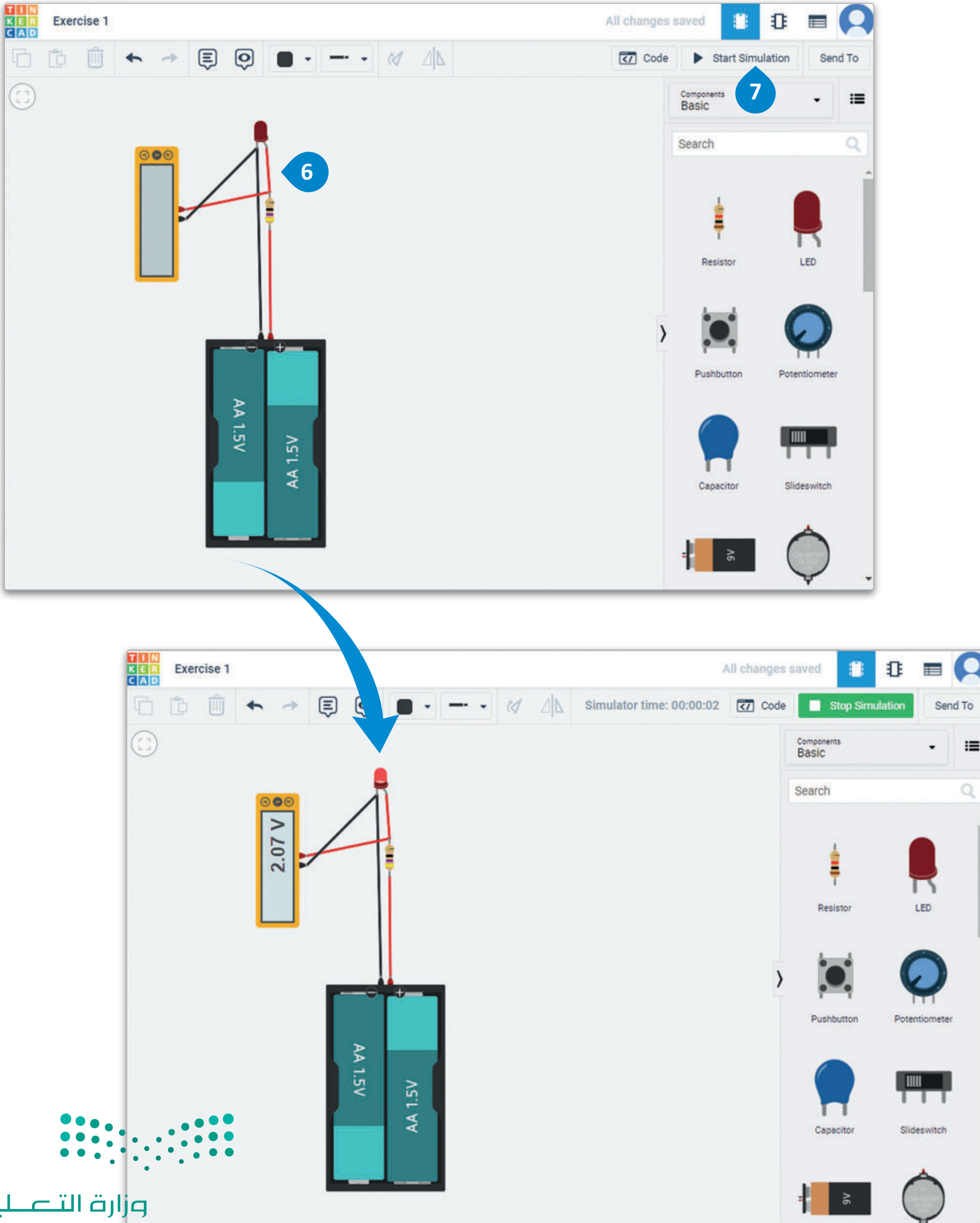


Figure 4.28: Voltage measurement across the anode and cathode of an LED

Voltage measurement across the two terminals of a battery:

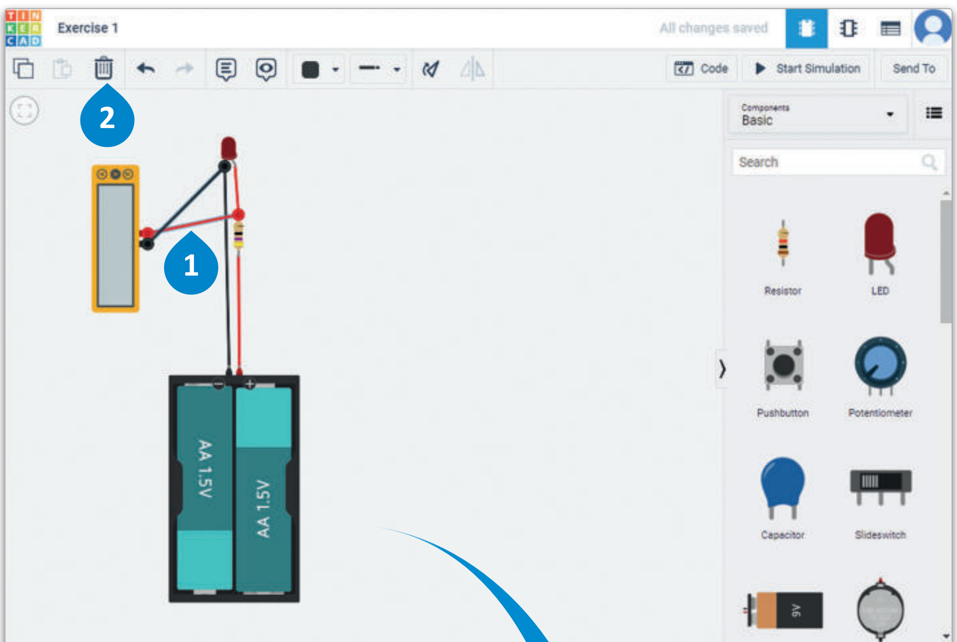
> Select the **wiring** of the multimeter by using Shift and click, 1 and click **Delete**. 2

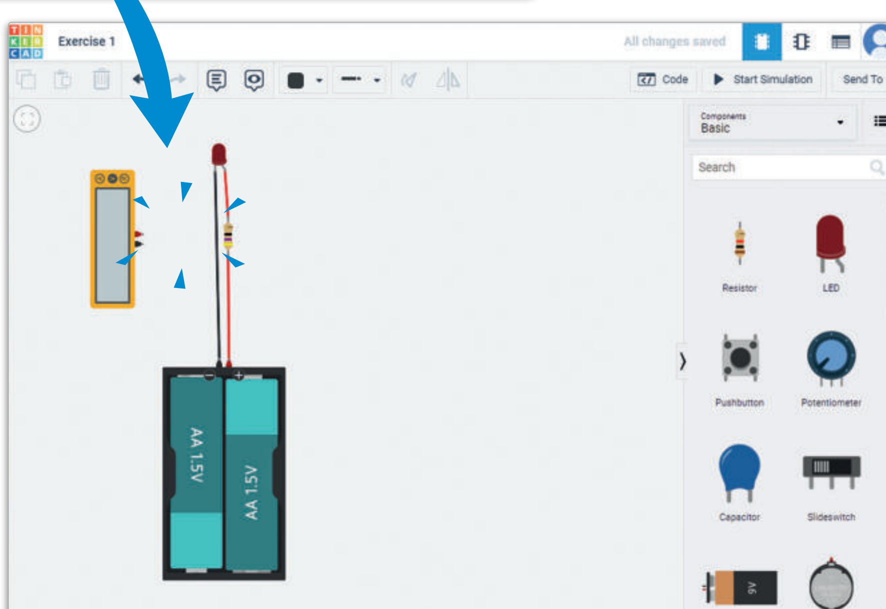
> Click on the **Multimeter** to select it, 3 and click **Rotate** three times. 4

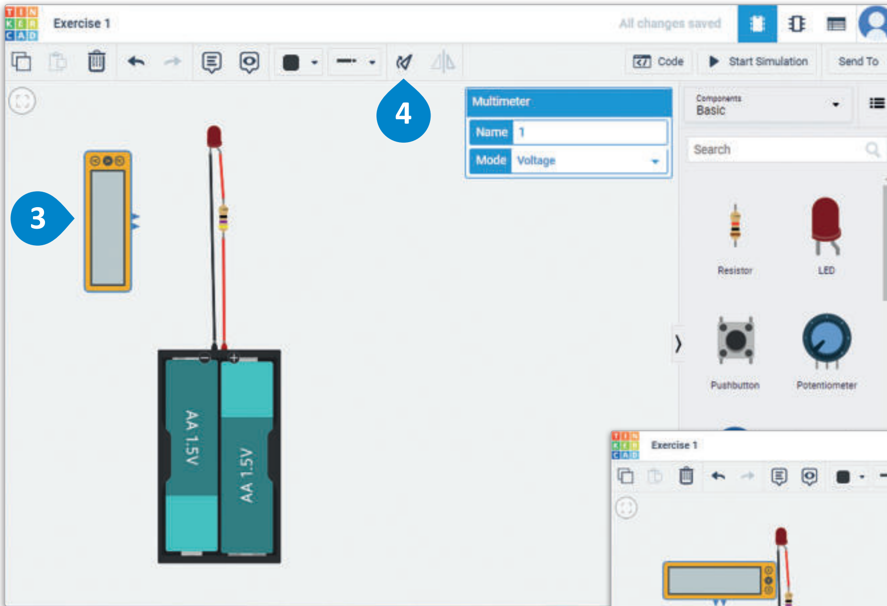
> Move the **Multimeter** by dragging and dropping. 5

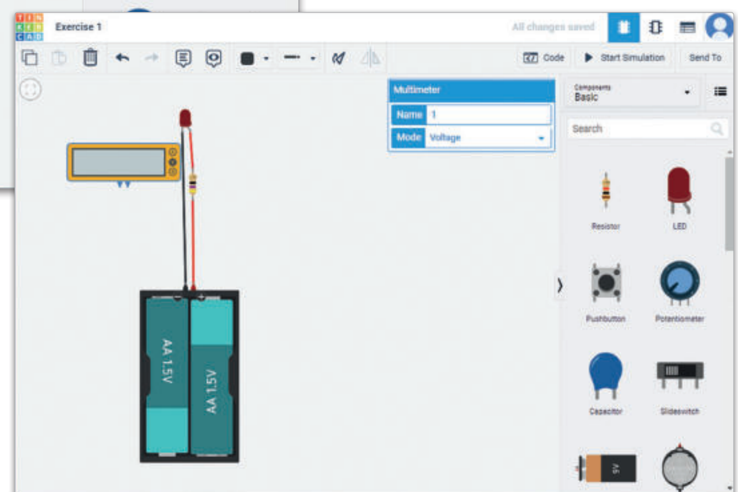
> Wire the **Multimeter** across the two terminals of the **Battery**. 6

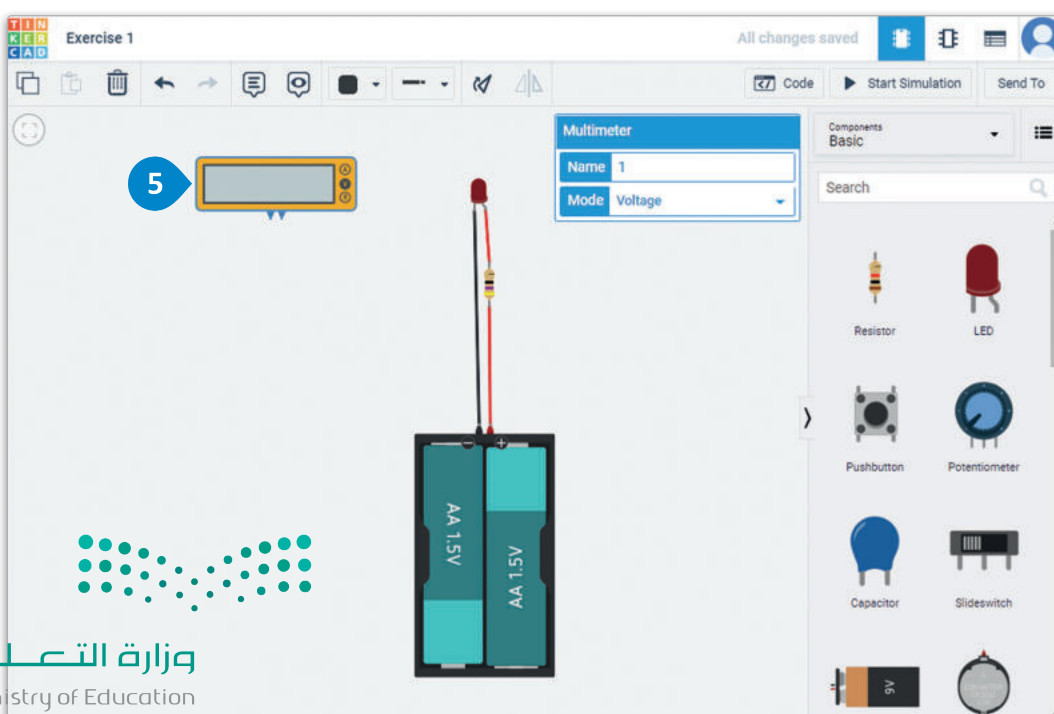
> Click **Start Simulation**. 7

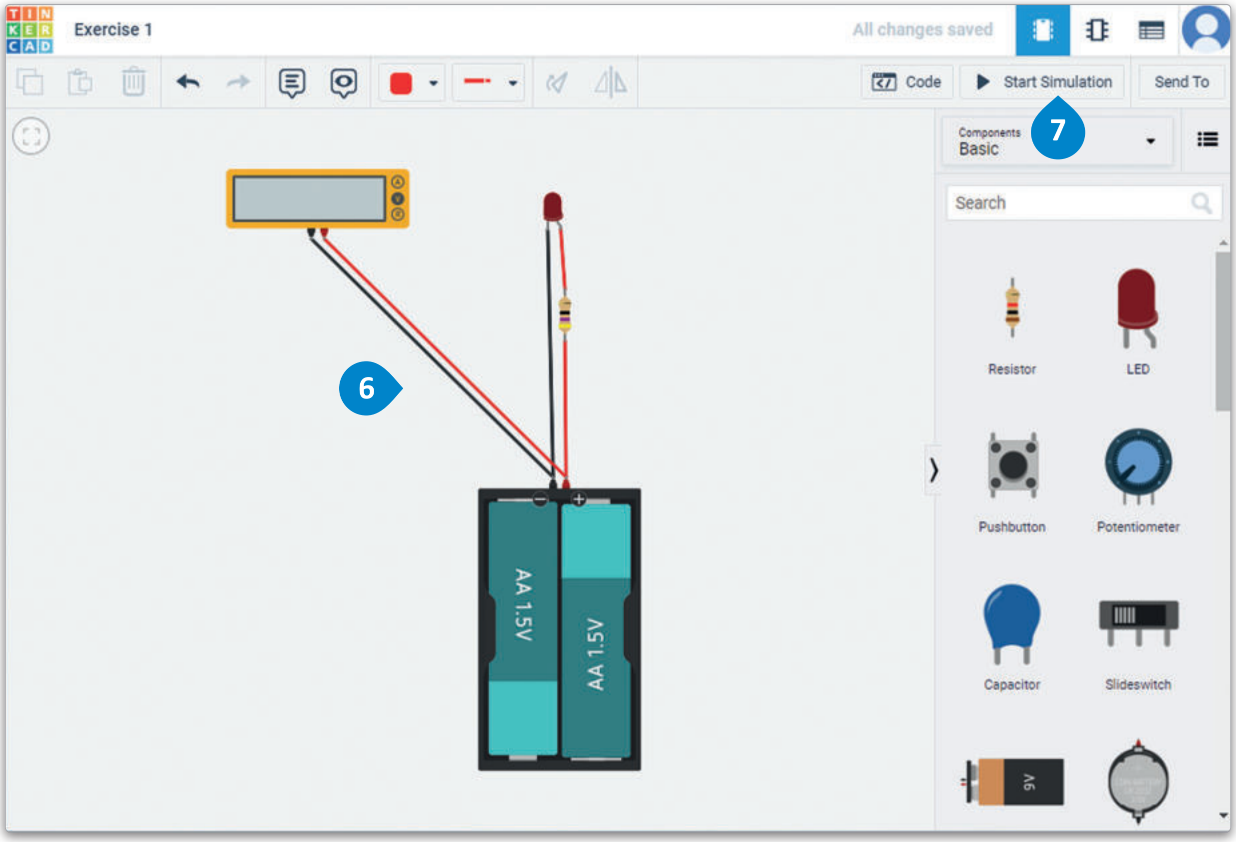





Exercise 1
All changes saved
Code
Start Simulation
Send To
Multimeter
Name 1
Mode Voltage
Components
Basic
Search
Resistor
LED
Pushbutton
Potentiometer
AA 1.5V
AA 1.5V
3
4


Exercise 1
Multimeter
Name 1
Mode Voltage
AA 1.5V
AA 1.5V


Exercise 1
All changes saved
Code
Start Simulation
Send To
Multimeter
Name 1
Mode Voltage
Components
Basic
Search
Resistor
LED
Pushbutton
Potentiometer
Capacitor
Slideswitch
AA 1.5V
AA 1.5V
5



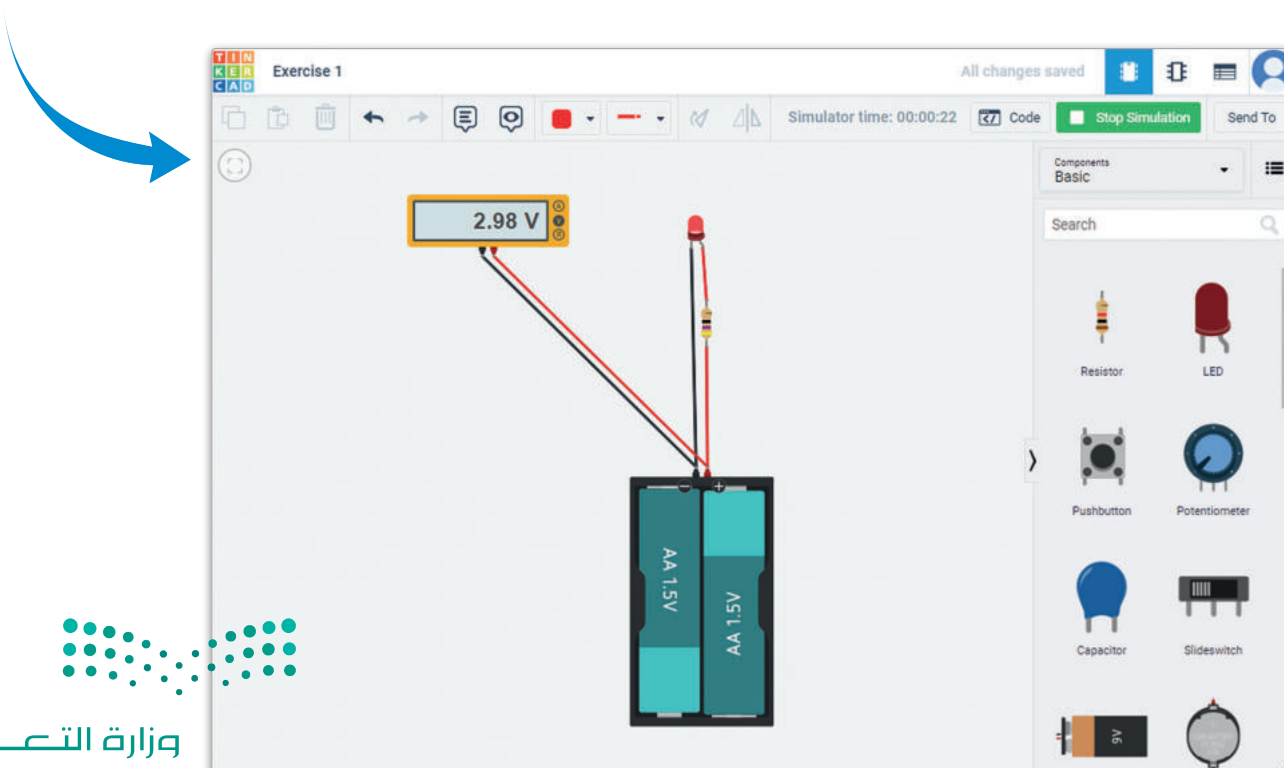


Figure 4.29: Voltage measurement across the two terminals of a battery

Finally, we will use the multimeter as an ammeter to measure the total current of the circuit (I). Note that voltmeters and ohmmeters are connected in parallel with the component being measured. Ammeters, on the other hand, must be connected in series.

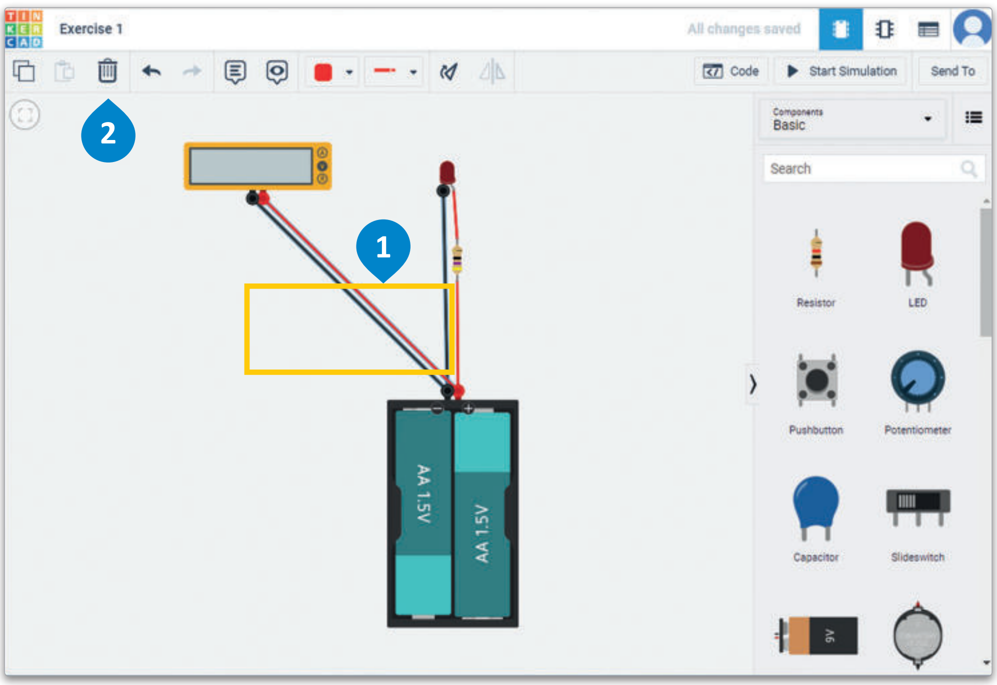
To measure the current:

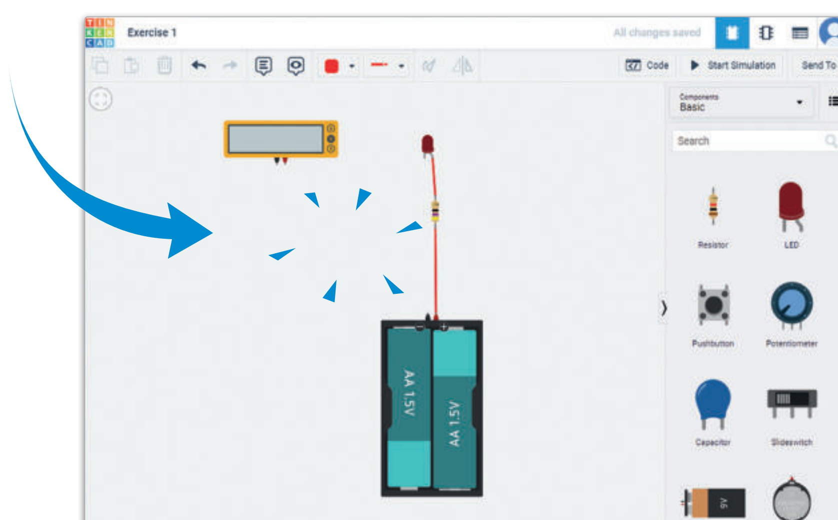
> Select the **wiring** of the multimeter and the **wire** from the cathode of the LED to the negative pole of the battery by using Shift and click, 1 and click **Delete**. 2

> Click on the **Multimeter**, 3 and from the **inspector** panel change its **Mode** to **Amperage**. 4

> Wire the multimeter to measure the total current. 5

> Click **Start Simulation**. 6





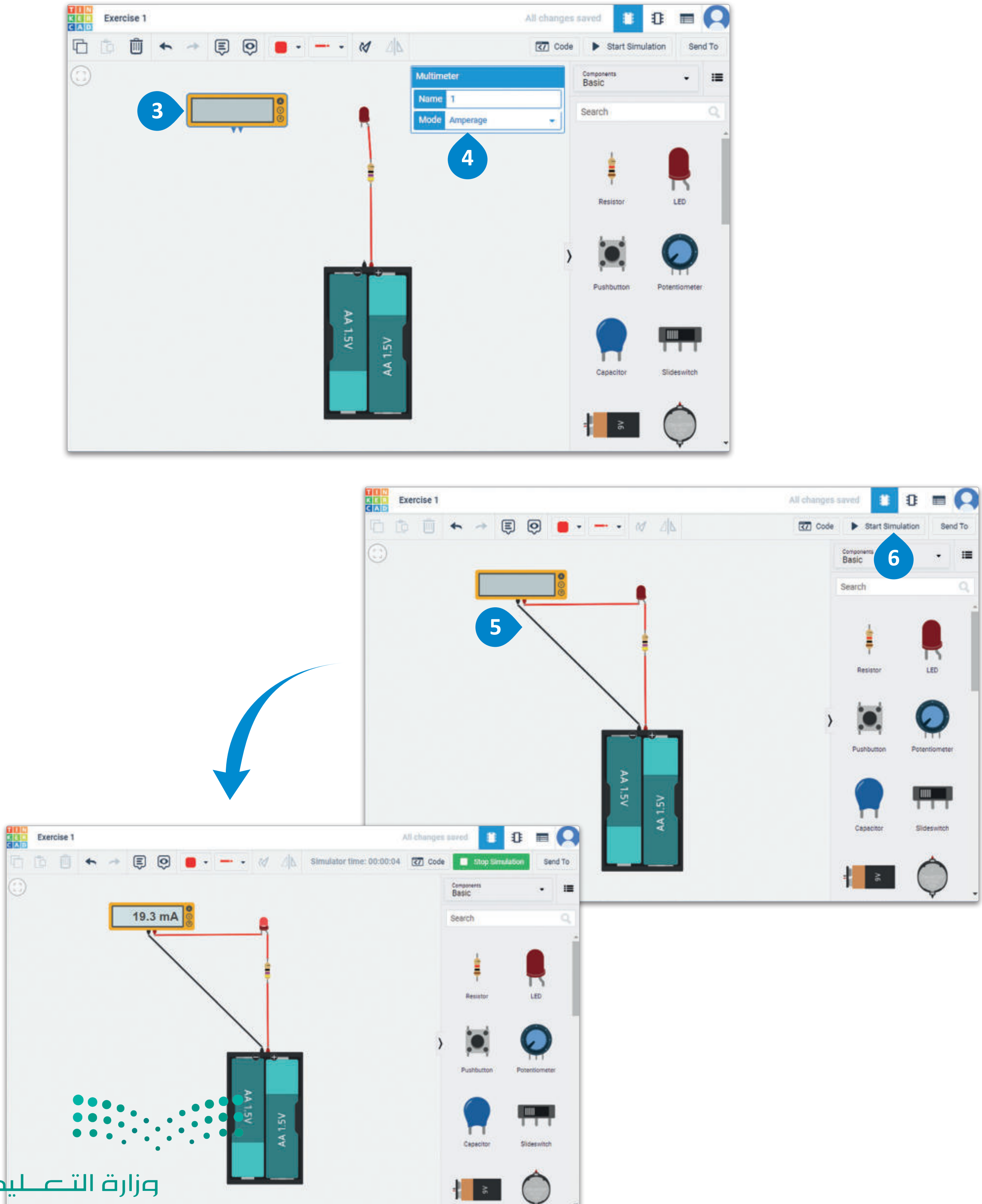


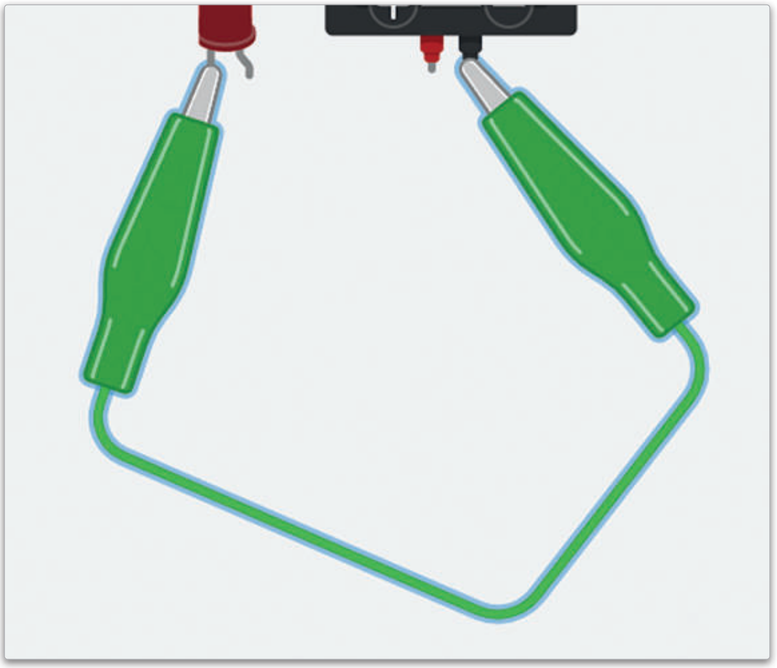
Figure 4.30: Measure the current

Exercises

1

Read the sentences and tick ✓ True or False.	True	False
1. Pushbuttons are ordinarily used in calculators, kitchen appliances, magnetic locks, etc.		
2. Using circuit simulation, we can test the functionality of a circuit without actually building the circuit.		
3. In Tinkercad Circuits, you can modify a circuit without stopping the simulation.		
4. After simulating a circuit, you can create it on a printed circuit board.		
5. Resistors are used in heaters, toasters, kettles, electric stoves, and many more heating appliances.		
6. Multimeters cannot be used to measure electrical quantities such as frequency, charge, etc.		
7. Voltmeters and ohmmeters are connected in series with the component being measured.		
8. Annotation is like sticky notes for your circuit.		
9. The Tinkercad Circuits multimeter has the option of measuring current in Volts.		
10. The main benefit of using a real breadboard is that if the components are placed incorrectly then they can simply be moved to another location on the breadboard.		

2 Tinkercad Circuits has different options for the wires you can use to connect the components of your circuit. One of them is the wire below that is common for prototyping:



What is the name of this wire type? Can you identify components that can be connected with this type of wire? What are the benefits of using it?

____

____

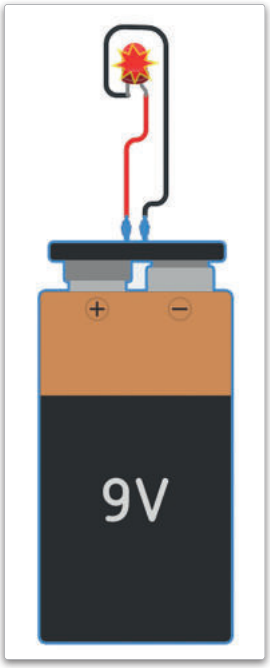
____

____

____

____

3 This circuit has a problem. Diagnose the problem and apply a fix. Justify the change you made to the circuit.



____

____

____

____

____

____

____

4 Explain the meaning of the green markings on the breadboard below.

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____

____

____

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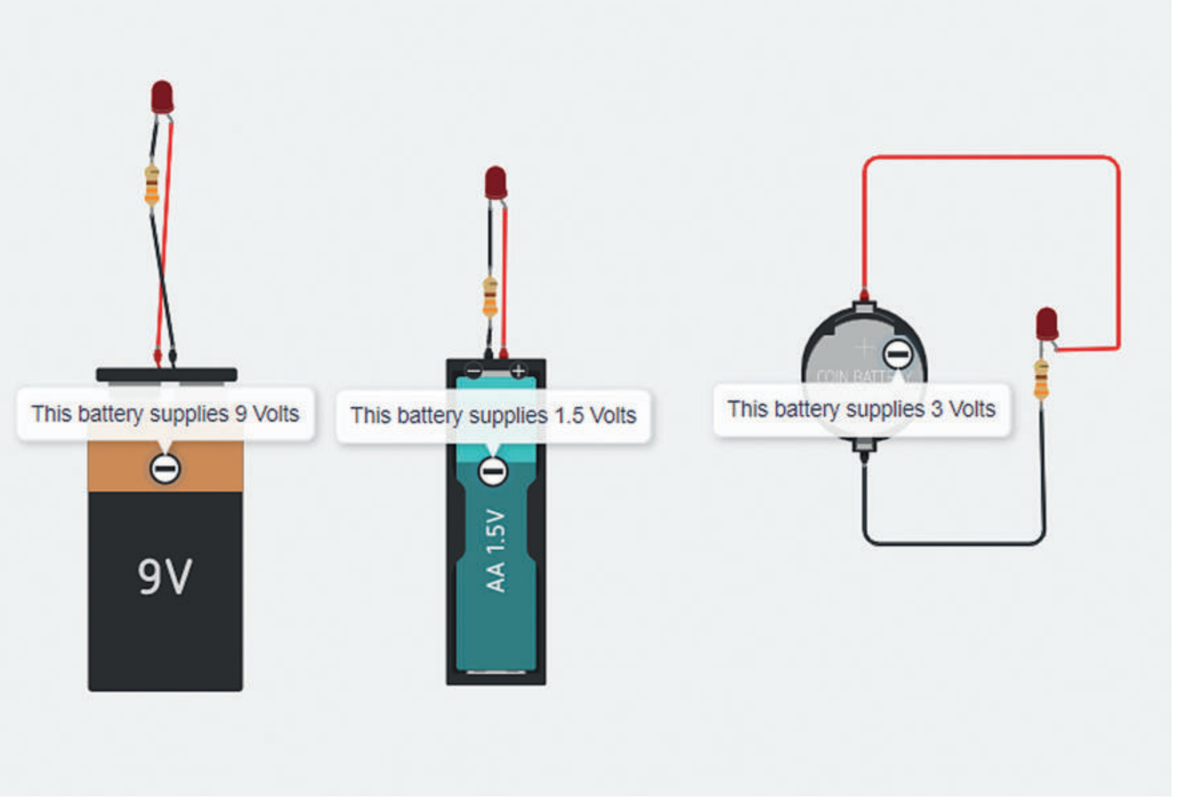
____

____

5 Design the circuit of Exercise 3 in Tinkercad Circuits using different types of batteries. Tinkercad Circuits mainly provides 3 types of batteries: 9V, 3V and 1.5V. Connect your circuit up as shown and note your observations after you simulate it.



____

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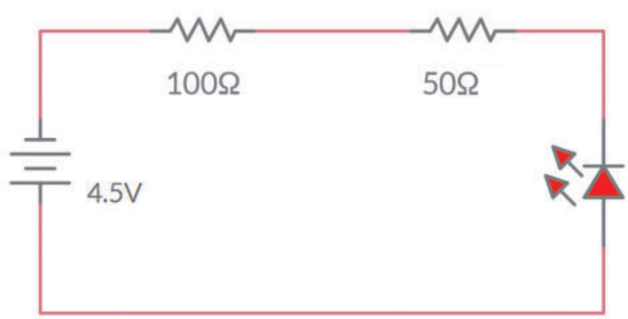
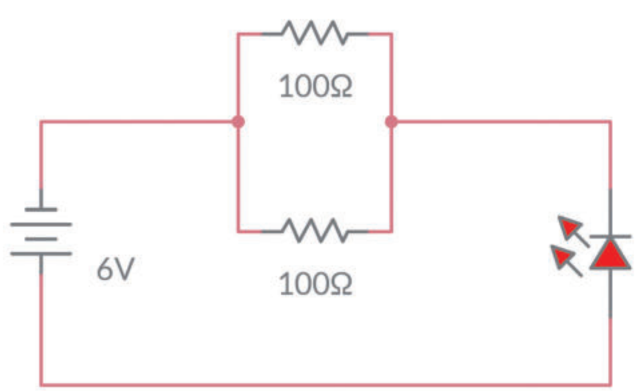
6 Build a circuit with four AA 1.5V batteries, an LED and a 500Ω resistor. Run the simulation and observe the amount of light emitted. Can you predict what will happen if you gradually reduce the number of batteries? Run the simulation with fewer batteries and assess your prediction. Explain what is happening and why.

7 Build and simulate the following circuits with Tinkercad Circuits. Test the electronic circuits and fix any issues you may observe. Change the direction of the battery. What do you notice?



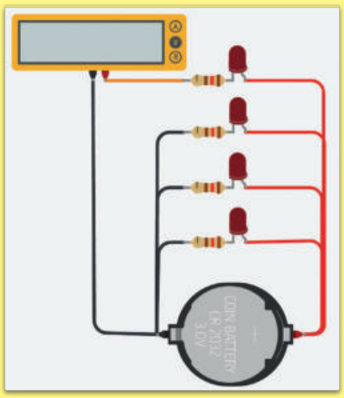


Project

***In this** project, you will learn how your circuit behaves under new conditions such as different battery type or resistance value.*

1

***You have** learned that the two fundamental types of circuits are series and parallel circuits. Let us implement the following parallel circuit.*



***You will** need:*

***1 x** Amperage Multimeter*

***4 x** 120Ω Resistors*

***4 x** Red LEDs*

***1 x** Coin Cell 3V Battery*

2

***Color the** wires appropriately to distinguish negative from positive.*

3

***Build the** circuit by adding one resistor and one LED at a time. Start with this circuit:*

4

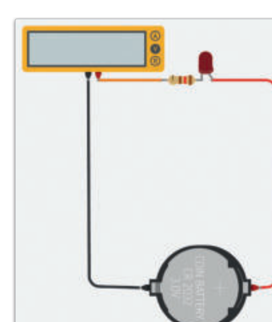
***Run the** simulation and measure the current using the multimeter. Write down the measurement.*

***Add another** resistor and another LED and note down the new current measurement. Repeat for the remaining resistors and LEDs.*

***Observe the** pattern in your measurements. Explain what is happening.*

***Add resistors** and LEDs, change the battery type or the resistance value of each resistor. How does your circuit behave under the new conditions?*

***Visit the** physics lab in coordination with the teacher and try to use the reading of the voltmeter with the batteries?*



Wrap up

Now you have learned:
- > how to design electronic circuits in Autodesk Tinkercad Circuits.
- > how to add, edit and wire electronic components.
- > how to simulate electronic circuits and take measurements.
- > how to test and troubleshoot electronic circuits.

KEY TERMS

Ammeter	LED	Resistor
Breadboard	Multimeter	Schematic View
Circuit	Ohmmeter	Voltmeter
Circuit View	Power Source	Workplane
Component List	Prototyping	
Current	Pushbutton	

5. Simulating a microcontroller-based system

In this unit, students will learn about microcontrollers and other electronic components. More specifically, students will learn how to program a micro:bit microcontroller with Python in Tinkercad Circuits to create simple and complex circuits with various sensors and actuators.

Learning Objectives

In this unit, you will learn to:

> Design circuits using a microcontroller.
> Recognize external components used in microcontroller circuits.
> Describe how different components affect circuit logic.
> Program a micro:bit microcontroller with Python.
> Use the micro:bit temperature and light sensors.
> Design microcontroller circuits for real-life scenarios.
> Demonstrate how a potentiometer regulates voltage in an electronic circuit.
> Describe the use of a transistor.
> Use a transistor as an amplifier in an electronic circuit.
> Use a DC motor as an actuator for movement.

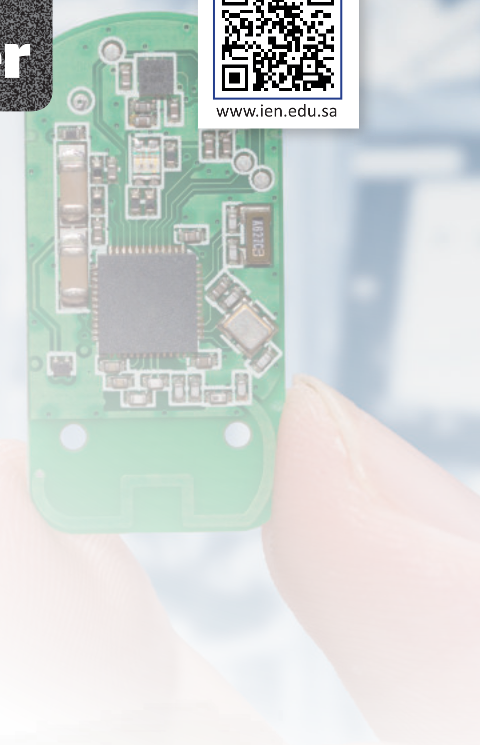
Tools

> Autodesk Tinkercad Circuits

Lesson 1

Programming a Microcontroller

Link to digital lesson
www.ien.edu.sa



Microcontrollers

In the modern world, computers are a common part of many people's lives. Most of us are familiar with computers that use a mouse and keyboard for user input and a monitor for output, however, another type of computer, the microcontroller, usually operates without human interaction. A typical computer could be used to run multiple programs simultaneously, such as playing video games and getting email, but the microcontroller can only run one program at a time. Essentially, a microcontroller is a specialized computer with mostly nonhuman input and output devices for interaction with the outside world. Other names for this type of computer are single-board microcontrollers or embedded systems. In all cases, it integrates a processor, memory and some kind of input and output.

Rather than having a mouse, keyboard, and monitor as peripherals, the microcontroller uses devices called sensors as inputs and actuators as outputs. A sensor examines the environment and senses specific stimuli, such as touch, sound, temperature,humidity and light almost in the same way as human senses detect stimuli from the surrounding world. These sensors respond to stimuli by generating a change in voltage or a digital signal. Our body works in a similar way, with our human sense organs that transmit signals to our brain through the nervous system.

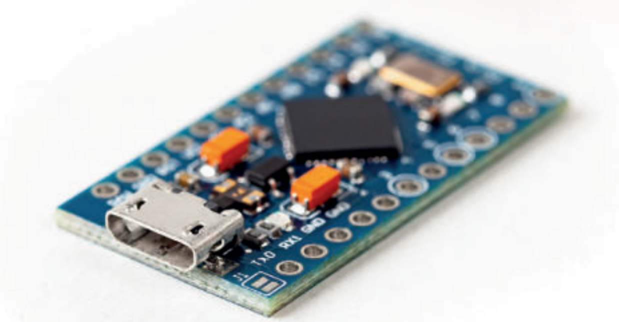


Figure 5.1: Microcontroller board

The Microcontroller is almost like a tiny computer brain. But this tiny brain gets stimuli from its sensors as input to a program running in a continuous loop. The program can react and change outputs accordingly. For example, if the temperature is extreme in a building, a microcontroller that checks for fire conditions can trigger an alarm.

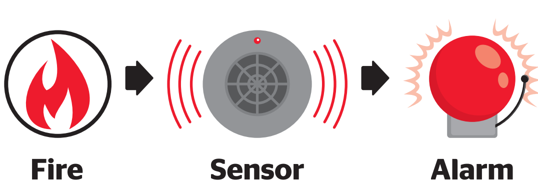


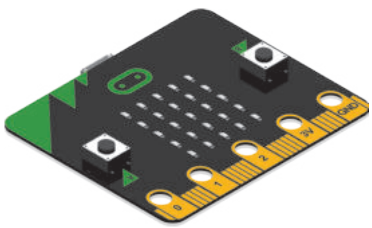
Figure 5.2: Fire alarm system

INFORMATION

The job of a microcontroller might be to run the air-conditioning system in a building, monitor and control the operation of an engine in a car, or run machinery on an automated assembly line.

Although microcontrollers can mimic some human functions, do not mistake their operation with true intelligence. We might call a device "smart" or "intelligent," but all of them operate in a predefined way, following a very specific procedure based on their programming. It does not matter how elaborate the device or how good the program is that runs on the machine. Computers and microcontrollers as hardware cannot truly be considered intelligent.

The Raspberry Pi is considered by some to be a microcontroller, like the Arduino. In reality, the Raspberry Pi is a tiny computer that can connect directly to a monitor and input devices such as a keyboard and mouse. At the same time, a full operating system can be loaded via a MicroSD memory card.



Micro:bit

Arduino UNO

Figure 5.3: Popular microcontrollers

There are various microcontrollers around us, such as in autonomous IoT devices or inside other electronic equipment and machinery. The most popular microcontrollers for prototyping are the Arduino and micro:bit boards. Both can be simulated in Tinkercad Circuits, but there are some important differences.

An Arduino microcontroller, such as Arduino Uno R3, is more powerful in terms of programming, but the micro:bit board has an integrated display and sensors for temperature, light, motion, sound and orientation.

Microcontrollers

Advantages

- They consume small amounts of electricity and do not produce much heat.
- Because of their size they can be placed in smaller circuits.
- They are adept at single task operations.
- They exist with a wide range of memory, from 4-bit to 128-bit microprocessors.

Disadvantages

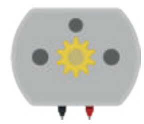
- In general, they cannot handle multitask operations.
- New programs need to be inserted manually.
- They have limited processing power.
- They generally have no operating system.

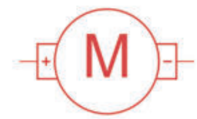
External Components for Microcontroller Circuits

DC motor

Direct Current (DC) motors are electronically controlled devices that generate rotary movement from electrical power. They include a shaft that rotates so that wheels and gears can be attached to them to provide a wide range of motion. DC motors are produced in a wide variety of forms, and they operate in a range from 1.5V to 24V and up to 8000 RPM (Rotations Per Minute). They can be used used for applications that require high RPM.


DC motor


Simulator component



Schematic symbol

Figure 5.4: DC motor

Piezo buzzer

Piezoelectric buzzers are small devices that can generate sound signals. They contain small crystals like quartz and topaz that exhibit the piezoelectric effect. When electrical currents pass through these crystals, they expand and contract repeatedly causing them to vibrate. These rapid vibrations are the source of the sounds generated by these buzzers.


Piezo buzzer


Simulator component

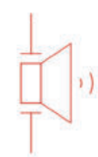
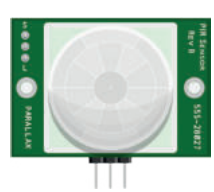

Schematic symbol

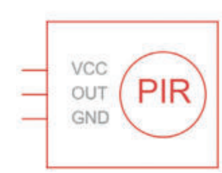
Figure 5.5: Piezo buzzer

PIR sensors

Passive Infrared (PIR) sensors are electronic sensors that can detect objects in a specific Field Of View (FOV). They work by measuring the infrared radiation signals that are present in the FOV that they examine. When an object passes through the FOV, the distribution of those signals changes and the sensor detects that an object is present. They are used for monitoring applications such as security alarms and room lighting controls.


PIR sensor


Simulator component



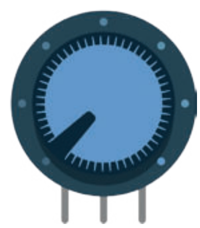
Schematic symbol

Figure 5.6: PIR sensor

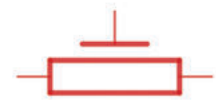
Potentiometer (Variable Resistor)

Potentiometers are small devices that are used to manually adjust the voltage that is applied to a specific part of a circuit. They utilize Ohm's law which we learned about in a previous lesson. Ohm's law states that $V = I \times R$. For constant current, if you want to change the voltage, you need to adjust the resistance. Potentiometers allow you to modulate the voltage to the desired value by manually adjusting the resistance.

Potentiometer



Simulator component

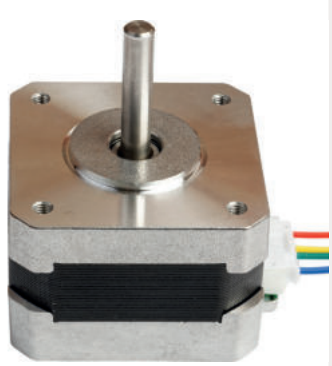


Schematic symbol

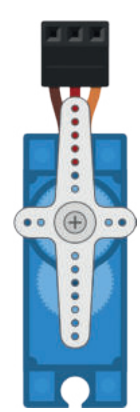
Figure 5.7: Potentiometer

Servomotors

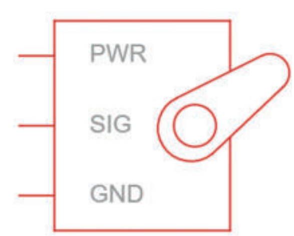
Servomotors are a special type of motor with two defining features. They operate within a limited range of motion, and they provide position feedback so that their controller is informed of the exact angle that the servomotor has turned. Servomotors are used for actions that require high-precision motion like robotic applications and manufacturing operations.



Servomotor



Simulator component



Schematic symbol

Figure 5.8: Servomotor

Micro:bit

The Micro:bit microcontroller in Tinkercad Circuits environment

With Tinkercad Circuits, you can simulate microcontroller circuits using a simple block-based programming language or the Python programming language.

In this unit, you will utilize the micro:bit as a microcontroller in an environment that allows for experimentation. In microcontroller projects there are two parts to every project. The first is the circuit itself, which includes the sensors, the actuators and the wiring that connects all components. The second is the code used to program the microcontroller. This code manages the inputs from the sensors and sends instructions to the actuators. In the Tinkercad simulator, Python for micro:bit is utilized.

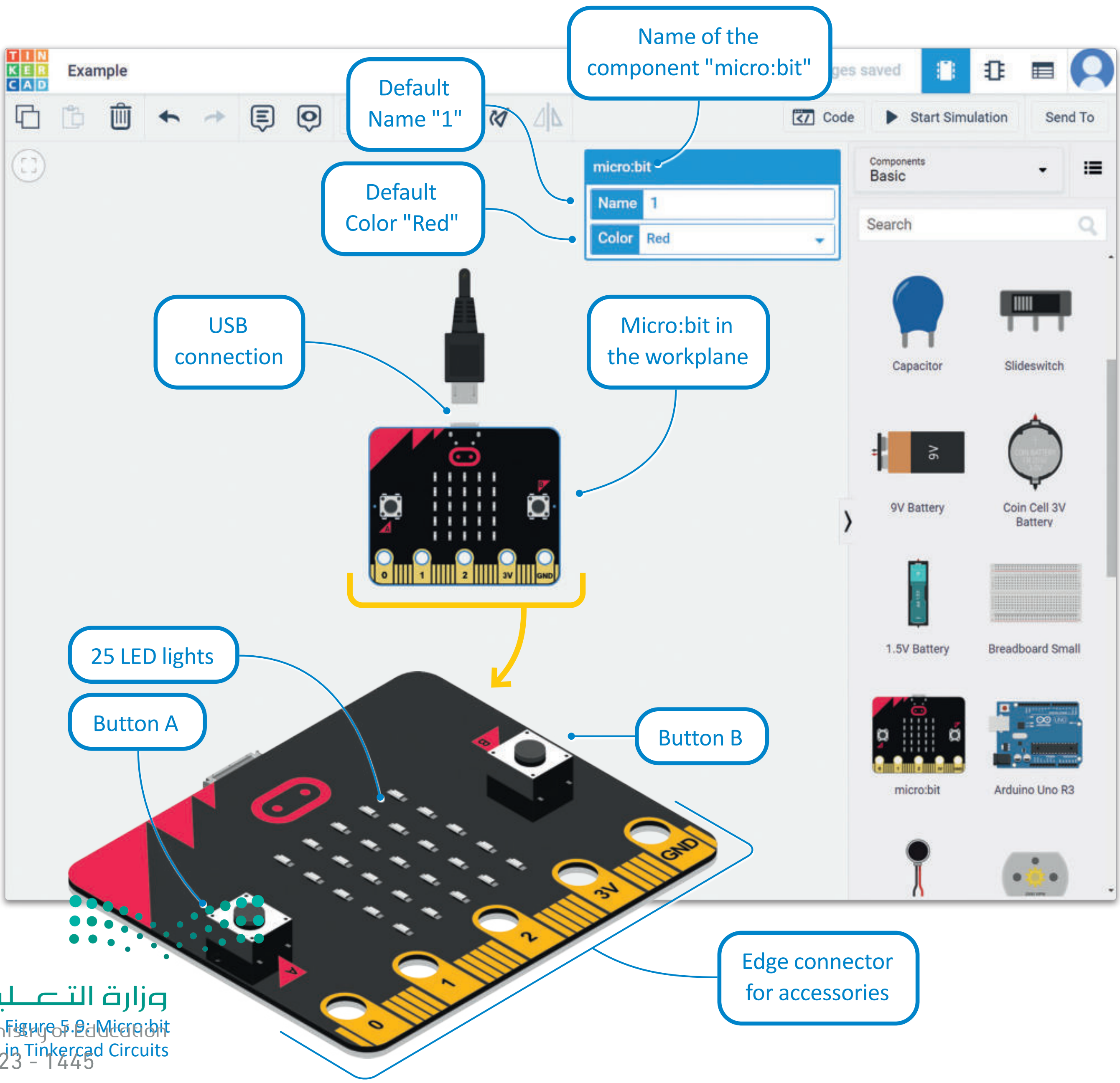


Figure 5.9: Micro:bit in Tinkercad Circuits

Python Programming

You have learned how to write code in Python in previous books/courses in this series. The code used here will be similar. Let's see how Python is implemented for micro:bit in the Tinkercad Circuits code editor.

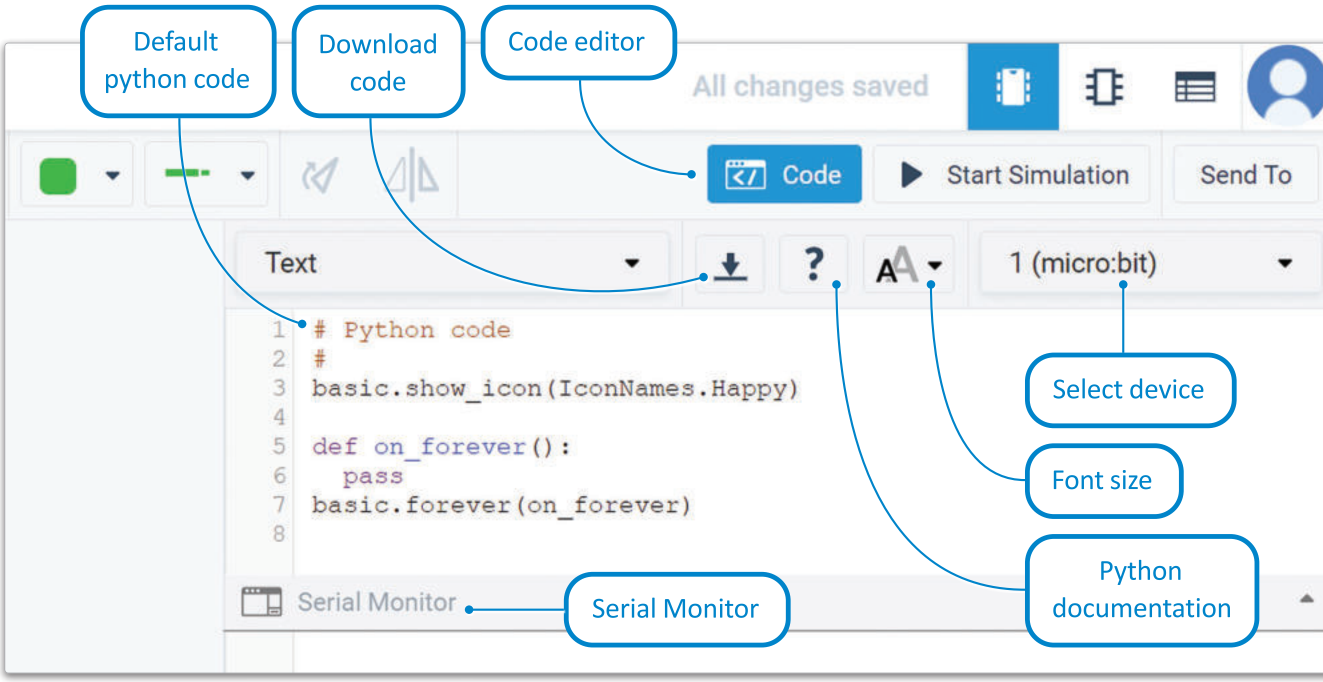


Figure 5.10: Tinkercad Circuits code editor

Let's take a look at some commands that we are going to use:

To pause after an action is completed, use the following method which takes an argument in milliseconds:

```
basic.pause(1000)
```

Pause for 1 second.

The following code will begin when you press the Start Simulation button and stop when you press the End Simulation button.

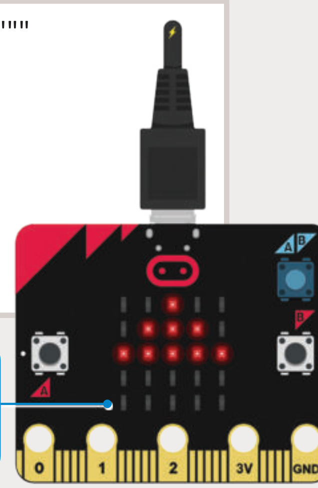
```
def on_forever():
  # Your circuit logic here
basic.forever(on_forever)
```

The code that will replace the comment will run without stopping.

Display a custom shape through the LED light matrix:

```
basic.show_leds("""
. . # . .
. # # # .
# # # # #
. . . . .
. . . . .
""")
```

The LED lights matrix will turn on at the locations where the '#' symbols are.



LED light matrix

Let's see how you can use the things that you have learned.

You will create a program to show two icons, '0' then '1' ,alternating every second on the LED light matrix and repeating forever.

First you need to find micro:bit in the components library and drag it to the workplane.

To add micro:bit:

> Find **micro:bit** in the **components library** 1 and drag and drop it into the **workplane**. 2

> Click on the **drop down menu** 3 and choose **Green**. 4

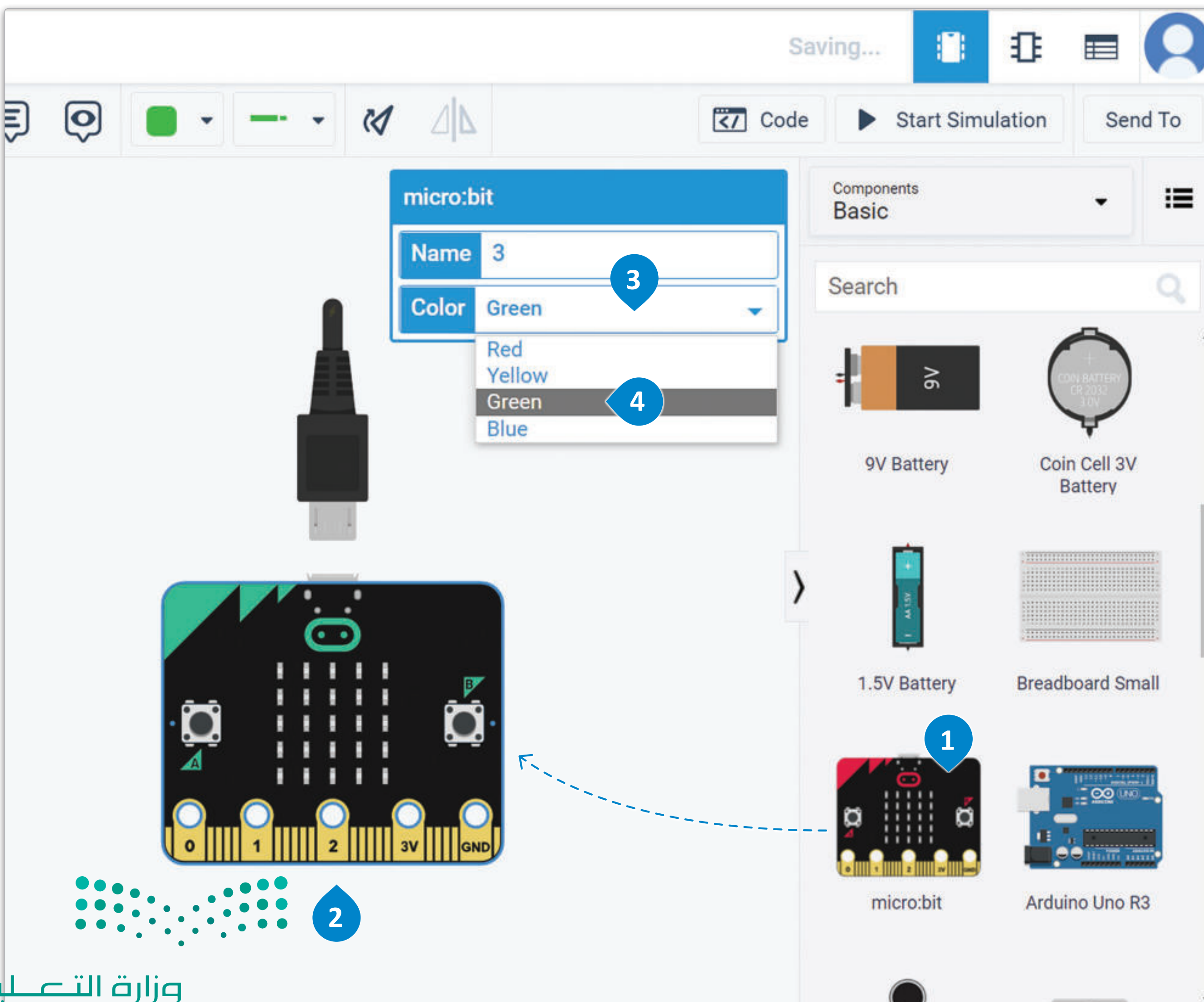


Figure 5.11: Add micro:bit

Now, you need to open the code editor:

To open the code editor:

> Click on **Blocks** drop down menu. 1
> Select **Text** from the drop down menu. 2
> Click **Continue** 3 to open text editor. 4

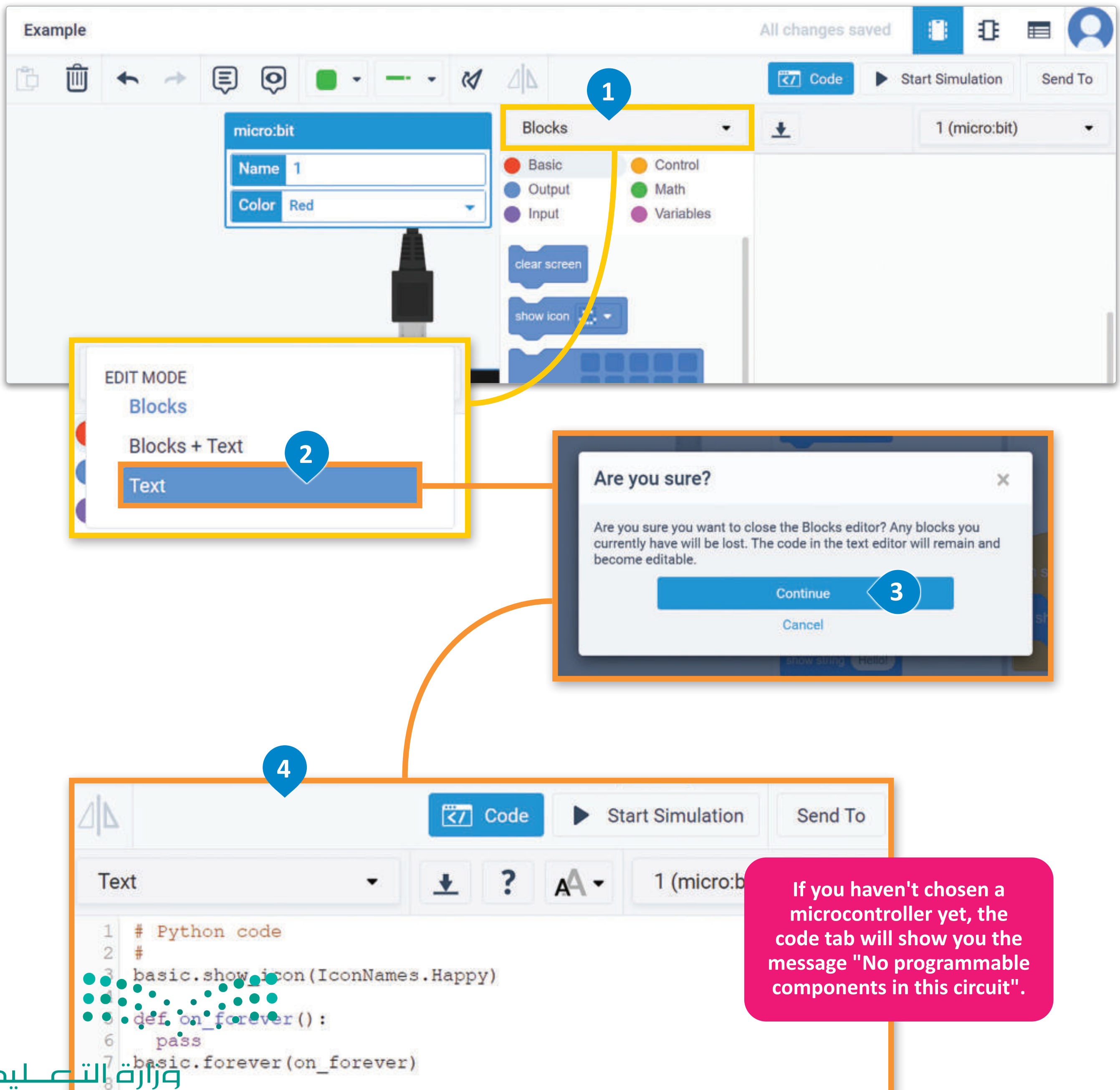


Figure 5.12: Open the code editor

Continue by writing the code in the code shown below editor and then start the simulation.

Writing code:

> Write the code in the **text editor**. 1

> Click **Start Simulation** button. 2

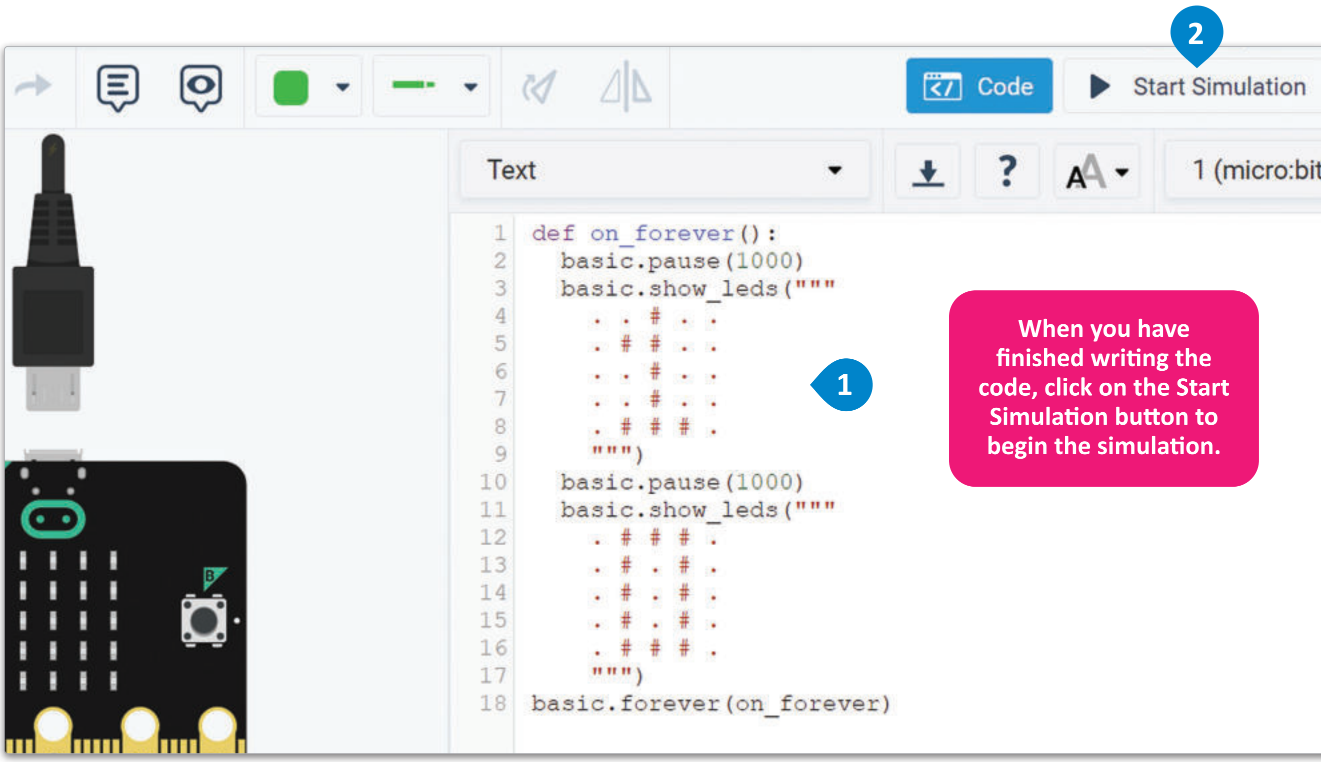
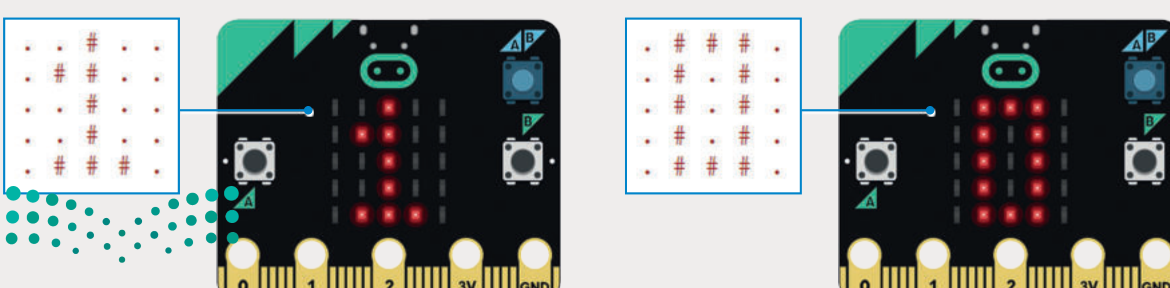


Figure 5.13: Writing code

When the simulation is running on the LED light matrix, you can see the following results:



micro:bit Sensors

When you start the simulation, a window appears in the workplane. This window lets you adjust the properties of the simulation environment that affect the micro:bit's sensors, more specifically, the compass, the light sensitivity sensor, the temperature sensor and the accelerometer.

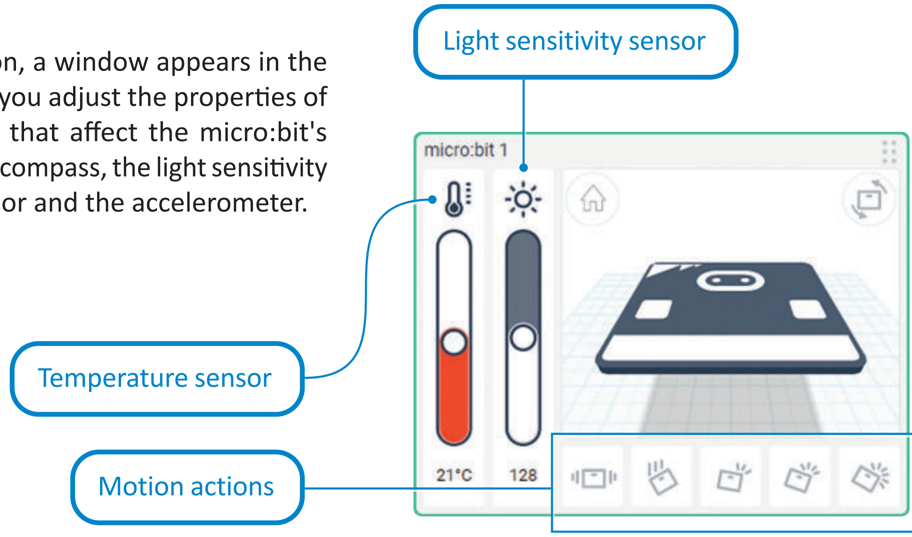


Figure 5.14: Micro:bit sensor adjustments

Temperature indicators

To get inputs from integrated micro:bit sensors, e.g. temperature and light level, you need the following methods:

In the plot_bar_graph() method, the second argument is the maximum value that is represented by the plot. For example, in the Tinkercad simulator the maximum light level and temperature values are 255 and 50 respectively.

input.temperature()

Input the current value of the temperature sensor

```
def on_forever():
  led.plot_bar_graph(input.temperature(), 50)
basic.forever(on_forever)
```

Temperature sensor maximum value 50 °C

input.light_level()

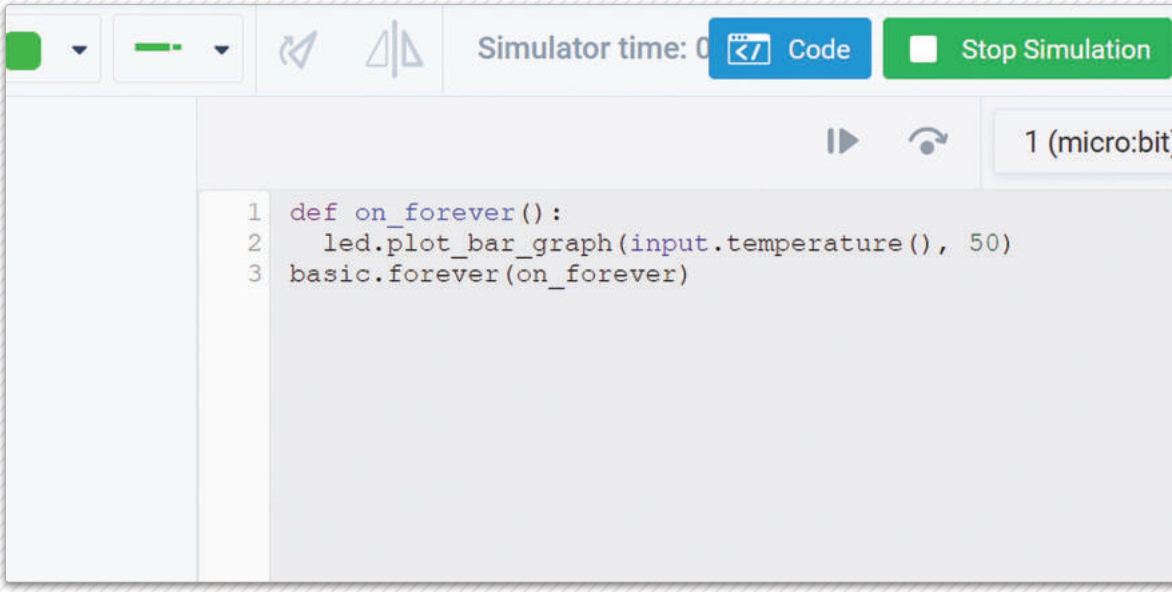
Input the current value of the light sensitivity sensor

```
def on_forever():
  led.plot_bar_graph(input.light_level(), 255)
basic.forever(on_forever)
```

Light sensitivity sensor maximum value 255

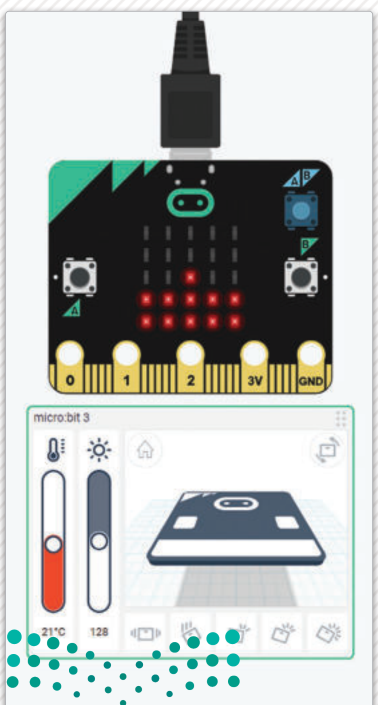
Let's first see an example of how you can use the temperature sensor with the LED light matrix.

Example

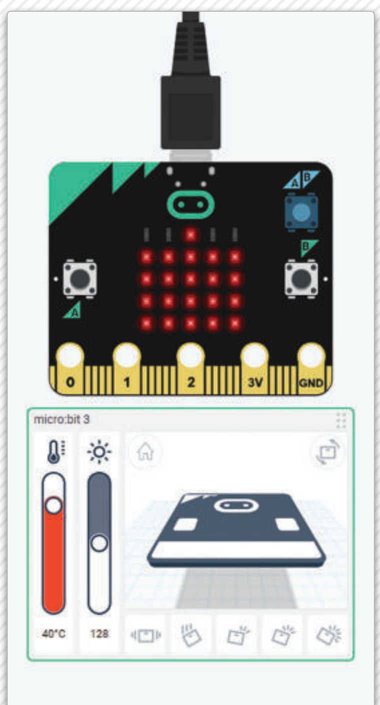



```
def on_forever():
  led.plot_bar_graph(input.temperature(), 50)
basic.forever(on_forever)
```

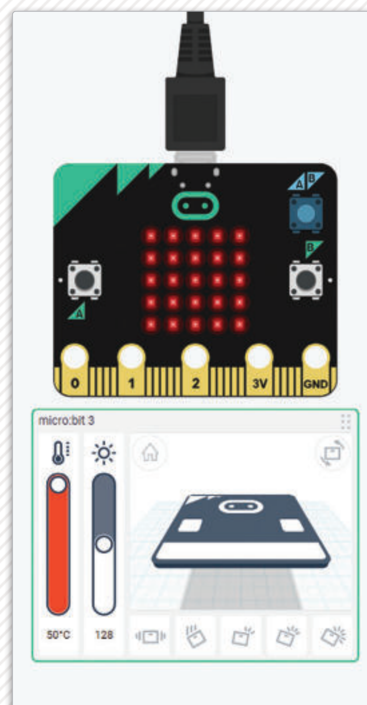
Temperature at 21 °C



Temperature at 40 °C



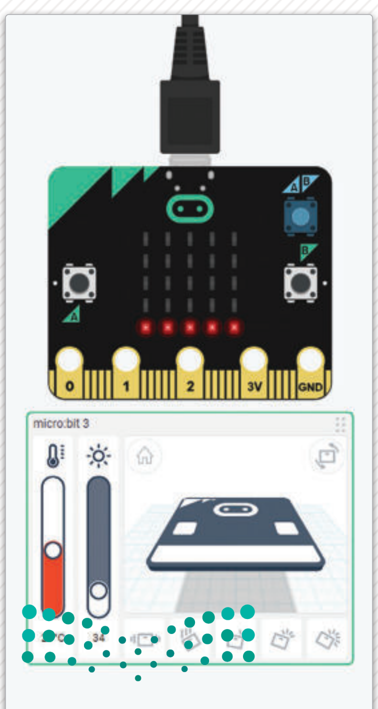
Temperature at 50 °C



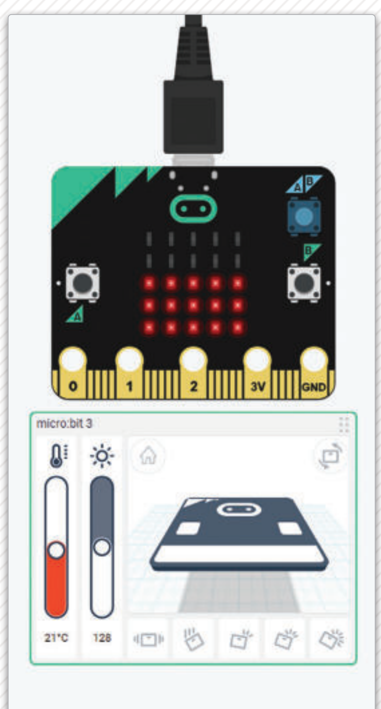
Now, let's see another example but this time you are going to use the light sensitivity sensor with the LED light matrix.

Example

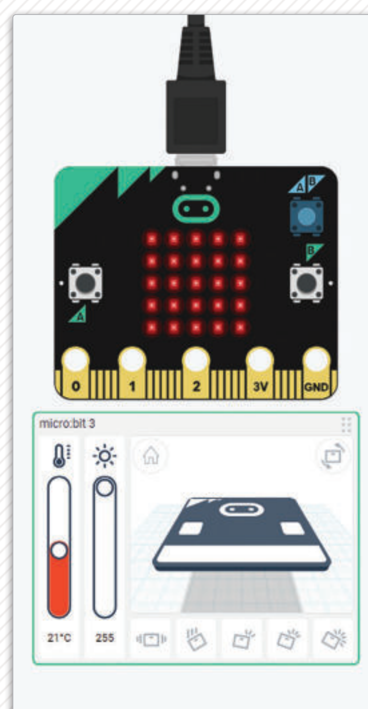
Light level at 34



Light level at 128



Light level at 255



Exercises

1 How do you use a microcontroller?

____

____

____

____

2 What are the advantages of using microcontrollers?

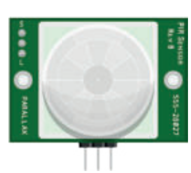
____

____

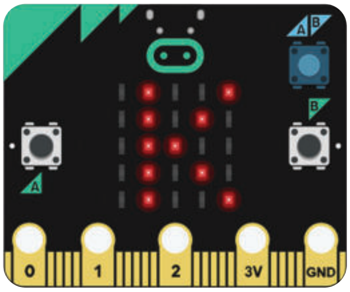
____

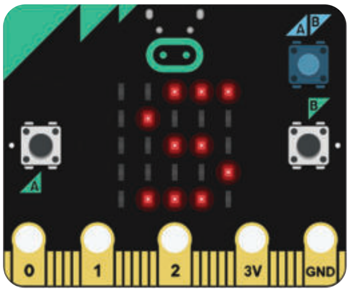
____

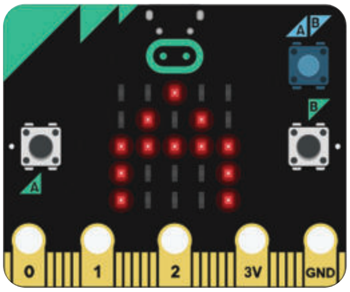
3 Match the items in the first row with those in the second.

Simulator component					
Name	**PIR sensor**	**Servomotor**	**Piezo buzzer**	**Potentiometer**	**DC motor**

4 Create a program to show the three letters, " K ", " S "and " A " alternating every second on the LED light matrix and repeated forever.







Change the program to make each letter flash twice quickly before it shows the next letter. Add a pause with a blank matrix at the end of the loop.

5 Why do we use the value 50 as a maximum value for temperature when we use led.plot_bar_graph?

What will happen if we use another value?

Run the simulator and explain what you observe.

____

____

____

____

6 Create a program on the micro:bit that displays an UP arrow when the temperature is above 21 degrees and a DOWN arrow when the temperature is lower than 21 degrees.

What else do you need to check?

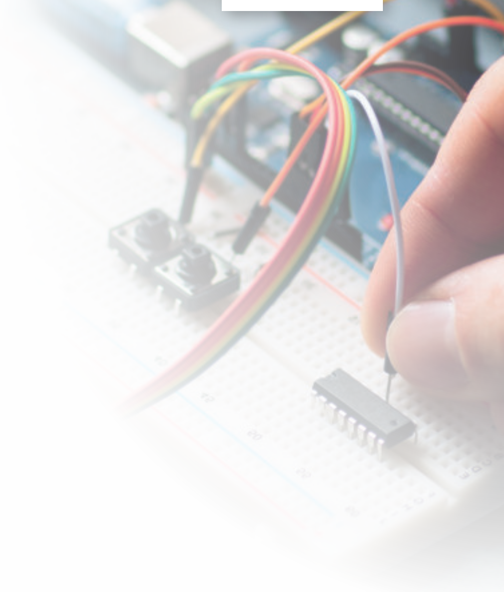
Fix your program so it works properly in all temperature conditions.

Llink to digital lesson

www.ien.edu.sa

Lesson 2

Circuit with Microcontroller



Building a Simple Traffic Light System

Microcontrollers like micro:bit can also be connected to a breadboard. This can make it easier to design more complex circuits by allowing more components to be interconnected.

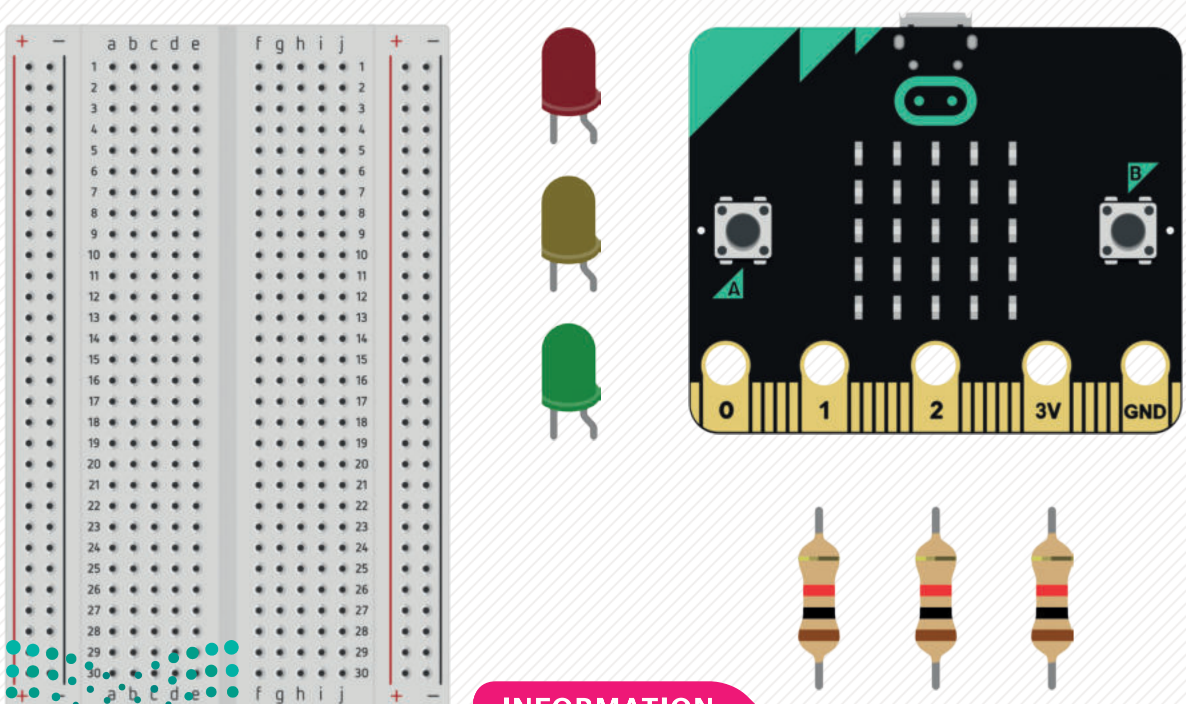
We will begin this lesson by building a simple traffic light system with 3 LEDs and 3 resistors connected to a breadboard.

Each LED will emit light briefly for 300 millisecondsbefore the microcontroller switches to the next LED. The LEDs are connected to the pins P0, P1 and P2 of the micro:bit.

- P0 --> Red LED
- P1 --> Yellow LED
- P2 --> Green LED

The micro:bit will send a digital signal of 1 to each pin for 300 milliseconds. This will allow electrical current to flow through the wires and the LEDs to emit light. The circuit and the code are illustrated below.

Components that you will use in this project



INFORMATION

A resistor is used to limit the current through the LED and to prevent excess current that can burn out the LED.

Let's start by adding the micro:bit to the workplane.

To add micro:bit:

> Find the **micro:bit** in the **components library** 1 and drag and drop it into the **workplane**. 2

> Click on the **drop down menu** 3 and choose **Green**. 4

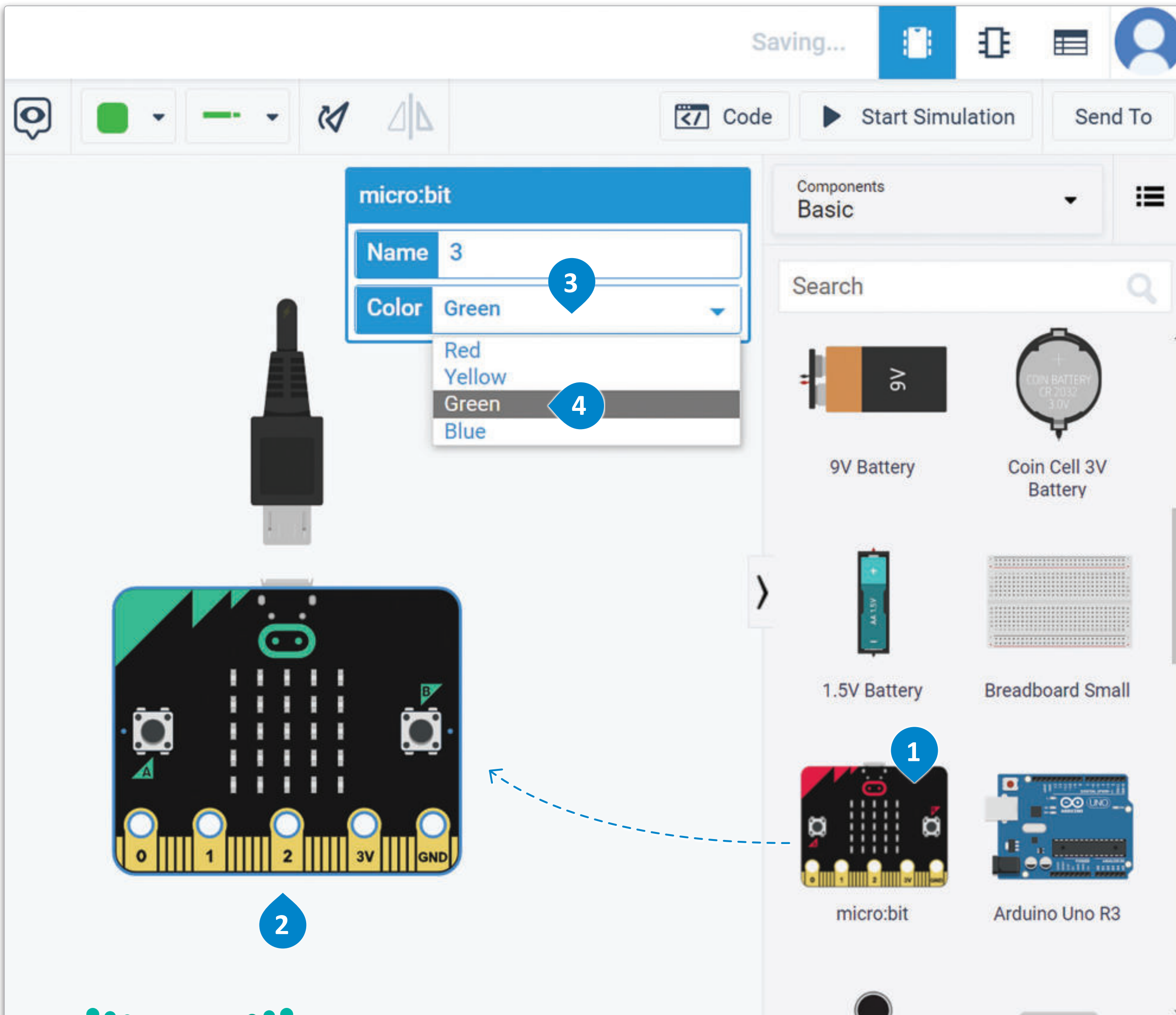


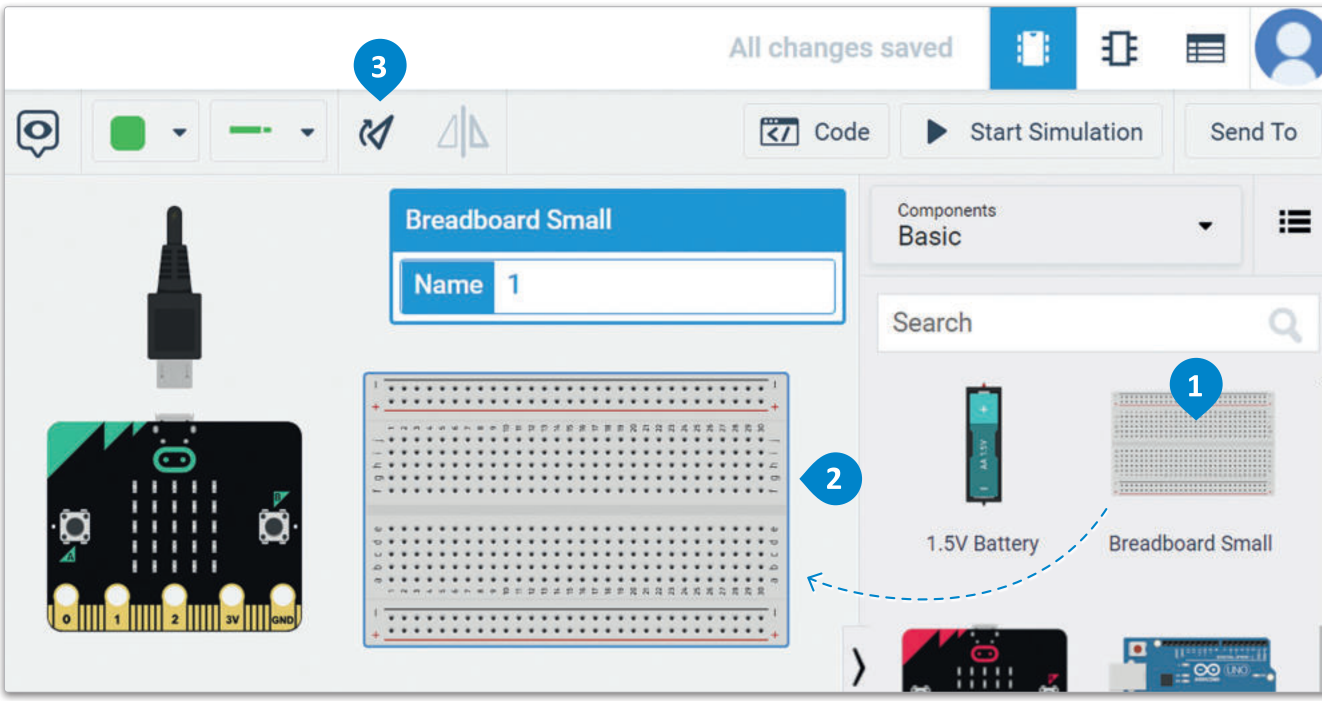
Figure 5.15: Add micro:bit

Now, you will add a breadboard to the workplane.

To add breadboard:

> Find the **breadboard** in the **components library** 1 and drag and drop it into the **workplane**. 2

> Click on the **rotation** button three times. 3



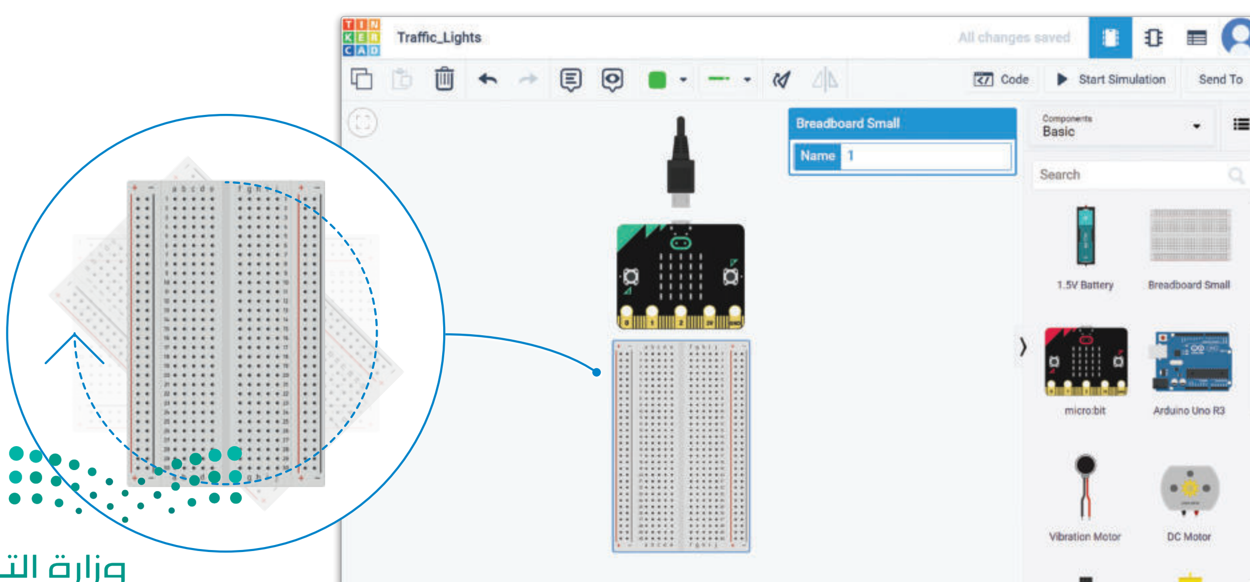


Figure 5.16: Add breadboard

Next, you will add three LEDs to the workplane and change their colors to red, yellow and green. You will also add three resistors of 1kΩ each to the workplane.

To add LEDs and resistors:

> Find the **LED** in the **components library** 1 and drag and drop three of them into the **workplane**. 2

> Change the colors of the **second LED** from **red** to **yellow** and the **third LED** from **red** to **green**. 3

> Find the **resistor** in the **components library** 4 and drag and drop three of them into the **workplane**. 5

> **Rotate** the **LEDs** and **resistors** to be horizontal. 6

Don't forget, in Tinkercad when you place a resistor in the workplane, the default value is 1kΩ.

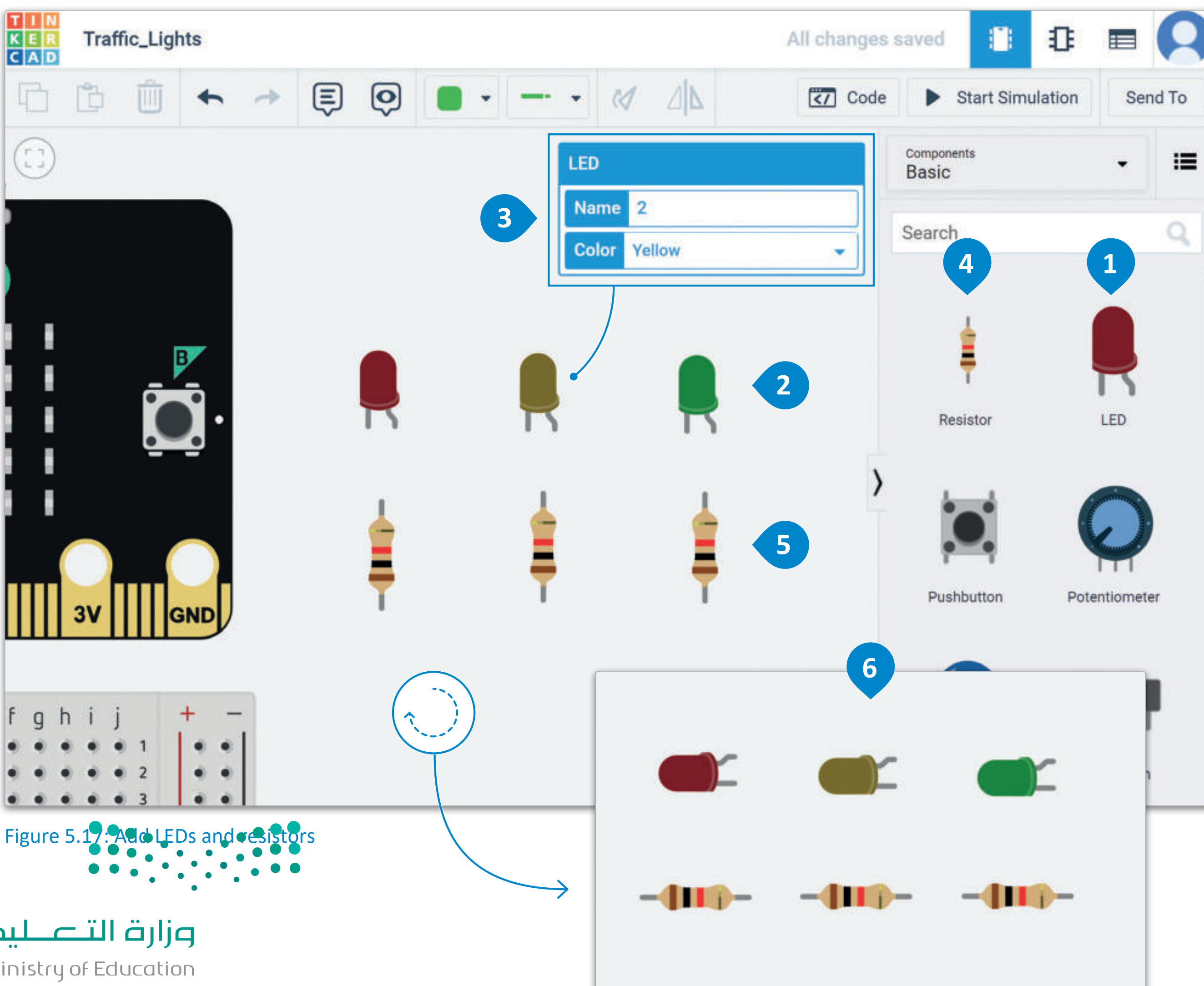


Figure 5.17: Add LEDs and resistors

Continue by connecting each resistor – LED light pair in series on the breadboard.

To connect components on the breadboard:

> Drag 1 and connect the three **LEDs** and **resistors** to the **breadboard** so that each wire of the **LEDs** and **resistors** is in a hole. 2

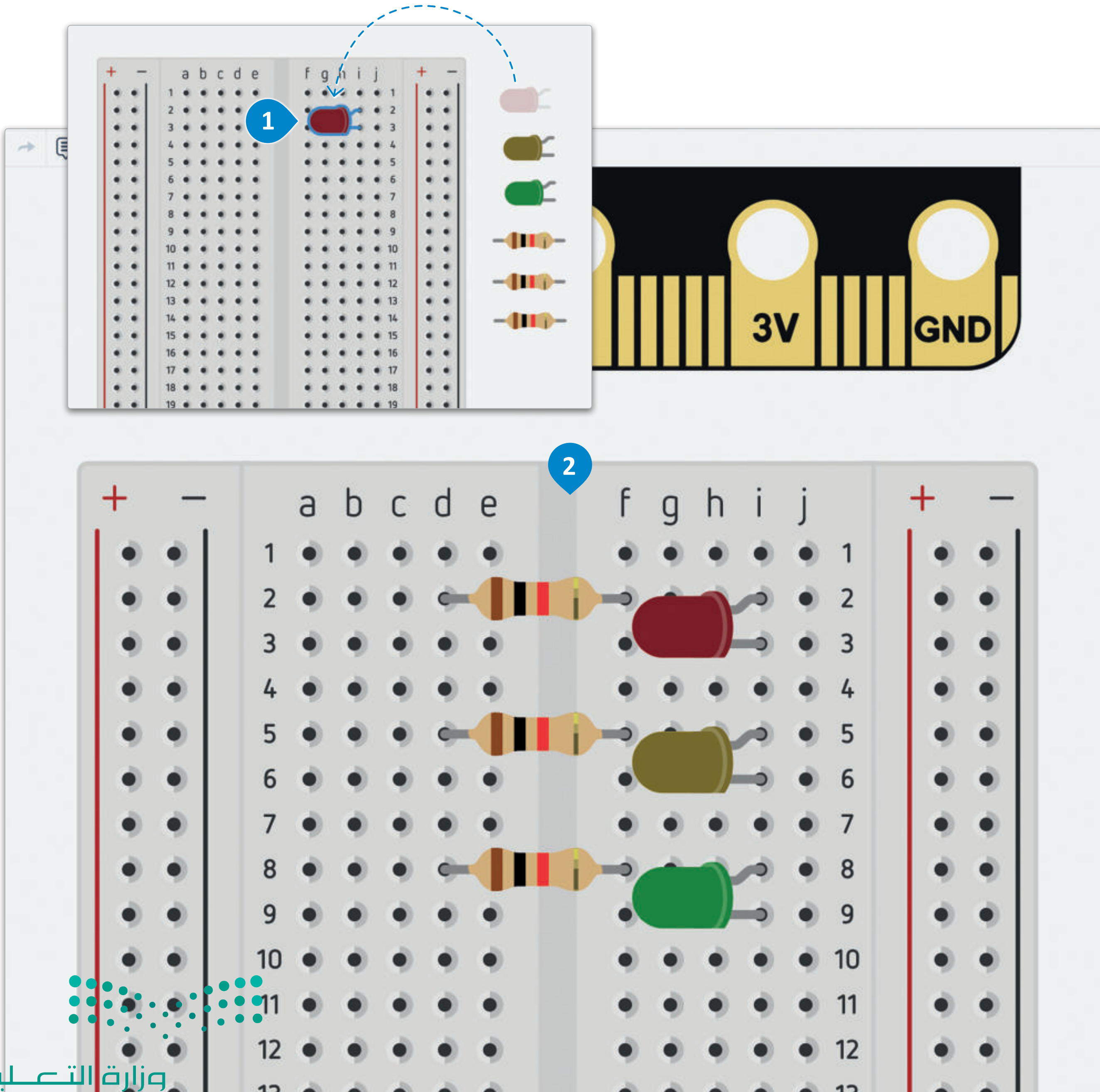


Figure 5.18: Connecting components on the breadboard

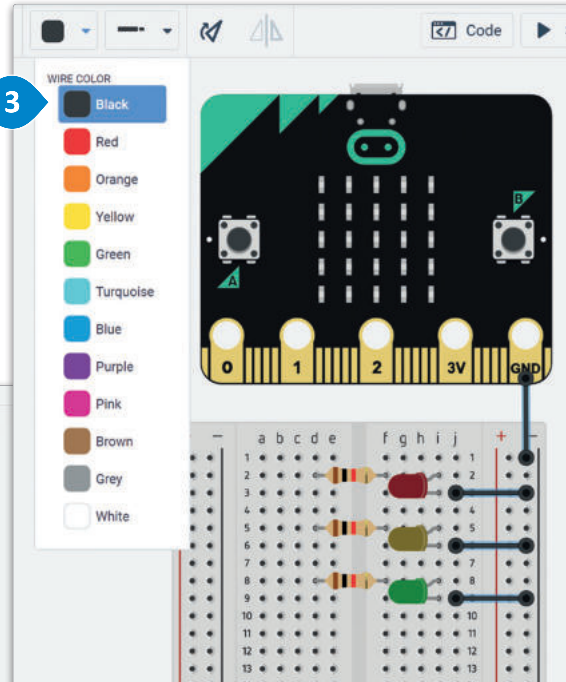
Now you are going to use wires to connect the cathode of each LED light to the ground pin of the micro:bit.

To wiring cathodes to the ground pin:

> Connect the micro:bit **ground pin** to the **negative column** of the **breadboard**. 1

> Connect the three **LED cathodes** to the **negative column** of the **breadboard**. 2

> Change all the wires to **black** to indicate the **negative** connections. 3



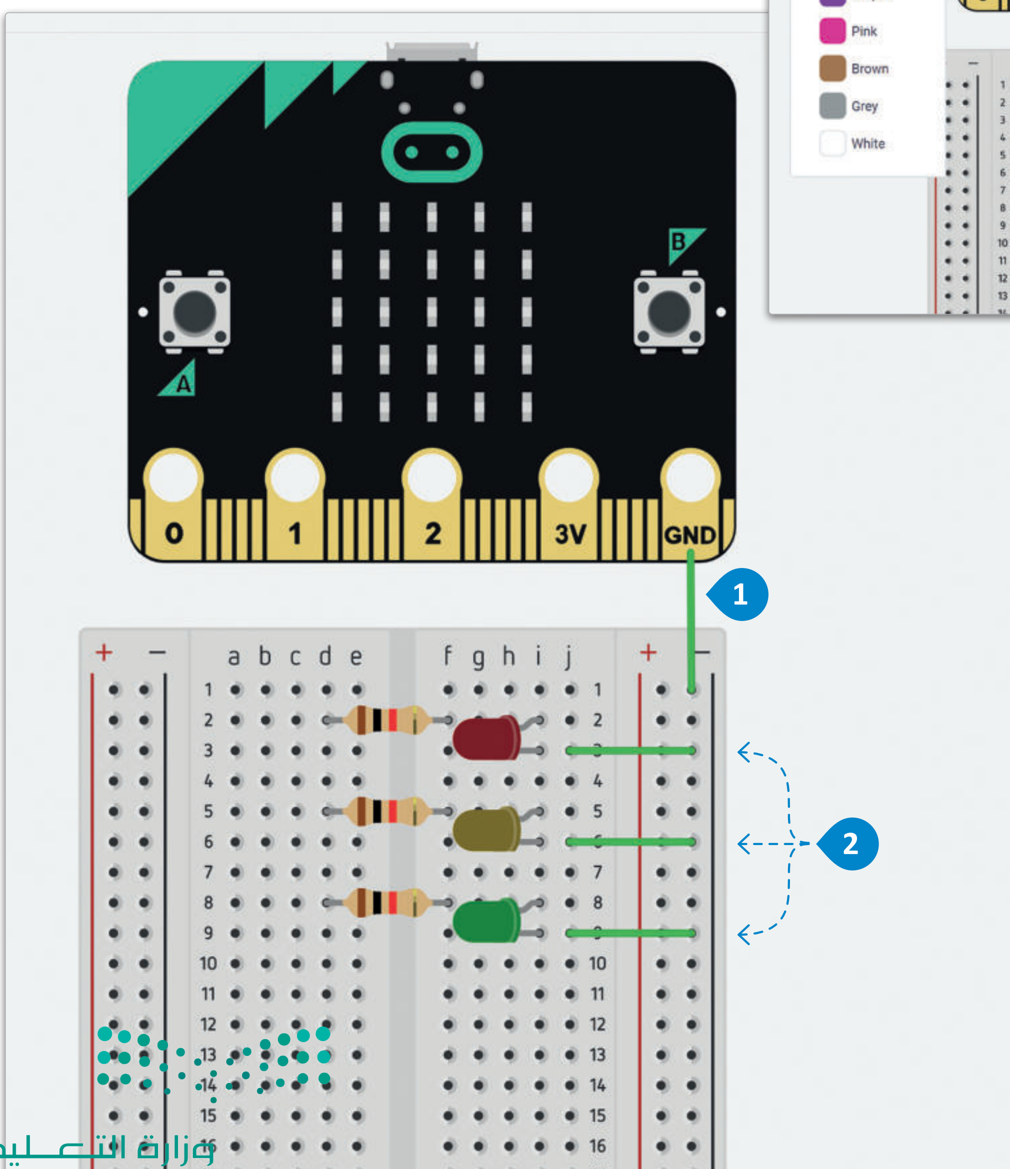


Figure 5.19: Wiring cathodes to the ground pin

Finally you are going to connect the pins P0, P1 and P2 to each resistor – LED light pair.

To wiring pins:

> Connect micro:bit **P0** to hole **a2** of the **breadboard**. 1

> Connect micro:bit **P1** to hole **a5** of the **breadboard**. 2

> Connect micro:bit **P2** to hole **a8** of the **breadboard**. 3

To have a clear circuit with well-organized wires, when you have one point of a wire attached to a component, you can click on a point in the workplane to bend the wire there. Another way to bend a wire is by double clicking the wire at a specific point.

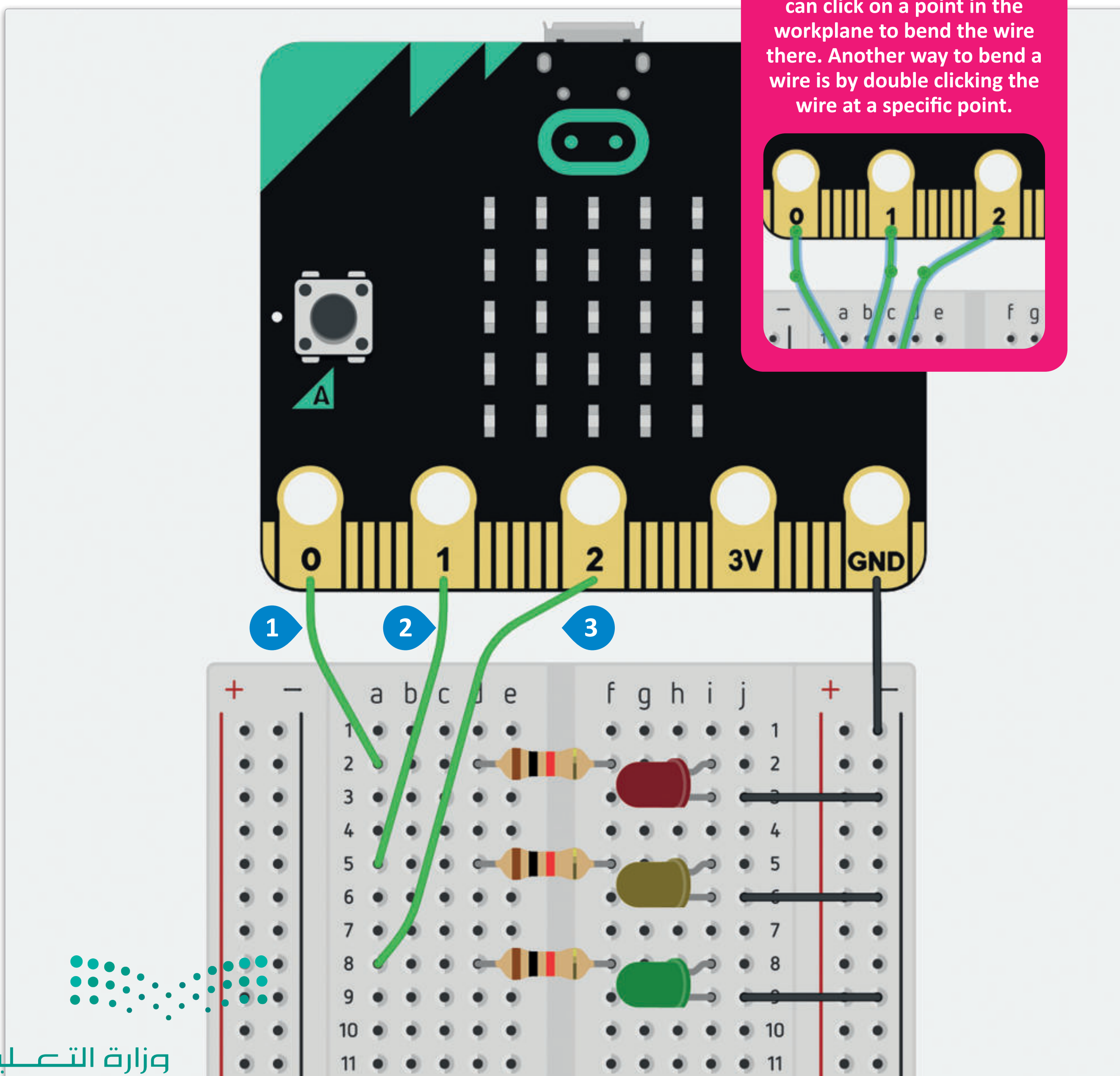


Figure 5.20: Wiring pins

Now that you have finished preparing the components you are ready to start coding. Let's take a look at some of the commands for micro:bit pins that you can use in Python:

To set which pin the micro:bit (P0, P1, or P2) sends pitch signals from:

```
pins.analog_set_pitch_pin(AnalogPin.P0)
```

To read a value from analog pin P0 use the following command:

```
pins.analog_read_pin(AnalogPin.P0)
```

To write a value to a pin, use the following commands. Here we write the value from the analog pin P0 to the analog pin P2.

```
p0_value = pins.analog_read_pin(AnalogPin.P0)
pins.analog_write_pin(AnalogPin.P2, p0_value)
```

Analog pin values can be any number, while digital pin values must be 0 or 1.

```
pins.digital_write_pin(DigitalPin.P1, 0)
pins.digital_write_pin(DigitalPin.P1, 1)
```

Write the following code and start the simulation.

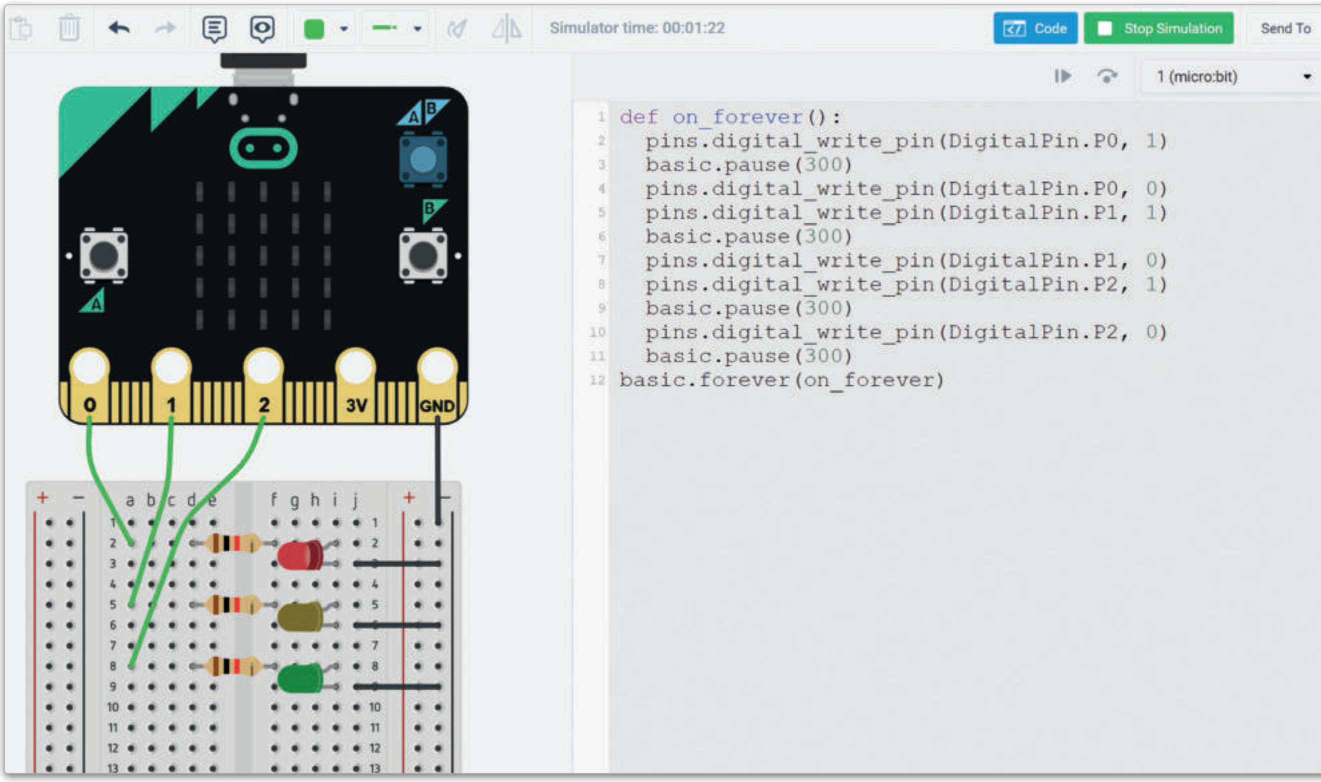
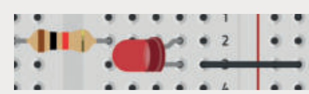


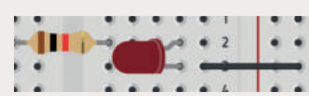
Figure 5.21: Test code

You will observe the three LED lights flashing alternately every 300 ms.

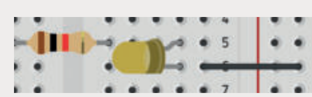
pins.digital_write_pin(DigitalPin.P0, 1)



pins.digital_write_pin(DigitalPin.P0, 0)

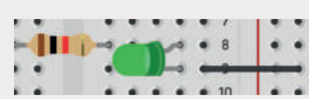


pins.digital_write_pin(DigitalPin.P1, 1)

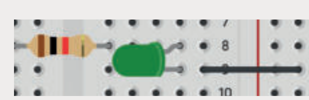


pins.digital_write_pin(DigitalPin.P1, 0)

pins.digital_write_pin(DigitalPin.P2, 1)



pins.digital_write_pin(DigitalPin.P2, 0)



Building a Detection Alarm System

We will now build a circuit that uses a PIR sensor and a piezo buzzer to create an alarm system. We will program the analog pin P2 of the micro:bit to emit analog pitch signals. The negative end of a piezo buzzer will be connected to the micro:bit ground, and its positive end will be connected to the analog pin P2 in order to receive the pitch signals.

The PIR sensor will detect if an object has entered its FOV. If there is an object present, it will send a digital signal of 1 to the micro:bit pin P0. The micro:bit will then display an exclamation mark and emit a pitch sound twice with an interval of 100 milliseconds.

The PIR sensor is connected to 3 wires, one for the ground, one for the power, via the 3V pin of the micro:bit, and one for the digital signal it sends to pin P0.

Let's create the circuit and write the code for our project.

Figure 5.22: PIR sensor and a piezo buzzer

To add micro:bit:

> Find **micro:bit** in the **components library** 1 and drag and drop it into the **workplane**. 2

> Click on the **drop down menu** 3 and choose **Green**. 4

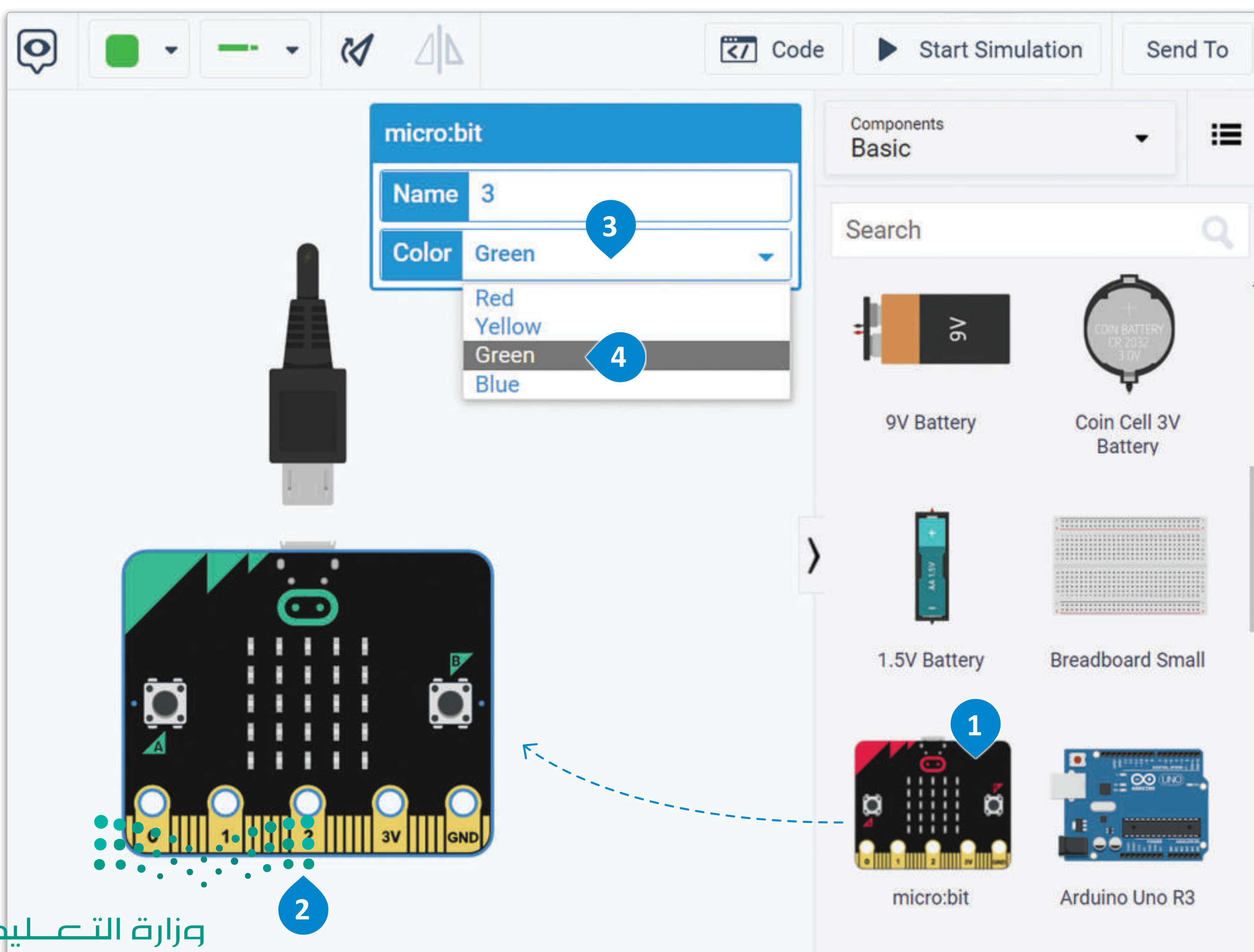


Figure 5.23: Add the micro:bit

Add a piezo buzzer to the workplane.

To add piezo buzzer:

> Find the **piezo buzzer** in the **components library** 1 and drag and drop into the **workplane**. 2

> **Rotate the piezo buzzer** so the **pins** point towards the **micro:bit**. 3

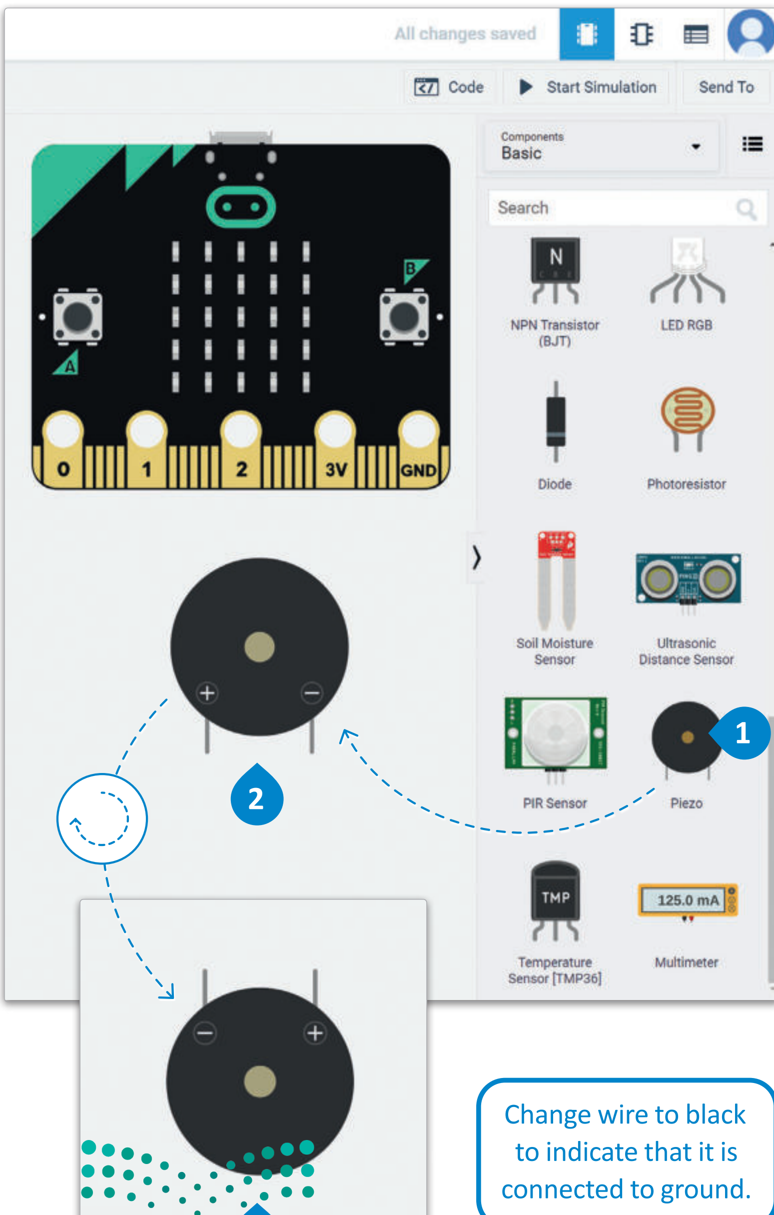


Figure 5.24: Add a piezo buzzer

Connect the positive end of the piezo buzzer to pin P2 of the micro:bit.

This will be the analog pin that will send a pitch signal to the piezo buzzer.

Wire the piezo buzzer:

> Connect the **positive pin of the piezo buzzer** 1 to **pin 2** of the **micro:bit**. 2

> Connect the **negative pin of the piezo buzzer** 3 to the **ground pin** of the **micro:bit**. 4

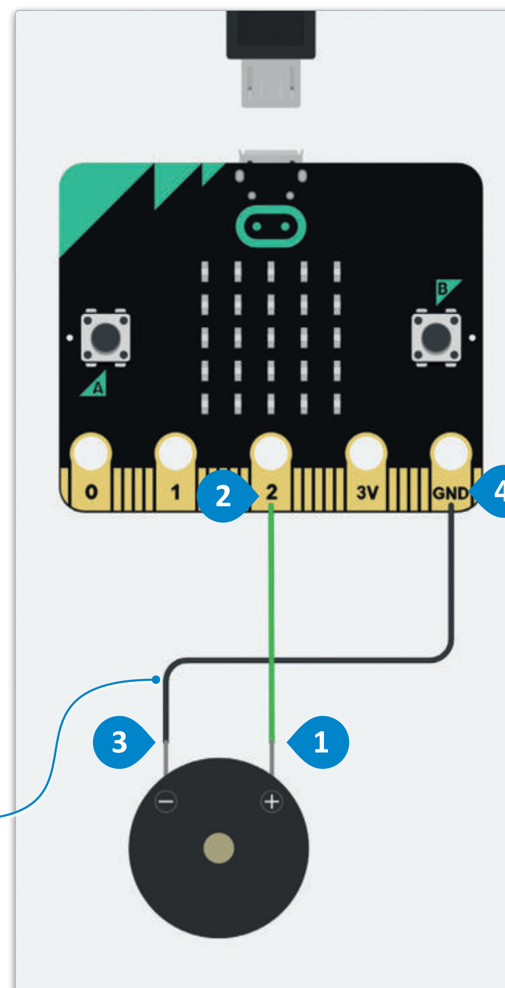


Figure 5.25: Wire the piezo buzzer

Add a PIR Sensor to the workplane.

To add PIR Sensor:

> Find the **PIR Sensor** in the **components library** 1 and drag and drop it into the **workplane**. 2

> **Rotate** the **PIR Sensor** so the **pins** point towards the **micro:bit**. 3

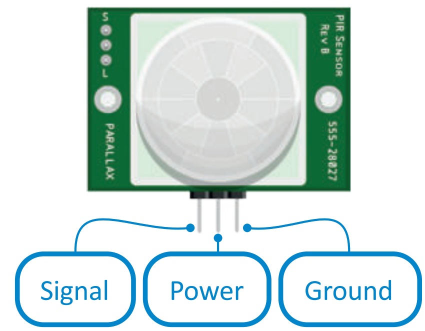


Figure 5.26: PIR Sensor

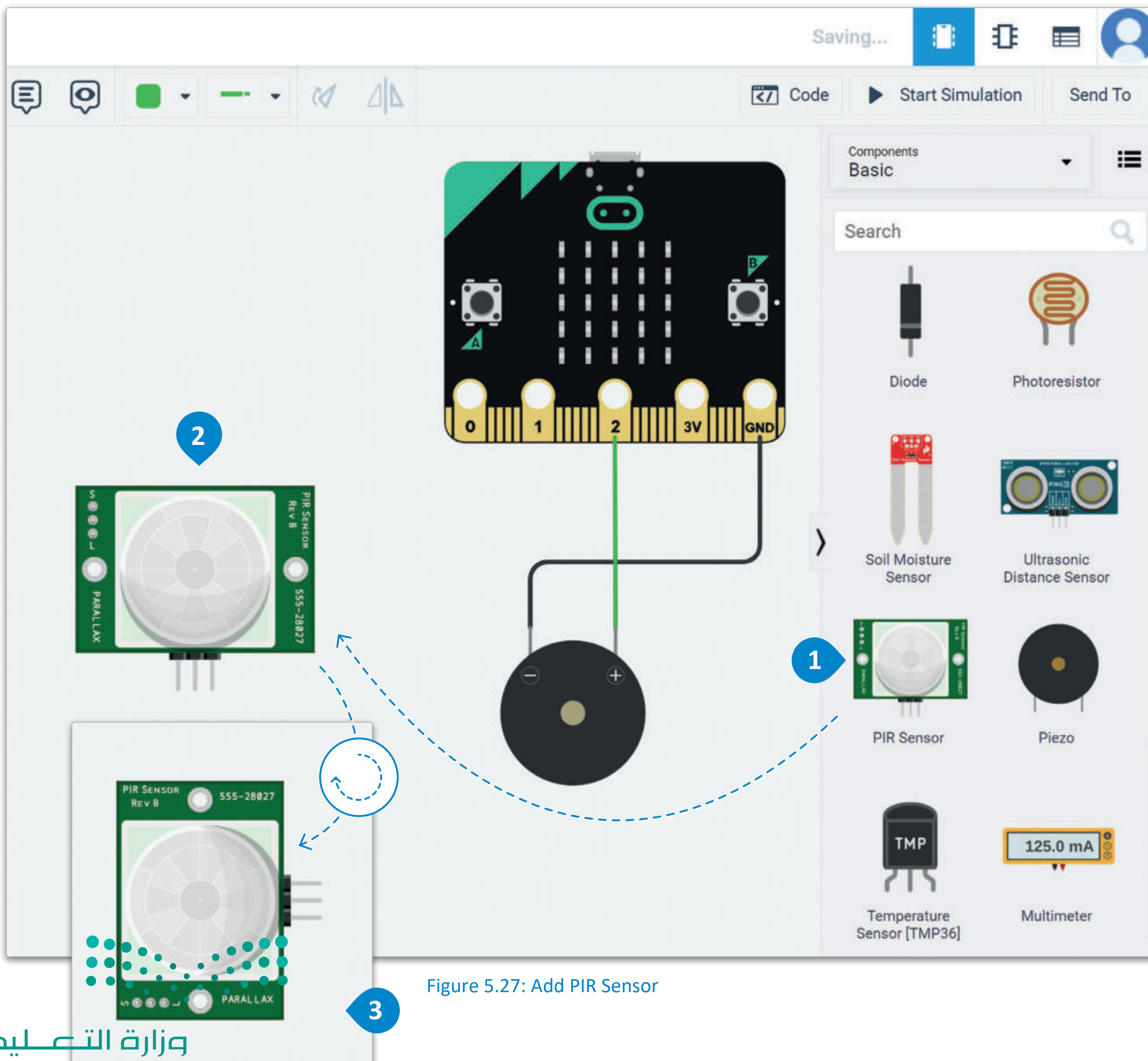


Figure 5.27: Add PIR Sensor

Connect the ground end of the PIR Sensor to the GND pin of the micro:bit.

To connect PIR:

> Connect the **PIR Sensor Ground pin** 1 to the **GND pin of** the **micro:bit.** 2

The default color of a new wire is the color that you used for your previous wire.

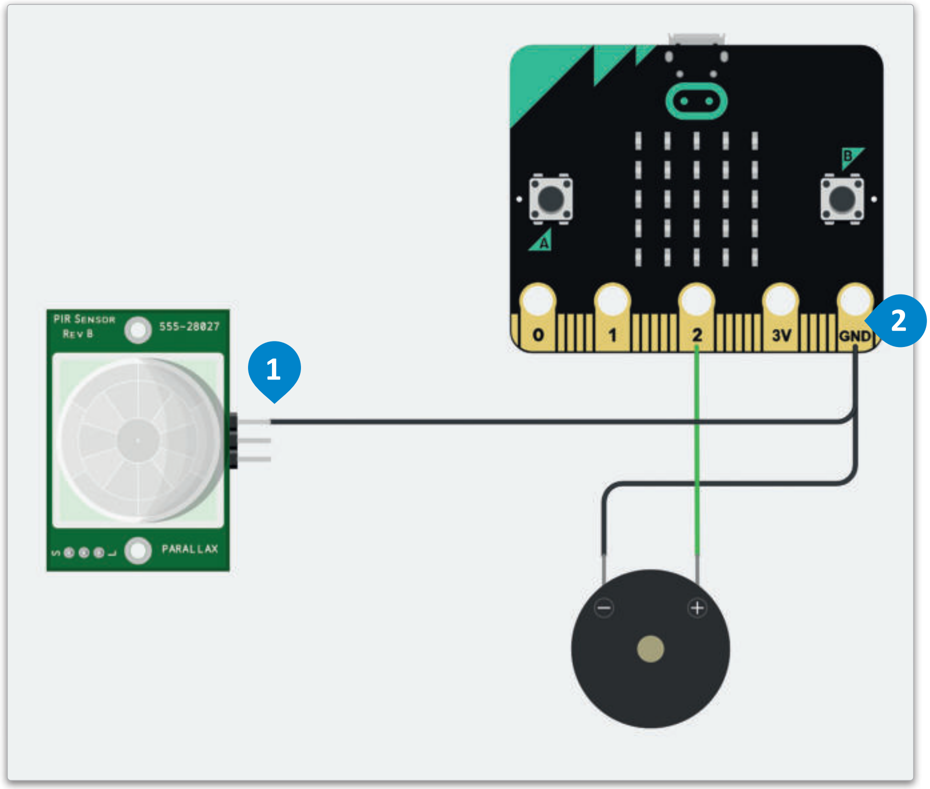


Figure 5.28: Connect the Ground pin of the PIR Sensor

Connect the Power pin of the PIR Sensor to the 3V power source of the micro:bit.

To connect PIR:

> Connect the **PIR Sensor Power pin** 1 to the **3V power source** of the **micro:bit.** 2

> Change the color of the wire to **red.** 3

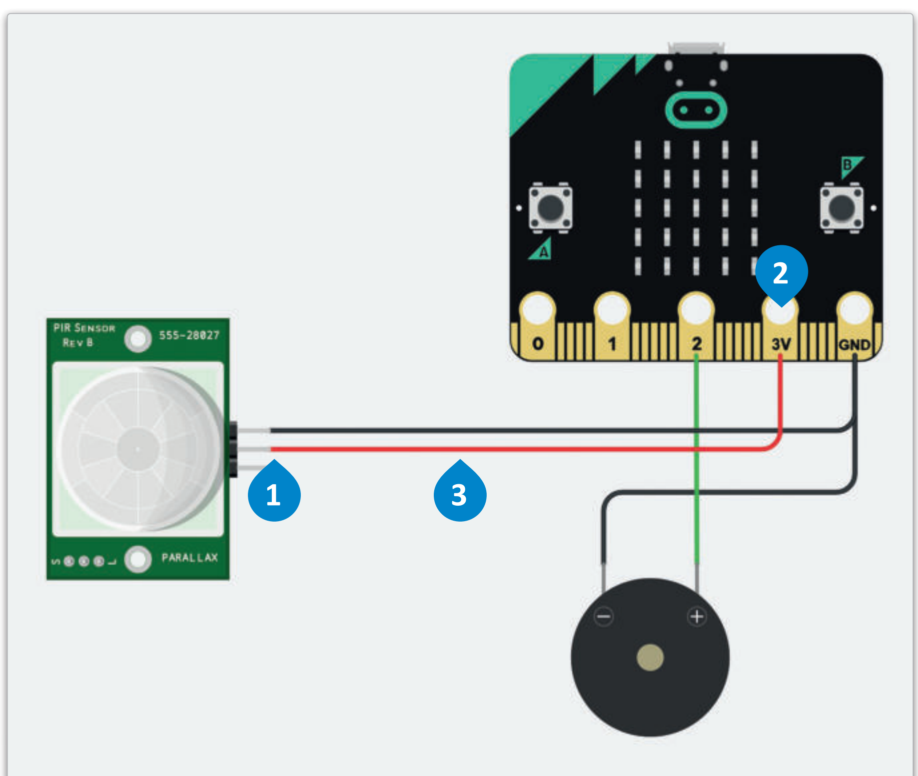


Figure 5.29: Connect the Power pin of the PIR sensor

Connect the Signal pin of the PIR Sensor to pin P0 of the micro:bit. This will be the digital pin that will send a signal of 1 when there is an object detected in the PIR Sensor's FOV.

To connect PIR:

> Connect the **PIR Sensor Signal pin** 1 to **pin 0** of the **micro:bit**. 2

> Change the color of the **wire** to **green**. 3

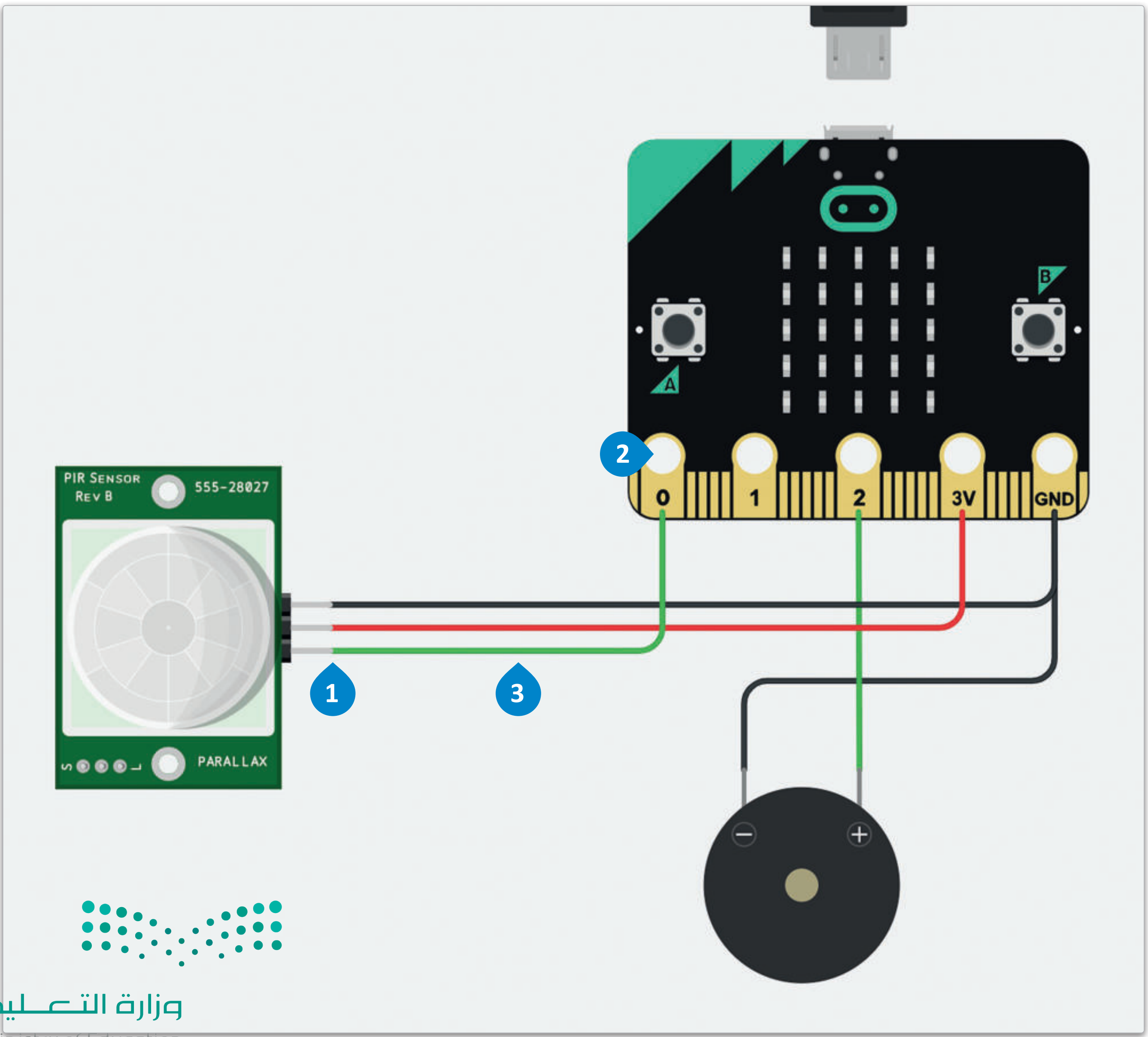


Figure 5.30: Connect the Signal pin of the PIR sensor

Now that you have finished with the connections, you can add the following code and test it.

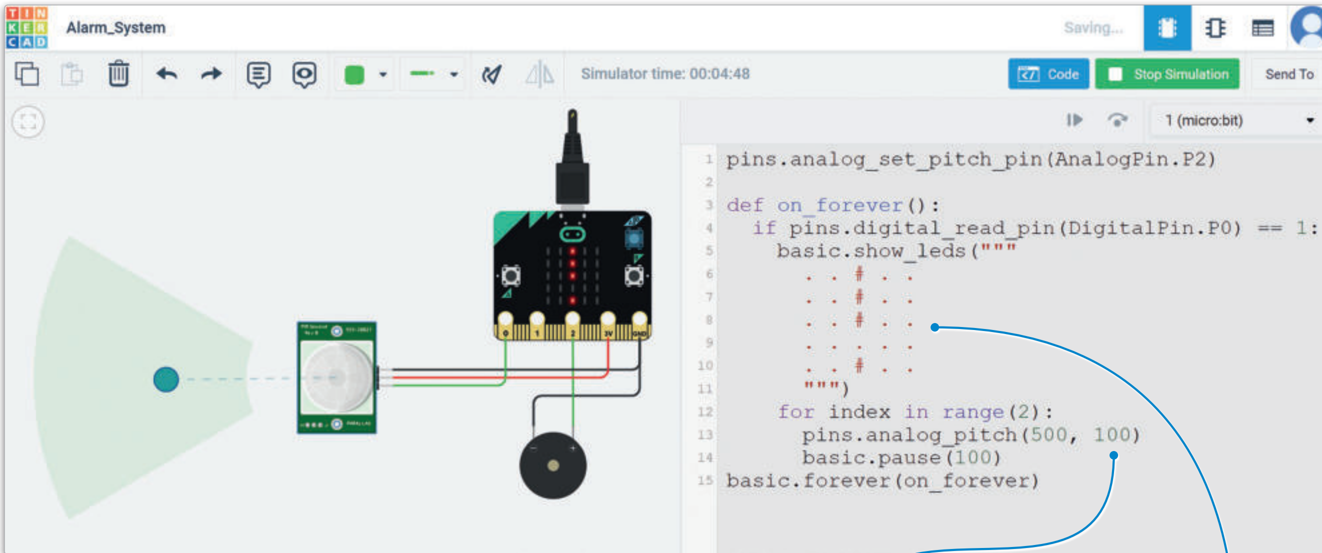


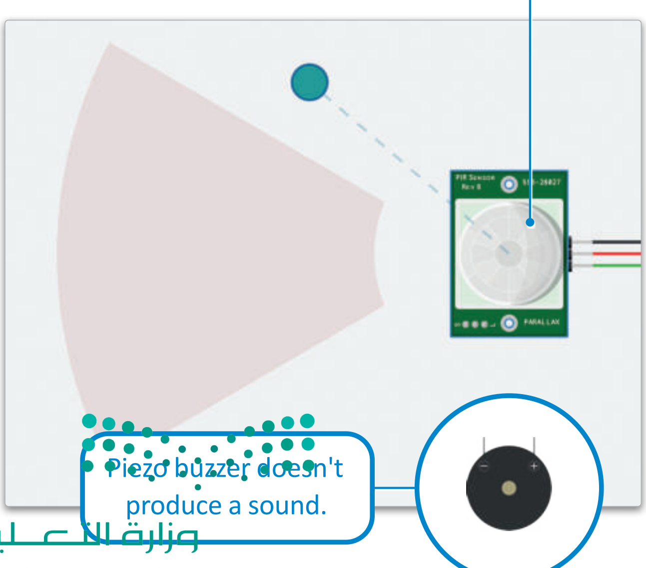
Figure 5.31: Test code

When you use the piezo buzzer in a project, make sure that the volume on your computer is high enough for you to hear the sound that the piezo buzzer produces.

Piezo buzzer produces a sound two times at a frequency of 500 hertz, every 100 milliseconds (0.1 seconds).

Display an exclamation mark when the PIR Sensor detects an object.

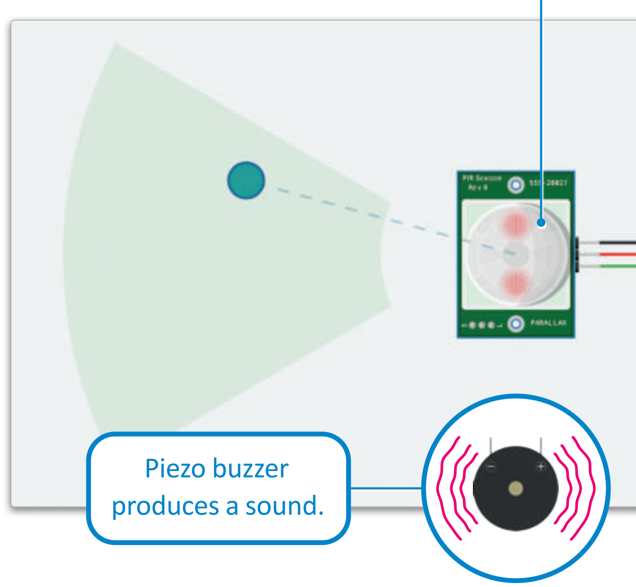
No object has entered the PIR Sensor FOV.



Piezo buzzer doesn't produce a sound.

Figure 5.32: No object in PIR sensor FOV

An object has entered the PIR Sensor FOV.



Piezo buzzer produces a sound.

Figure 5.33: Object in PIR sensor FOV

Exercises

1 Which component will you use to easily connect more electronic components?

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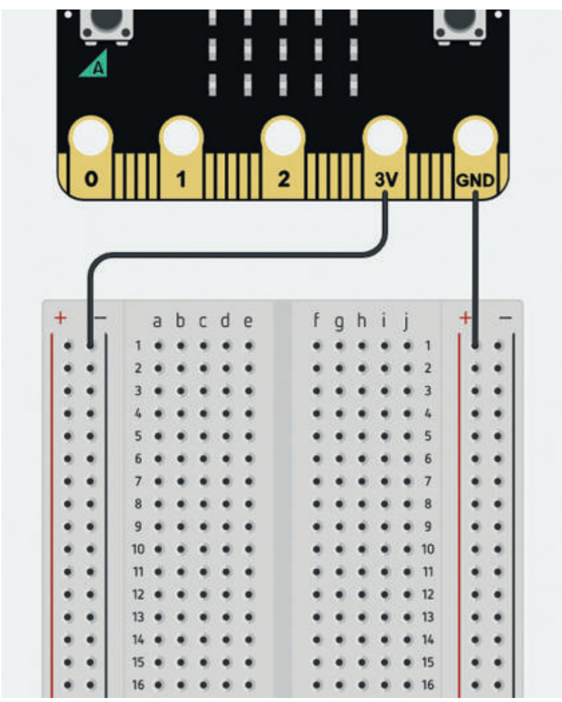
2 Can you identify the problem with these connections? What do you need to do to correct it?



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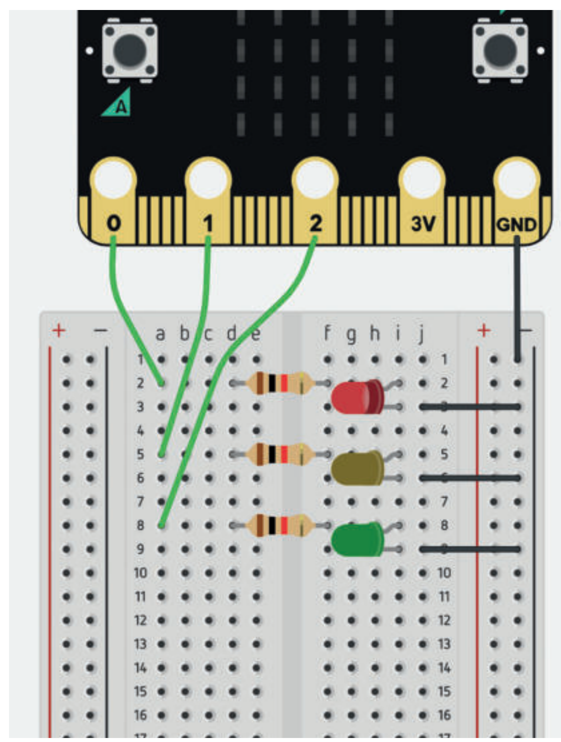
3 Why do we use the resistors in the following electronic circuit?



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4 In the traffic light circuit in the lesson we do not use the 3V pin of the micro:bit board. How do we power each LED?

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5 What is the main difference between a distance sensor and a PIR sensor? Search on the Internet for applications of each electronic component.

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6 How many electronic components can you connect to the ground pin of the micro:bit board?

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7 In all micro:bit projects, you define a function named on_forever. Explain how you use it and why it is required.

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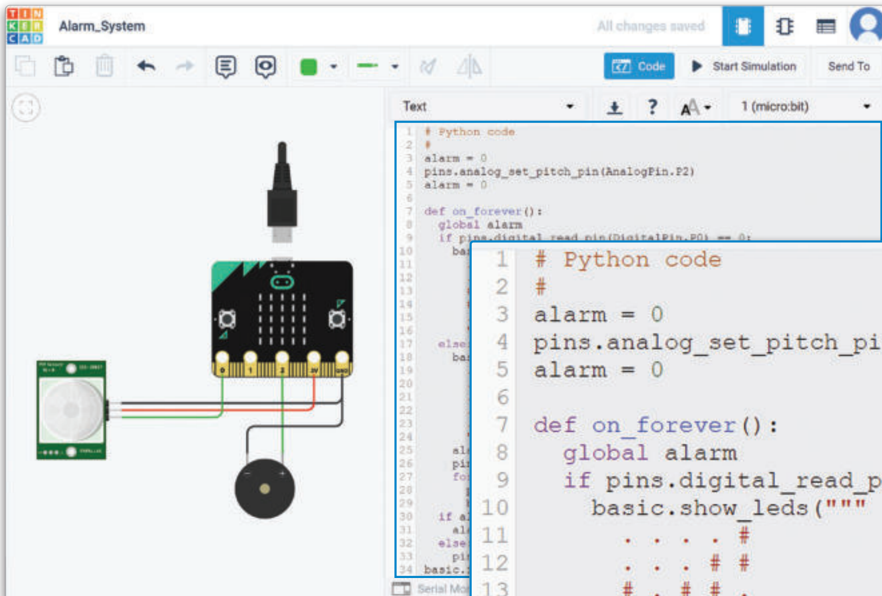
8 Examine the following circuit and its code carefully and find the problem. What do you need to do to fix it?




```python
# Python code
#
alarm = 0
pins.analog_set_pitch_pin(AnalogPin.P2)
alarm = 0

def on_forever():
  global alarm
  if pins.digital_read_pin(DigitalPin.P0) == 0:
    basic.show_leds("""
      . . . . #
      . . . # #
      # . # # .
      # # # . .
      . # . . .
      """)
  else:
    basic.show_leds("""
      . . # . .
      . . # . .
      . . # . .
      . . . . .
      . . # . .
      """)
    alarm = 10
    pins.digital_write_pin(DigitalPin.P1, 1)
    for index in range(3):
      pins.analog_pitch(440, 200)
      basic.pause(100)
  if alarm > 0:
    alarm += -1
  else:
    pins.digital_write_pin(DigitalPin.P1, 0)
basic.forever(on_forever)
```

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وزارة التعليم
Ministry of Education
2023 - 1445

Lesson 3
Real Life Applications

Link to digital lesson

www.ien.edu.sa

There are two different types of potentiometers, the rotary potentiometer and the linear potentiometer.

The rotary potentiometer is the one we have looked at and is the component available in Tinkercad Circuits.

The linear potentiometer works with a sliding contact that can be moved along a path connected through the resistor.

How a Potentiometer Varies the Voltage

A potentiometer is a type of passive electronic device. Potentiometers operate by moving a sliding contact across a uniform resistance. The input voltage is applied across the entire length of the resistor in a potentiometer, and the output voltage is the voltage drop between the fixed and sliding contacts, which changes with the position of the sliding contact.

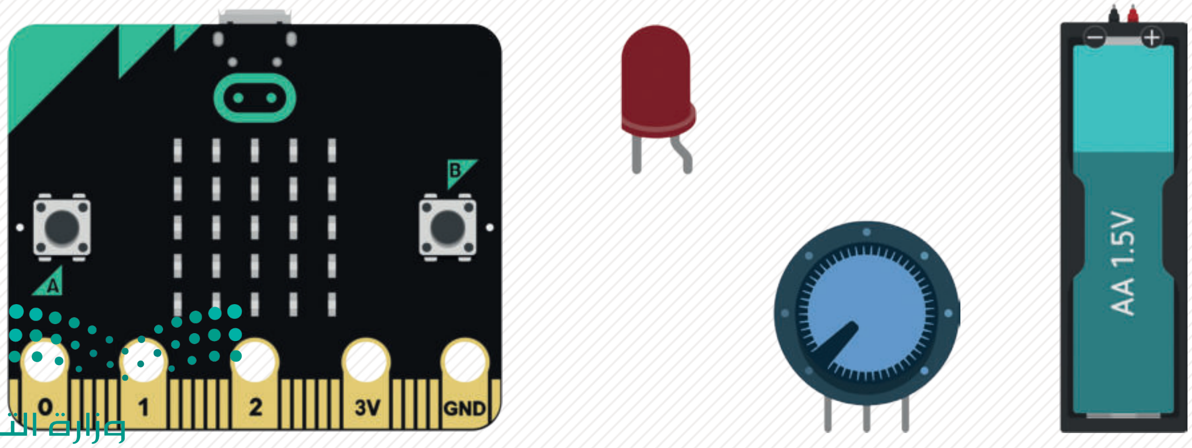
The first project you will create in this lesson uses a potentiometer to regulate voltage. For this project you will use a micro:bit and the following components:

- 1 Potentiometer
- 1 LED
- 1 1.5V Battery

Figure 5.34: Linear potentiometer

You can use a transistor in a circuit that controls components like motors that require a higher voltage to operate.

Components that you will use in this project



Let's go and find the components that you will need for this project. Place a micro:bit, an LED light, a 1.5V battery and a potentiometer in the workplane.

To add components:

> Find the **micro:bit** in the **components library**, drag and drop it into the **workplane** and change its color to green. 1

> Find a **1.5 V Battery** in the **components library** and drag and drop it into the **workplane**. 2

> Find the **LED** in the **components library**, drag and drop it into the **workplane** and **rotate** it so the pins point at the **micro:bit**. 3

> Find a **Potentiometer** in the **components library**, 4 drag and drop it into the **workplane** and **rotate** it so the pins point towards the **micro:bit**. 5

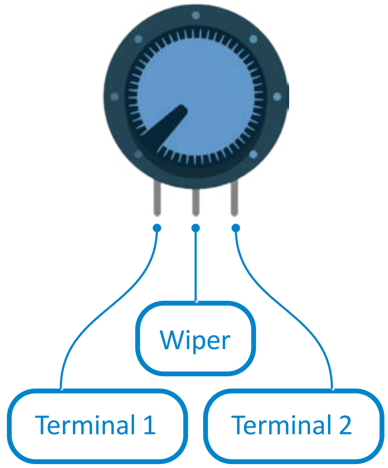


Figure 5.35: The terminals on a potentiometer

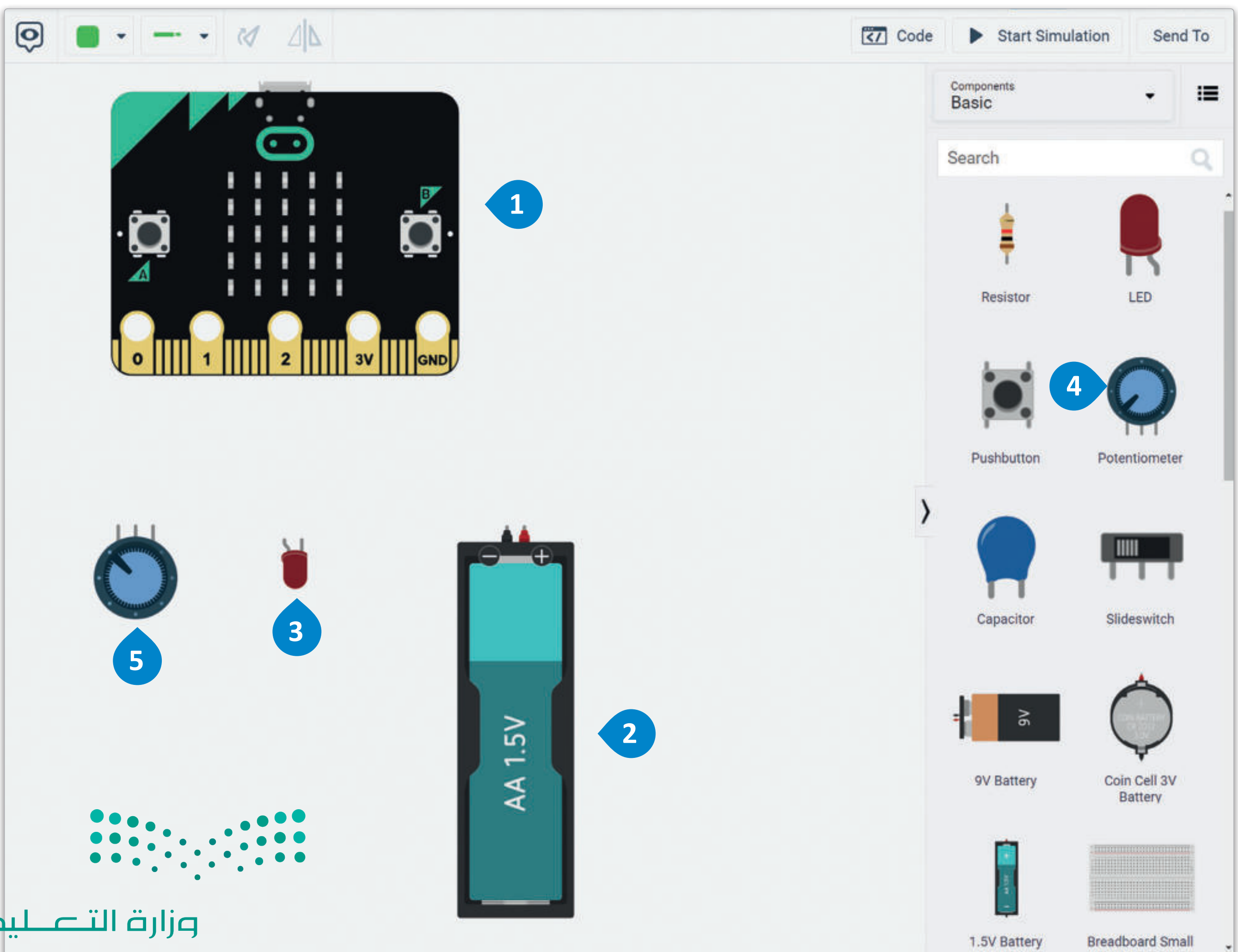


Figure 5.36: Add components

Next, you will connect the pins of the potentiometer with the pins of the micro:bit. More specifically, you are going to connect:

> the potentiometer Terminal 2 to the micro:bit GND.

> the potentiometer Wiper to the P0 pin of the micro:bit.

> the potentiometer Terminal 1 to the 3V power source of the micro:bit.

To connect the potentiometer to the micro:bit:

> Connect the **Potentiometer Terminal 2** to the **micro:bit GND** and change its color to **black**. 1

> Connect the **Potentiometer Wiper** to the **micro:bit P0 pin** and change its color to **green**. 2

> Connect the **Potentiometer Terminal 1** to the **micro:bit 3V power source** and change its color to **red**. 3

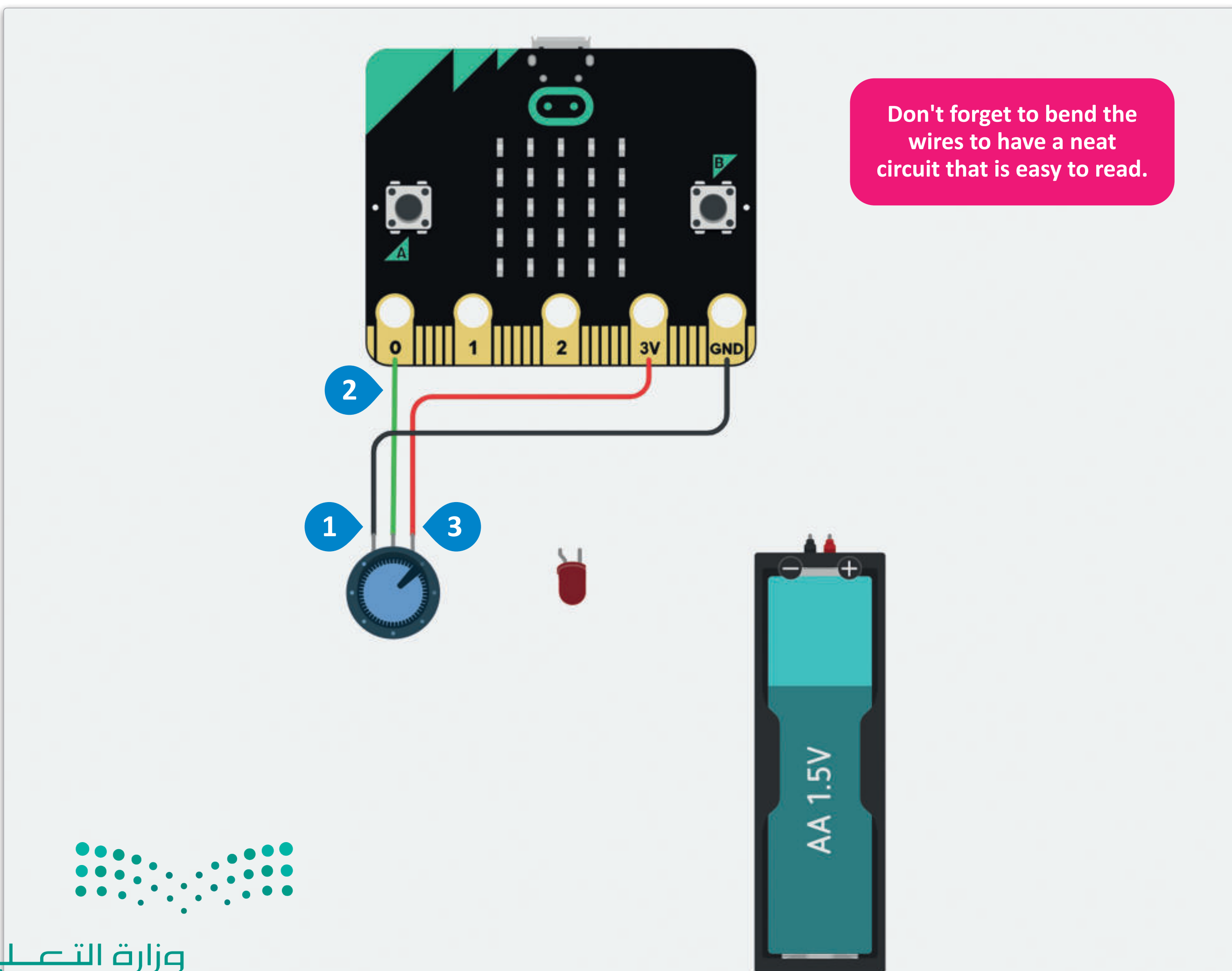


Figure 5.37: Connect the potentiometer to the micro:bit

Now, you will make the connections for the 1.5V battery and the LED.

To connect the 1.5V battery and the LED:

> Connect the **1.5V Battery negative pin** to the **micro:bit GND** and change its color to **black**. 1

> Connect the **1.5V Battery positive pin** to the **cathode** of the **LED** light and change its color to **red**. 2

> Connect the **anode** of the **LED light** to the **micro:bit P2 pin** and change its color to **green**. 3

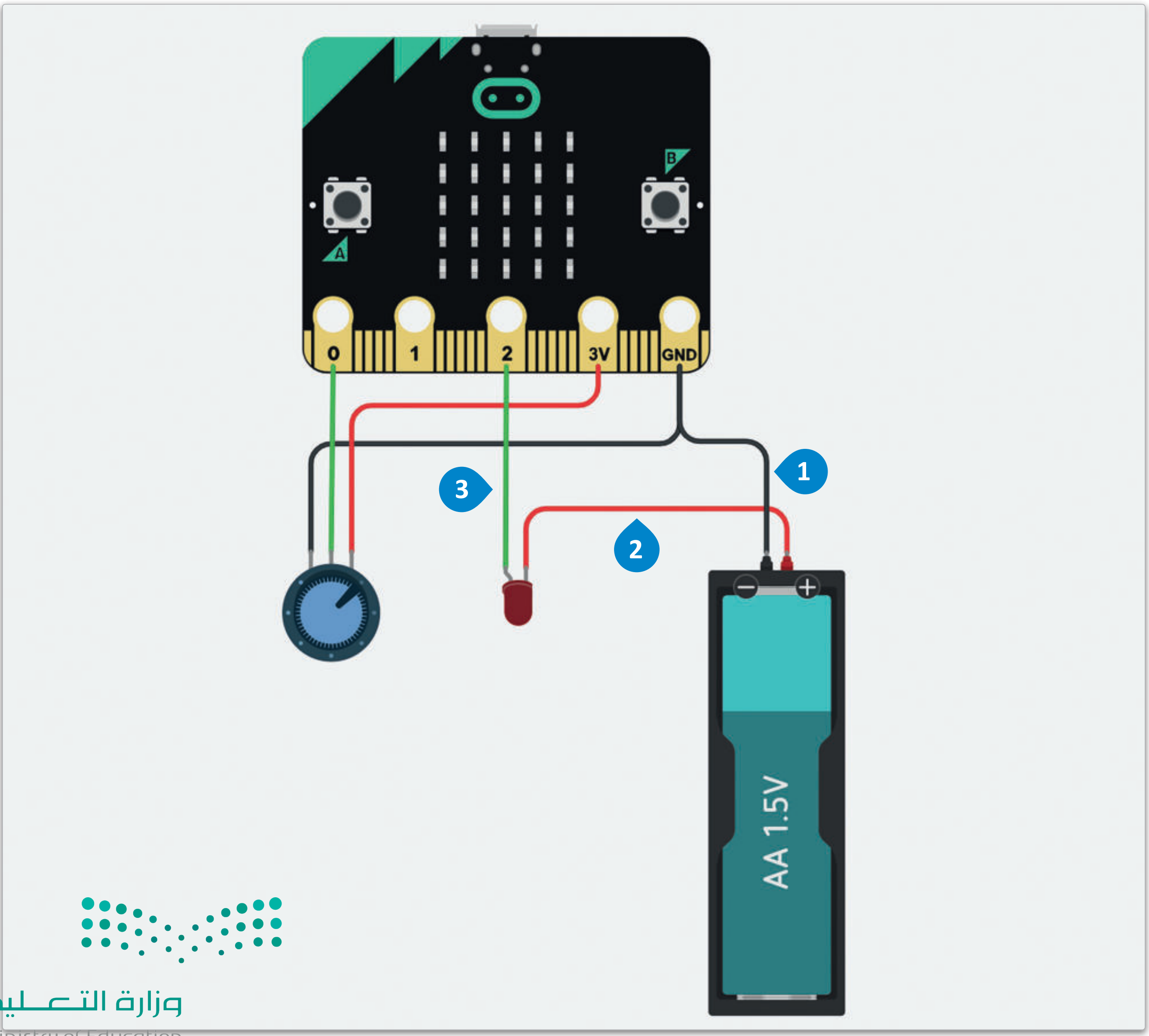
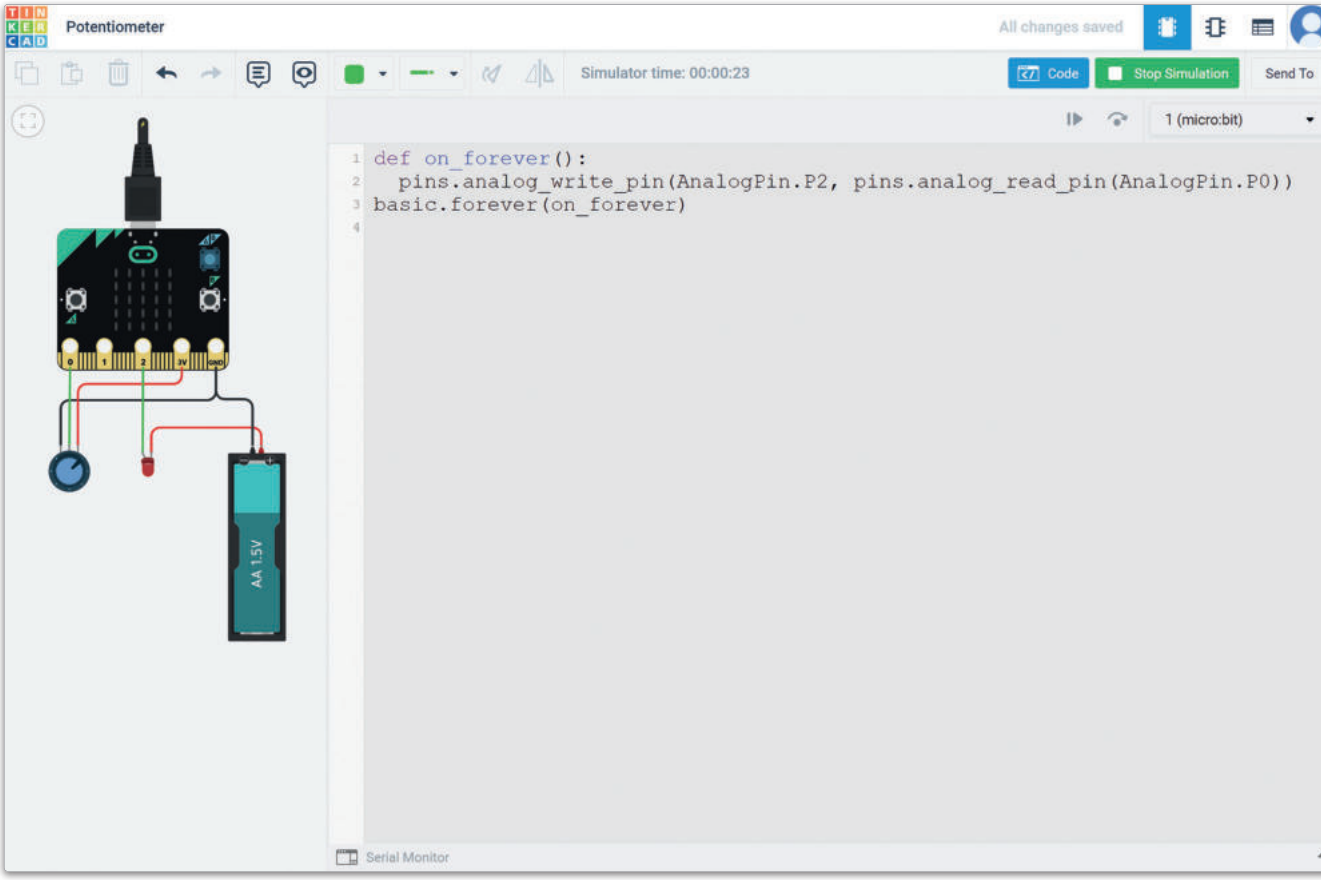


Figure 5.38: 1.5V Battery and LED connections

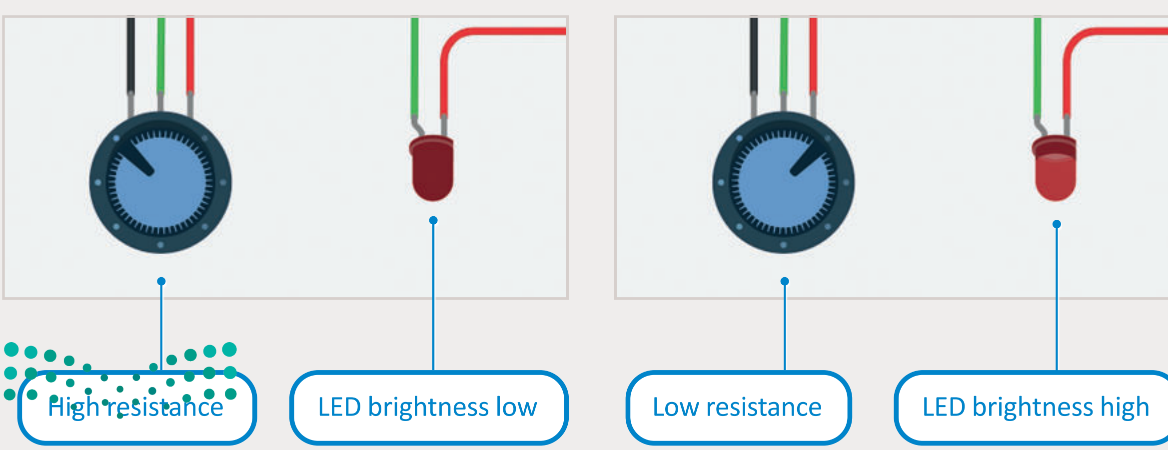
Write the code to program the microcontroller and start the simulation.




```
def on_forever():
  pins.analog_write_pin(AnalogPin.P2, pins.analog_read_pin(AnalogPin.P0))
basic.forever(on_forever)
```

Figure 5.39: Test code

Notice how the LED changes its brightness according to the voltage applied by the potentiometer.



A Basic Transistor Circuit

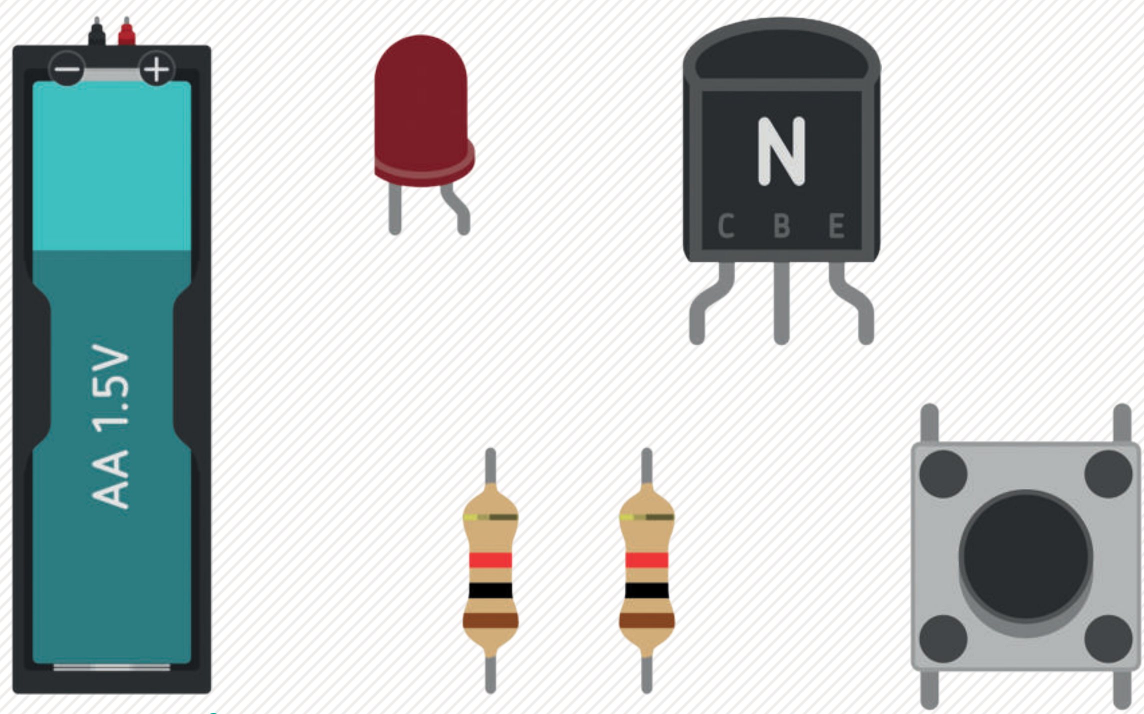
Transistors are required for digital circuits to function. Transistors are electronic components that are used in circuits to amplify or switch electrical signals or power, making them useful in a wide range of electronic devices.

The NPN transistor has three terminals, Collector, Base and Emitter. In Tinkercad Circuits the base is called "Terminal 1". A large current can flow from Collector to Emitter, with a small current entering the Base. In this case, it acts like a current controlled switch. NPN circuits are used in digital logic circuits as extremely fast switches.

In a later project you will design a circuit that combines a transistor, a potentiometer and a DC motor, but first you will implement a simple circuit to illustrate the basic connections of the NPN transistor. For this project you will use the following components:

- 1 BJT-NPN Type Transistor
- 1 Pushbutton
- 1 LED
- 1 1.5V Battery
- 2 Resistors

Components that you will use in this project



First, you will add a 1.5V Battery and a Pushbutton to the workplane and connect the positive pin of the 1.5V Battery with Terminal 1b of the Pushbutton.

To add and connect the 1.5V Battery and Pushbutton:

> Find the **1.5V Battery** in the **components library** and drag and drop it into the **workplane**. 1

> Find the **Pushbutton** in the **components library** 2 and drag and drop it into the **workplane**. 3

> Connect the **positive pin** to **Terminal 1b** of the **Pushbutton** and change its color to **red**. 4

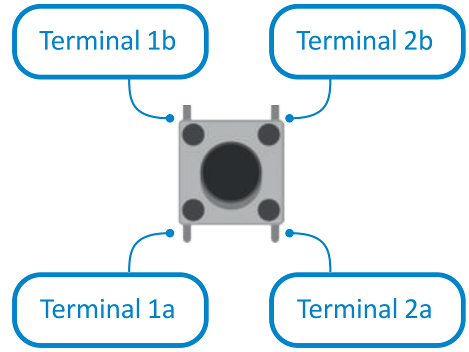


Figure 5.40: Pushbutton terminals

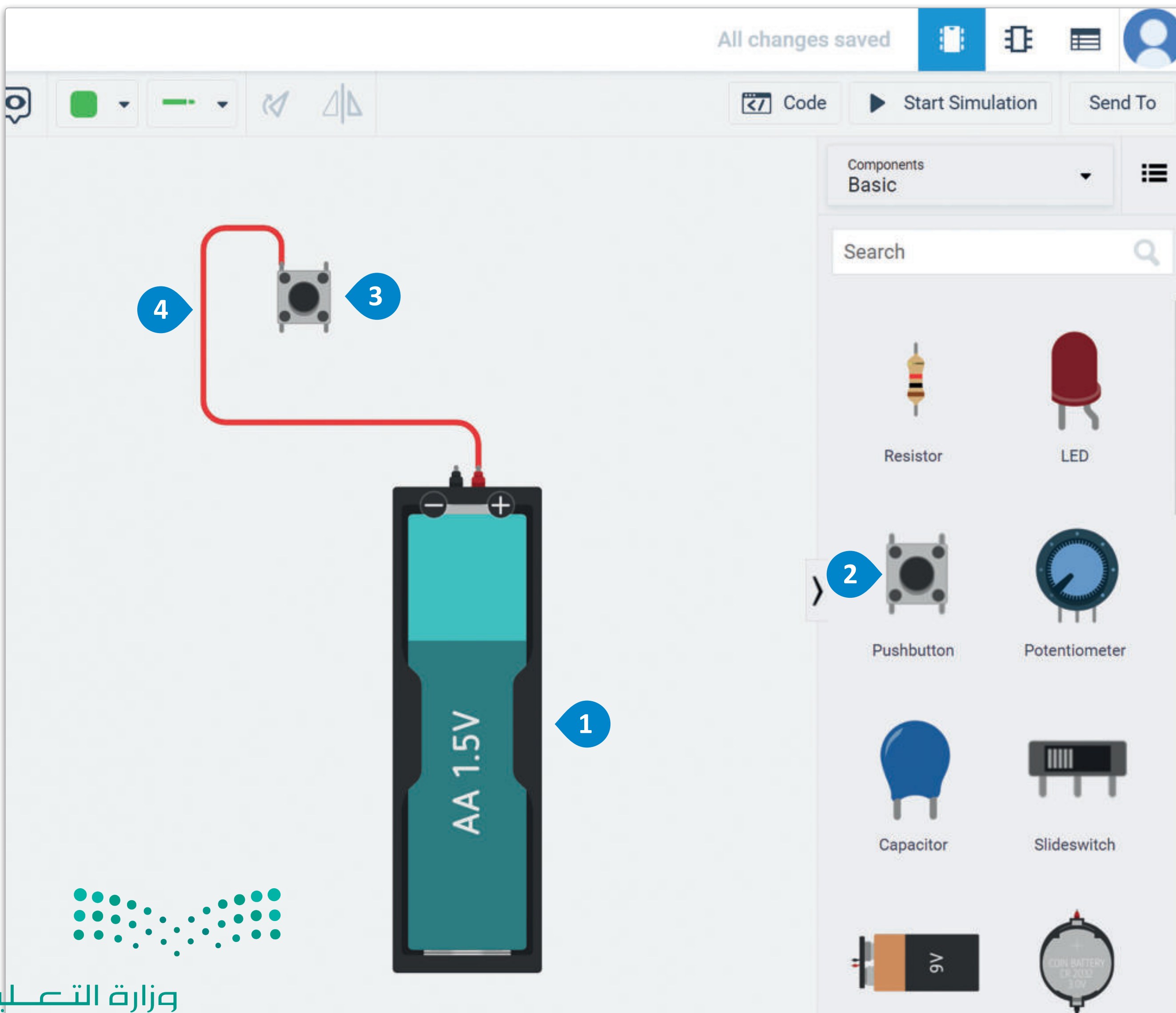


Figure 5.41: Add and connect the 1.5V Battery and Pushbutton

Then, you will add an LED to the workplane and connect its anode to Terminal 2b of the Pushbutton.

To add the LED and make the connections:

> Find the **LED** in the **components library** and drag and drop it into the **workplane**. 1

> Connect the **anode** of the **LED** to **Terminal 2b** of the **Pushbutton**. 2

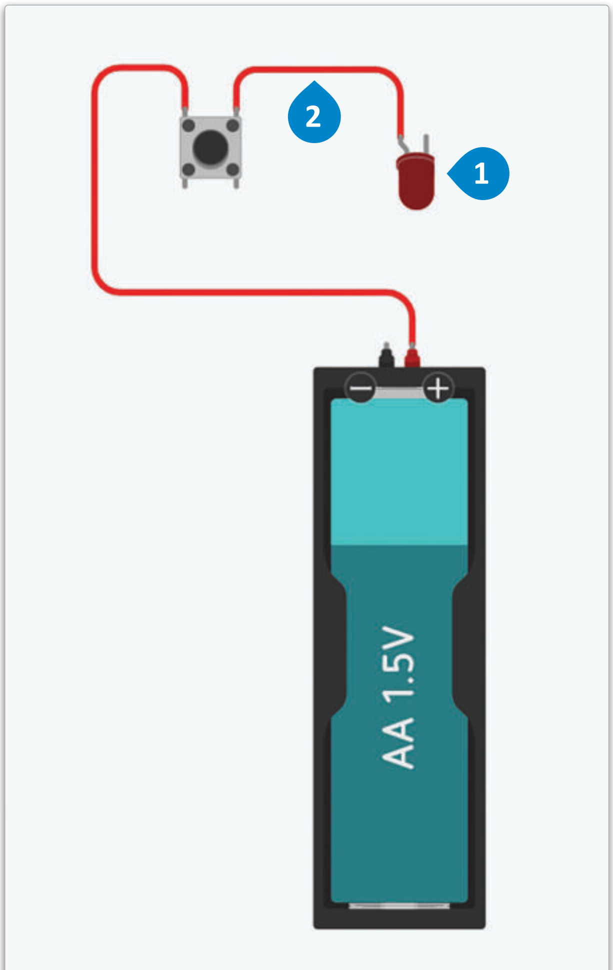


Figure 5.42: Add the LED and make the connections

The resistors are used to reduce the current flowing through the circuit.

Continue by adding a resistor to the workplane.

To add the first resistor and make the connections:

> Find the **Resistor** in the **components library**, drag and drop it into the **workplane** and **rotate** it so the pins point horizontally. 1

> Connect the **cathode** of the **LED** to **one leg** of the **Resistor** and change its color to **green**. 2

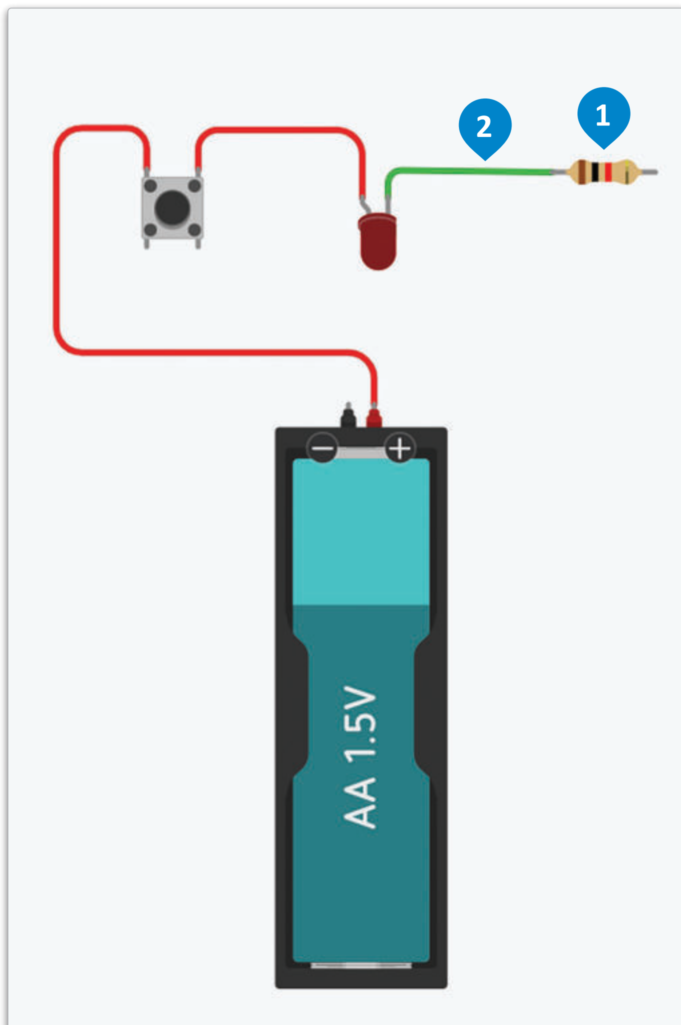


Figure 5.43: Add the first resistor and make the connections

Now, you will add the transistor to the workplane and connect it with the second leg of the resistor.

To add the transistor and make the connections:

> Find the **NPN Transistor** in the **components library** 1 and drag and drop it into the **workplane**. 2

> Connect the **Collector** of the **NPN Transistor** to the **second leg** of the **Resistor**. 3

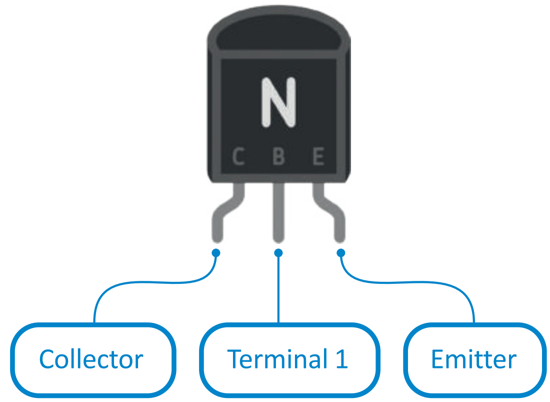


Figure 5.44: Transistor terminals

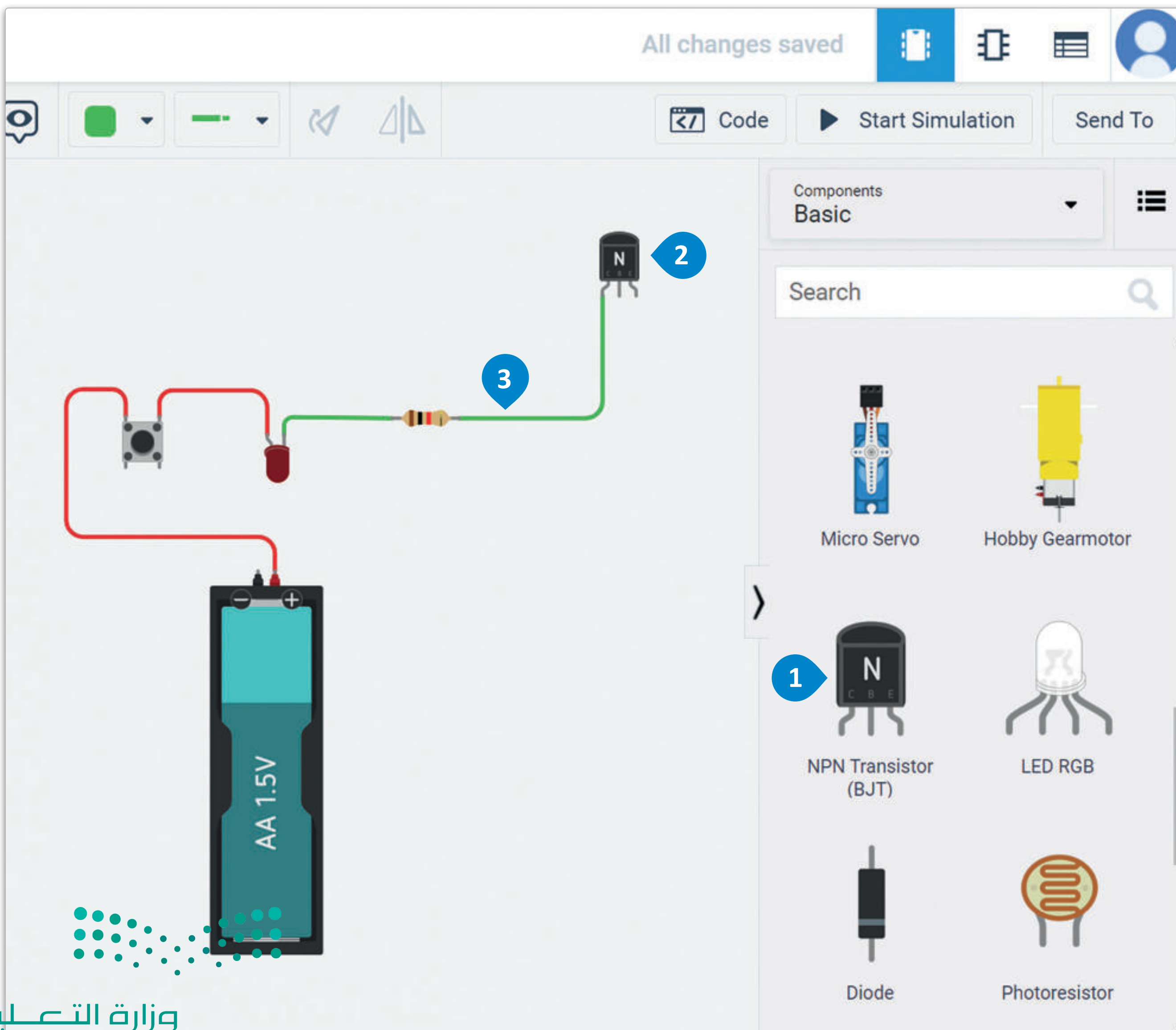


Figure 5.45: Add the transistor and make the connections

Next, add the second resistor and connect Terminal 1 of the transistor to the positive pin of the battery via the second resistor.

Finally, connect the emitter of the transistor to the negative pin of the battery.

To add the second resistor and make the connections:

> Find the **Resistor** in the **components library** and drag and drop it into the **workplane**. 1

> Connect **Terminal 1** of the **NPN Transistor** to the **second leg** of the **Resistor** and change its color to **red**. 2

> Connect the **positive pin** of the **1.5V Battery** to the **first leg** of the **Resistor**. 3

> Connect the **negative pin** of the **1.5V Battery** to the **emitter** of the **NPN Transistor** and change its color to **black**. 4

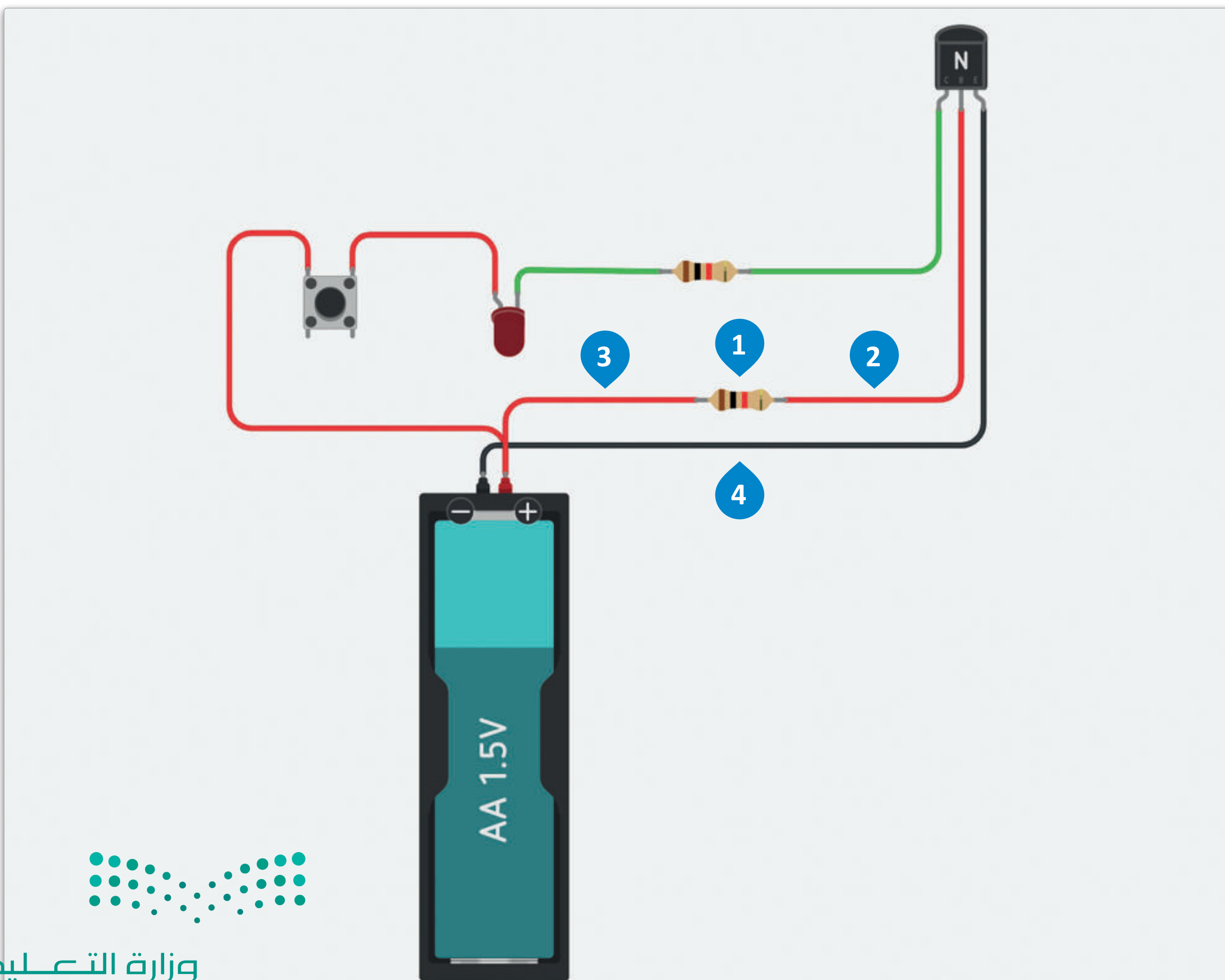


Figure 5.46: Add the second resistor and make the connections

Start the simulation and when you press the Pushbutton, the LED will light up.

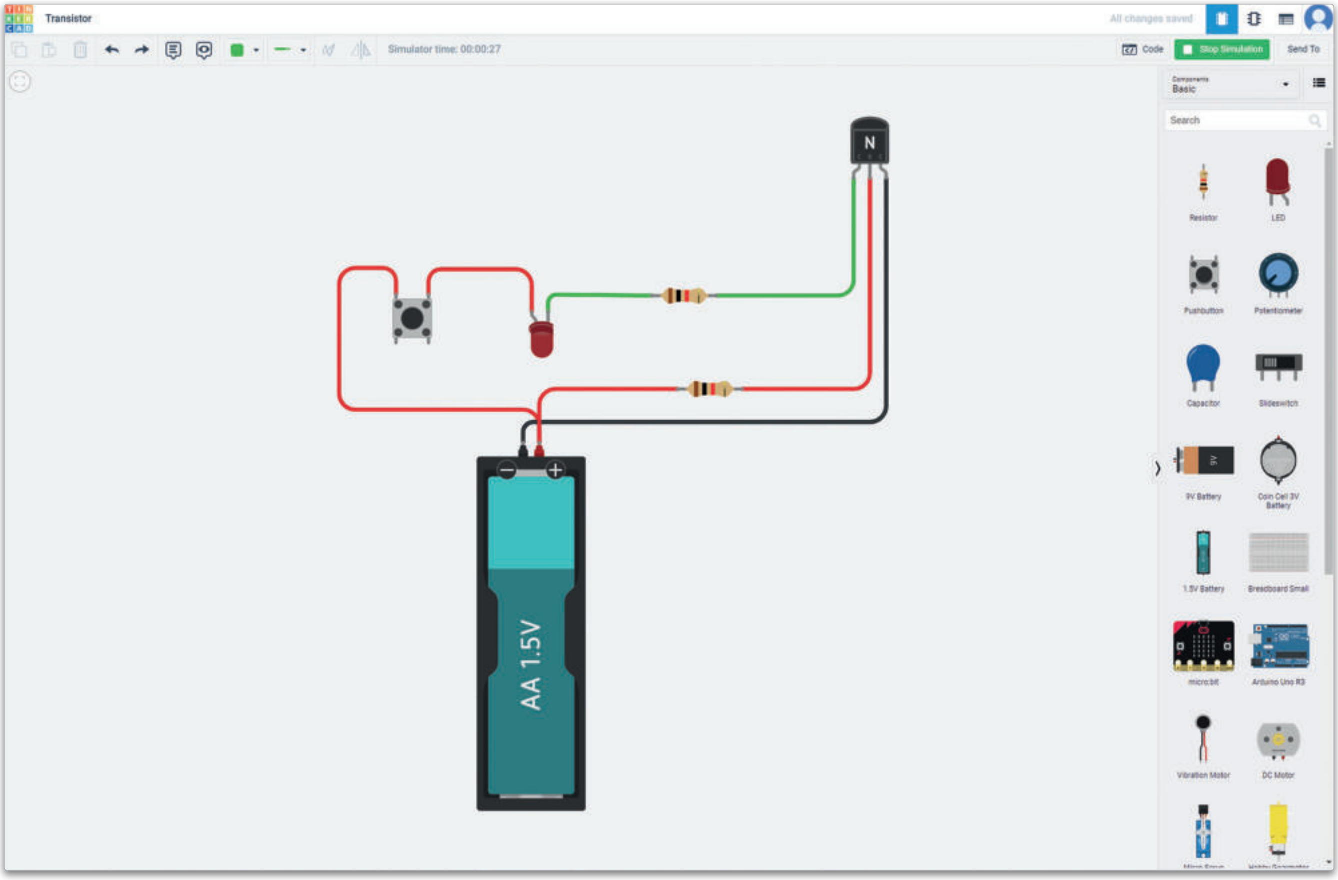


Figure 5.47: Start the simulation

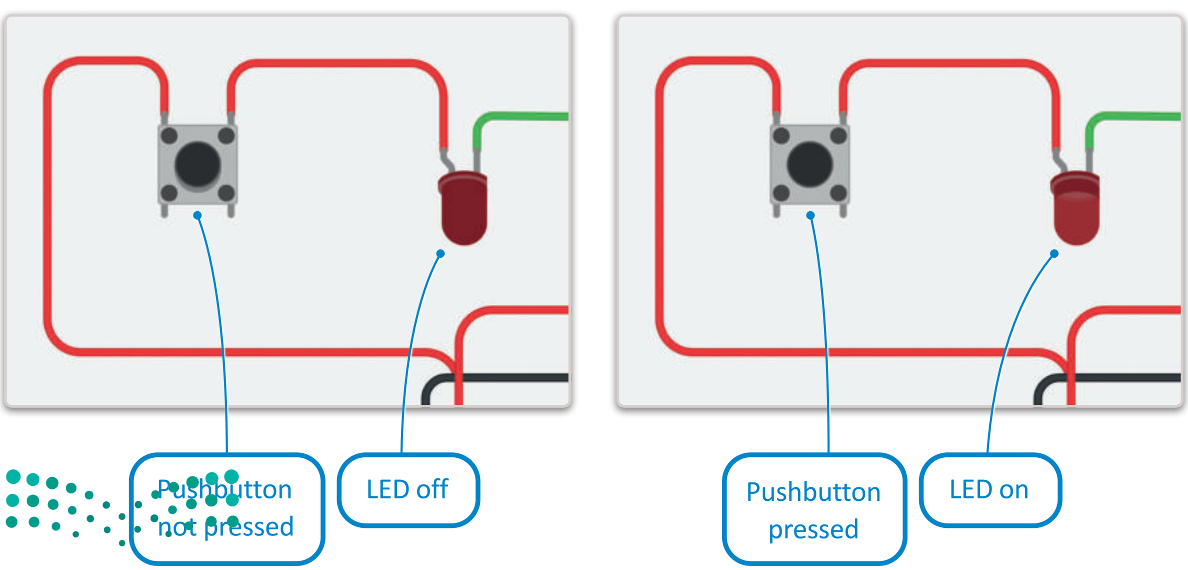


Figure 5.48: LED states

Build a DC Motor - Resistor Circuit

In this project, we will combine elements of the previous projects to connect a potentiometer to a DC motor through a transistor and a resistor. We will also need a battery to supply power to the DC motor. We can use the micro:bit code from our earlier project because, as before, all we need to do is to write the input from the potentiometer at analog pin P0 to analog pin P2.

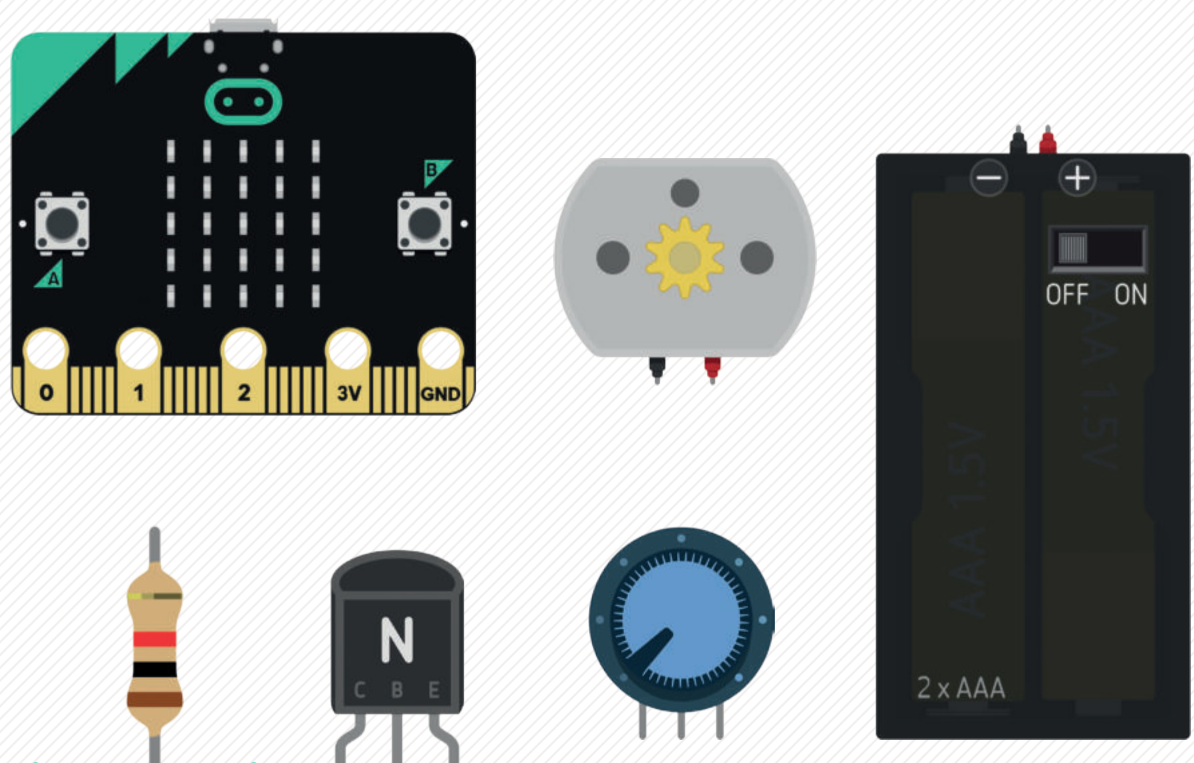
You can experiment with making changes to the circuit, for example changing the value of the resistor or switching the 2 AAA batteries connected to the circuit. Notice also how different resistor values affect the RPMs generated by the DC motor. This is the same circuit, but only the resistance values have changed from 100 kΩ to 200 kΩ.

For this project you will use a micro:bit and the following components:

- 1 Potentiometer
- 1 BJT-NPN Type Transistor
- 1 Resistor
- 2 1.5V Batteries
- 1 DC Motor

You can use a transistor in a circuit that controls components like motors that require a higher voltage to operate.

Components that you will use in this project



Let's start by adding the components to the workplane.

Take a potentiometer from the components library and place it on the workplane. Remember, that a potentiometer has three ends, Terminal 1, the Wiper and Terminal 2, which need to be connected to the micro:bit.

To add the potentiometer and make the connections:

> Find the **micro:bit** in the **components library**, drag and drop it into the **workplane** and change its color to **green**. 1

> Find the **Potentiometer** in the **components library**, 2 drag and drop it into the **workplane** and **rotate** it so the **pins** point towards the **micro:bit**. 3

> Connect the **Potentiometer Terminal 2** to the **micro:bit GND** and change its color to **black**. 4

> Connect the **Potentiometer Wiper** to the **micro:bit P0 pin** and change its color to **green**. 5

> Connect the **Potentiometer Terminal 1** to the **micro:bit 3V power source** and change its color to **red**. 6

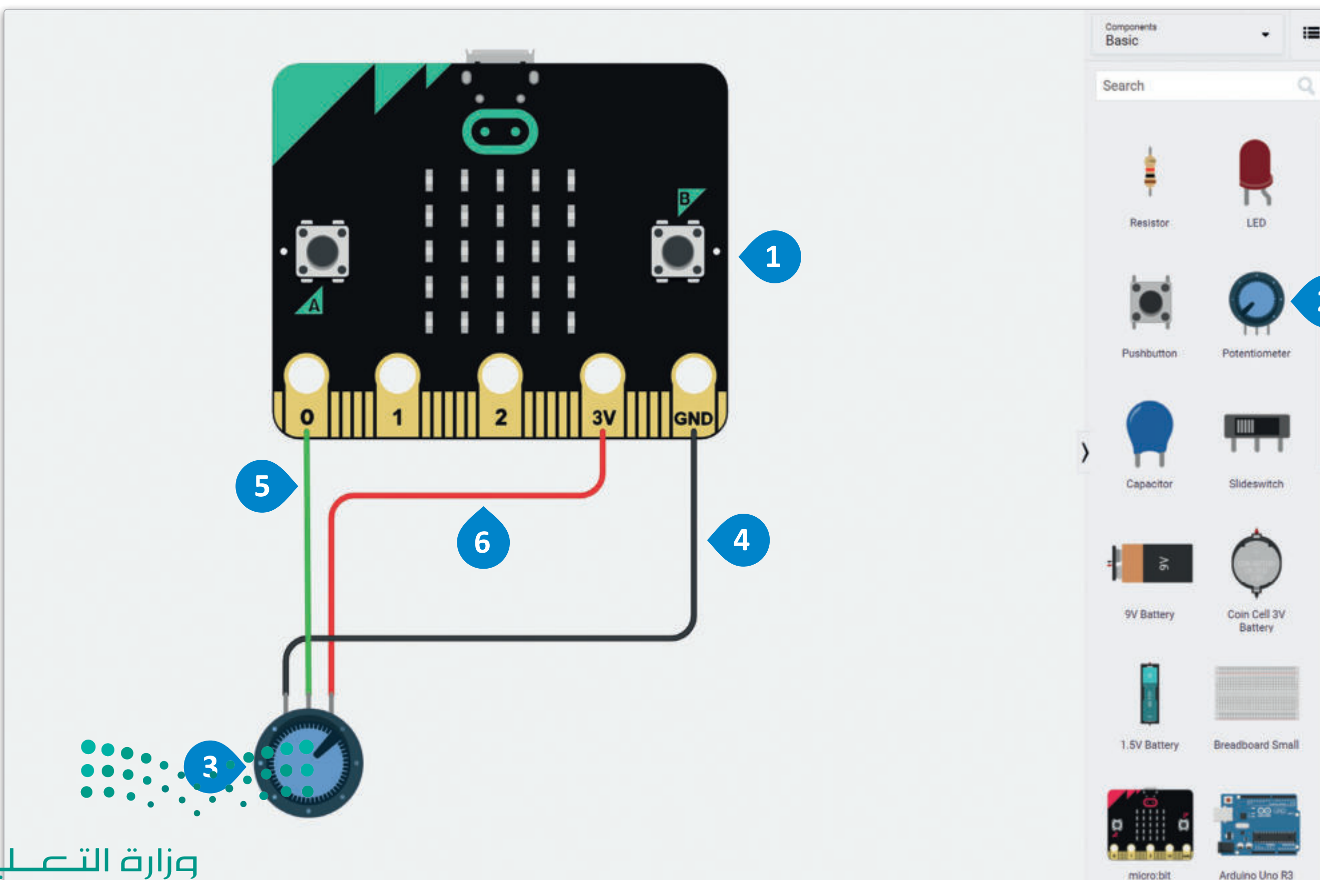


Figure 5.49: Add the potentiometer and make the connections

Then you will place a battery on the workplane and use the inspector panel to change it.

To create a two battery case:

> Find the **1.5V Battery** in the **components library** and drag and drop it into the **workplane**. 1
> Use the **Inspector panel**. 2
> Change **Count** to **2 batteries**. 3
> Change **Type** to **AAA**. 4
> Change **Built-in Switch** to **yes**. 5

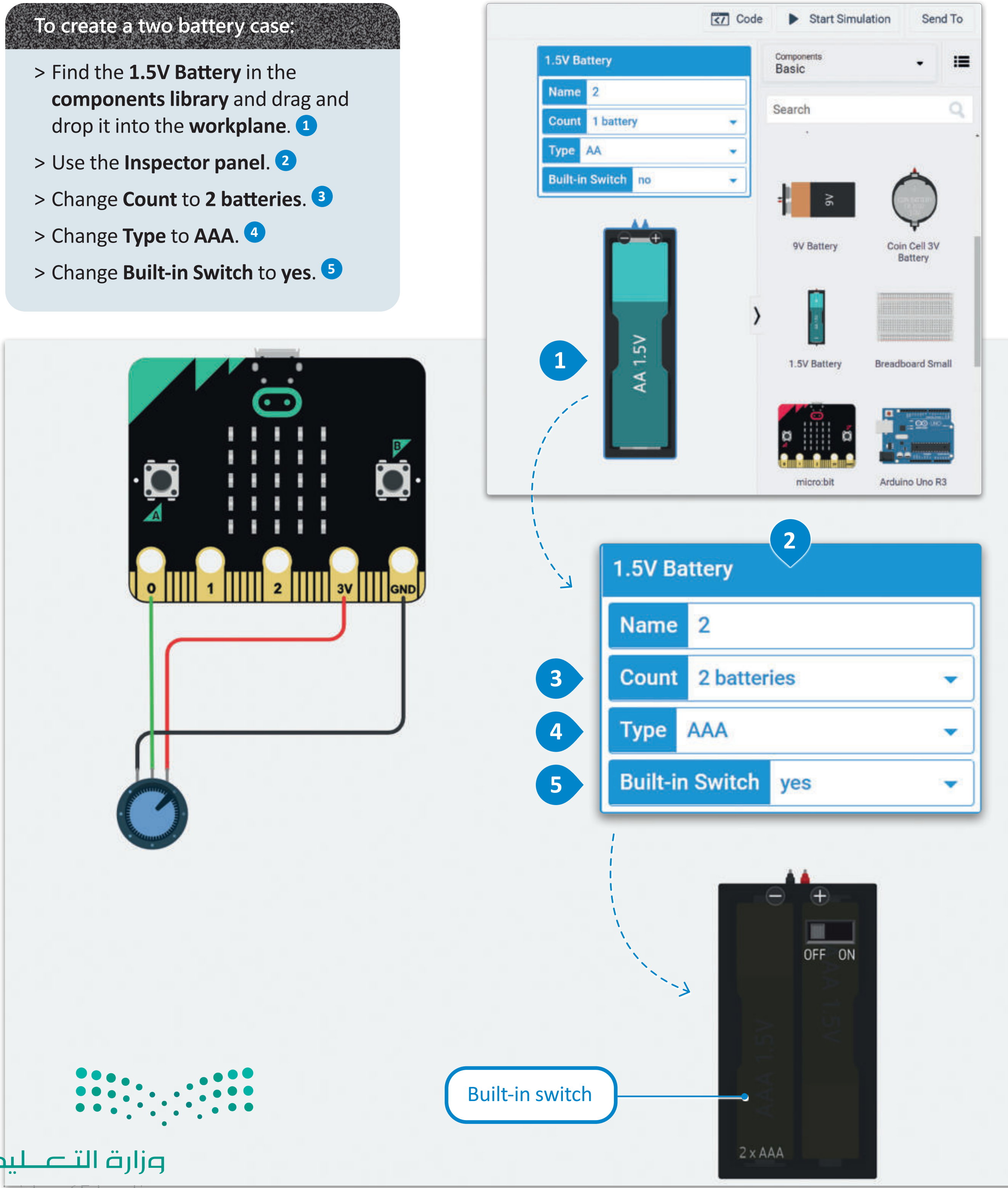


Figure 5.50: Create a two battery case

Place an NPN Transistor into the workplane.

The transistor will be used to transfer the amount of voltage that is applied by the potentiometer and regulate it using the resistor.

The transistor has three ends. The collector will be connected to a battery power source, Terminal 1 will be connected via the resistor to the micro:bit pin P2, which will take as input the voltage applied by the potentiometer to the pin P0, and the emitter will transfer the voltage to the DC motor.

To add the transistor and the resistor:

> Find the **NPN Transistor** in the **components library**, drag and drop it into the **workplane** and **rotate** it so the pins point towards the **micro:bit**. 1

> Find the **Resistor** in the **components library** and drag and drop it into the **workpane** to connect one leg of the **resistor** to **Terminal 1** of the **transistor**. 2

> Connect the **open end** of the **resistor** to **pin P2** of the **micro:bit** and change the wire color to **green**. 3

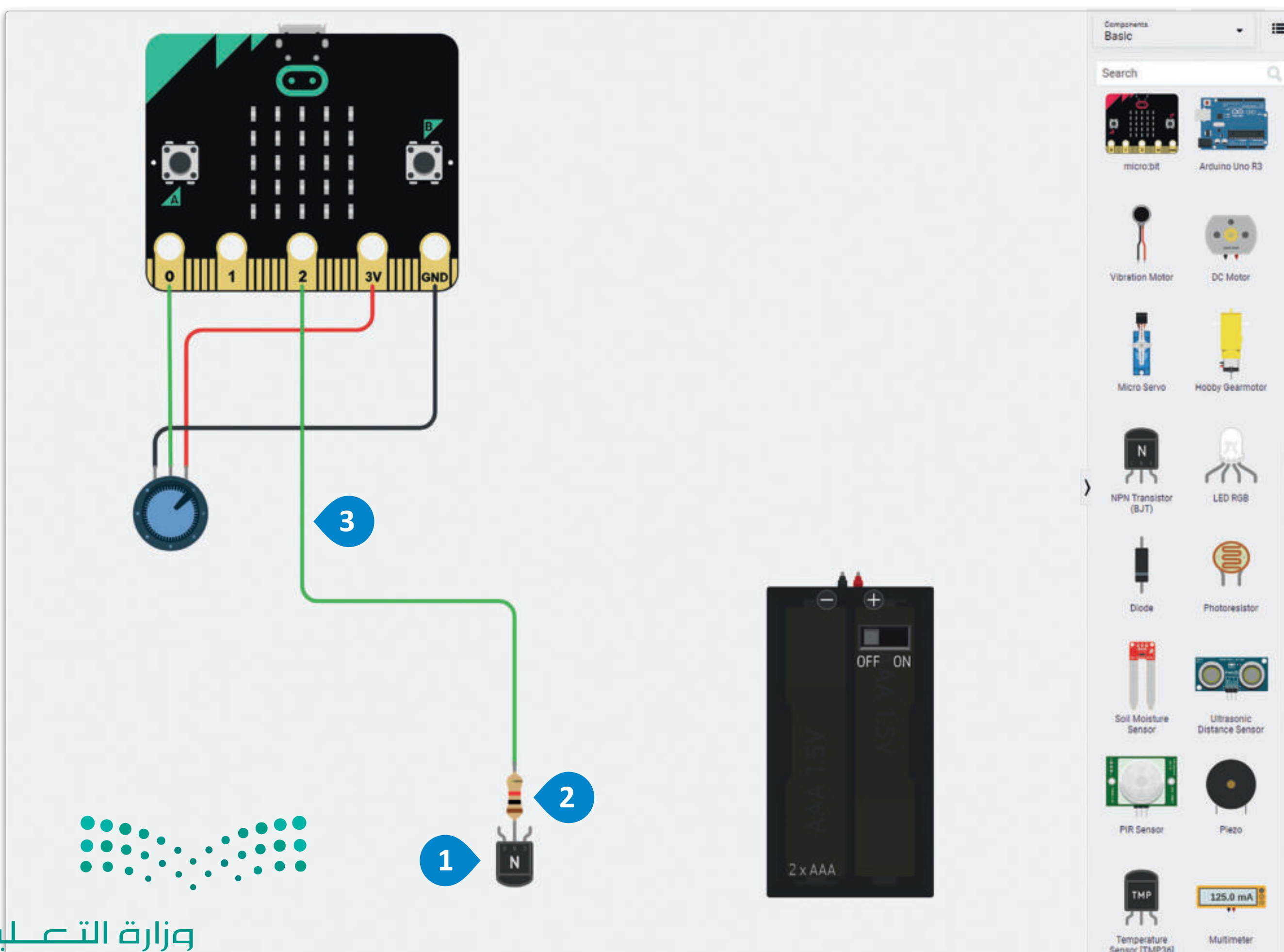


Figure 5.51: Add the transistor and the resistor

Now, you will add a DC motor to the workplane and connect Terminal 2 to the transistor emitter and Terminal 1 to the micro:bit GND.

To add the DC motor and make the connections:

> Find the **DC Motor** in the **components library**, 1 drag and drop it into the **workplane** and **rotate** it so the pins point towards the **transistor**. 2

> Connect **Terminal 1** of the **DC Motor** to the **micro:bit GND** and change the wire color to **black**. 3

> Connect **Terminal 2** of the **DC Motor** to the **Emitter** of the **transistor** and change the wire color to **green**. 4

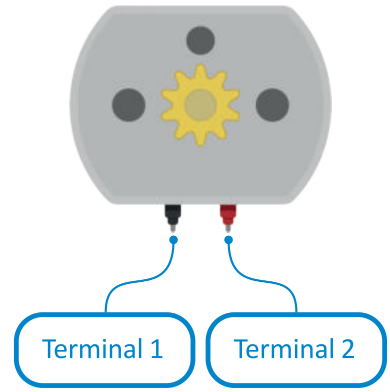


Figure 5.52: The terminals of a DC motor

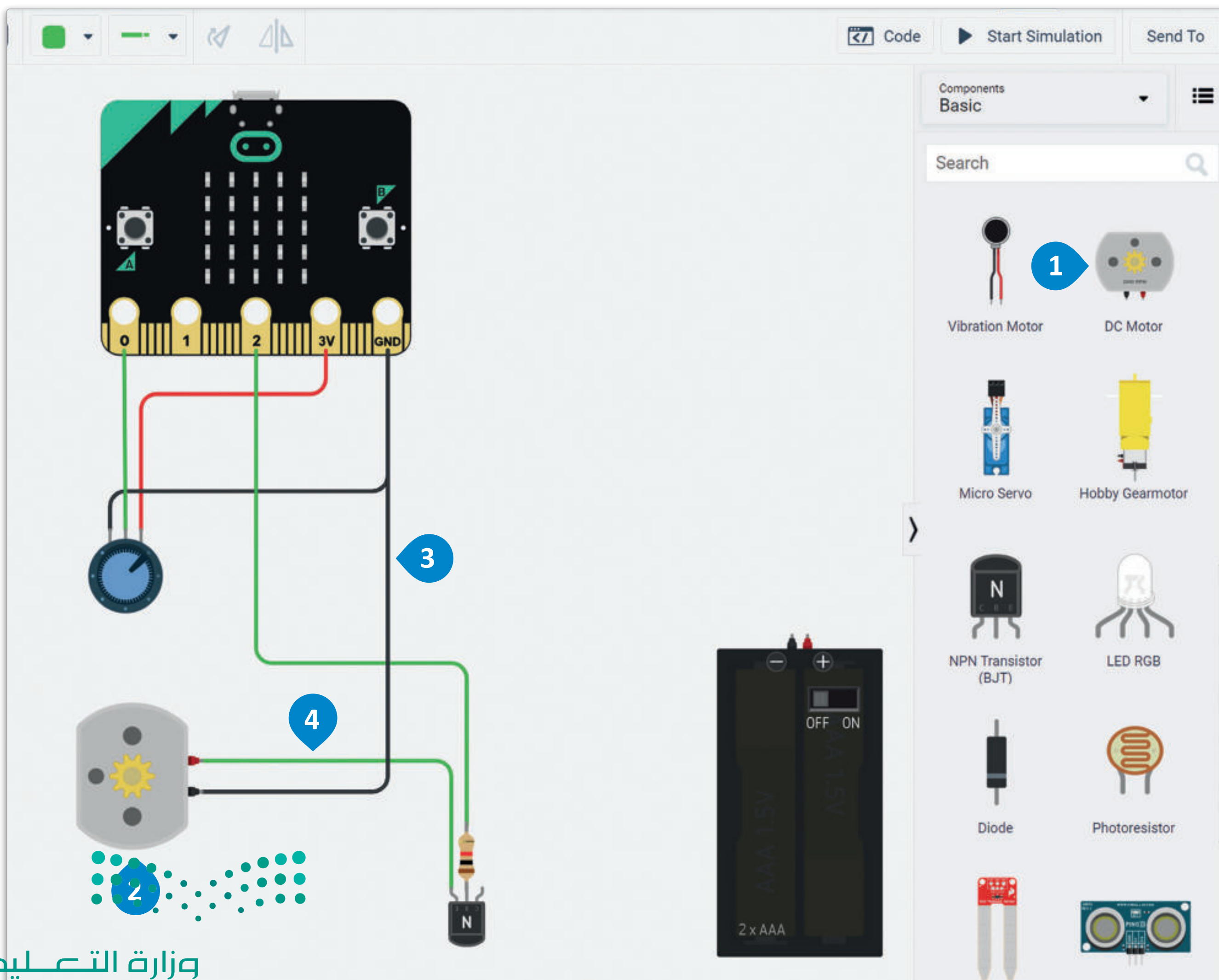


Figure 5.53: Add the DC motor and make the connections

Next, you will add the battery to the workplane, connect its negative pin to the micro:bit ground and its the positive pin to the transistor collector pin.

To connect the battery:

> Connect the **negative pin** of the **Battery case** to **micro:bit GND** and change the wire color to **black**. 1

> Connect the **positive pin** of the **Battery case** to the **Collector pin** of the **transistor** and change the wire color to **red**. 2

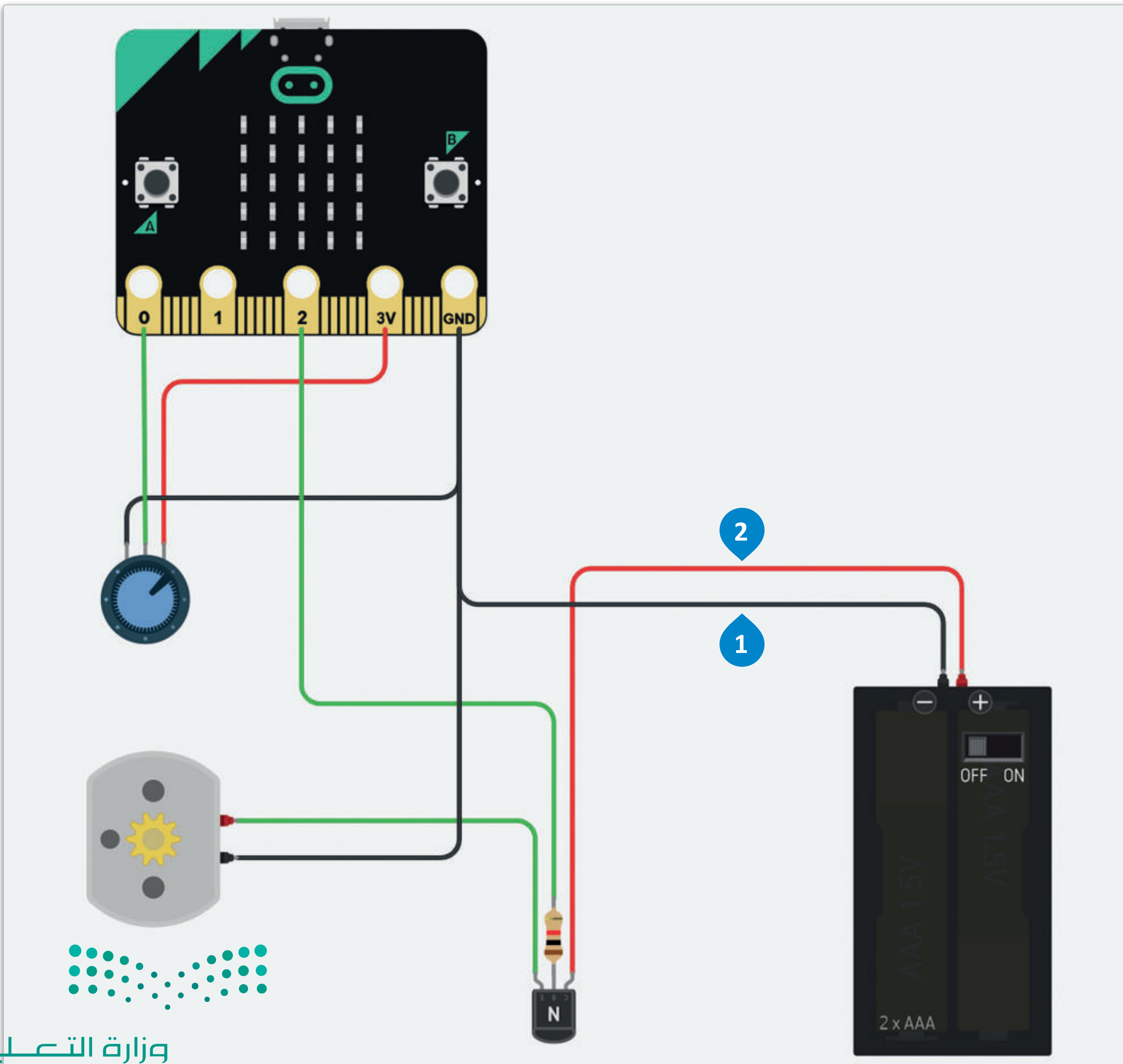


Figure 5.54: Connect the battery

Finally, write the code below and start the simulation.

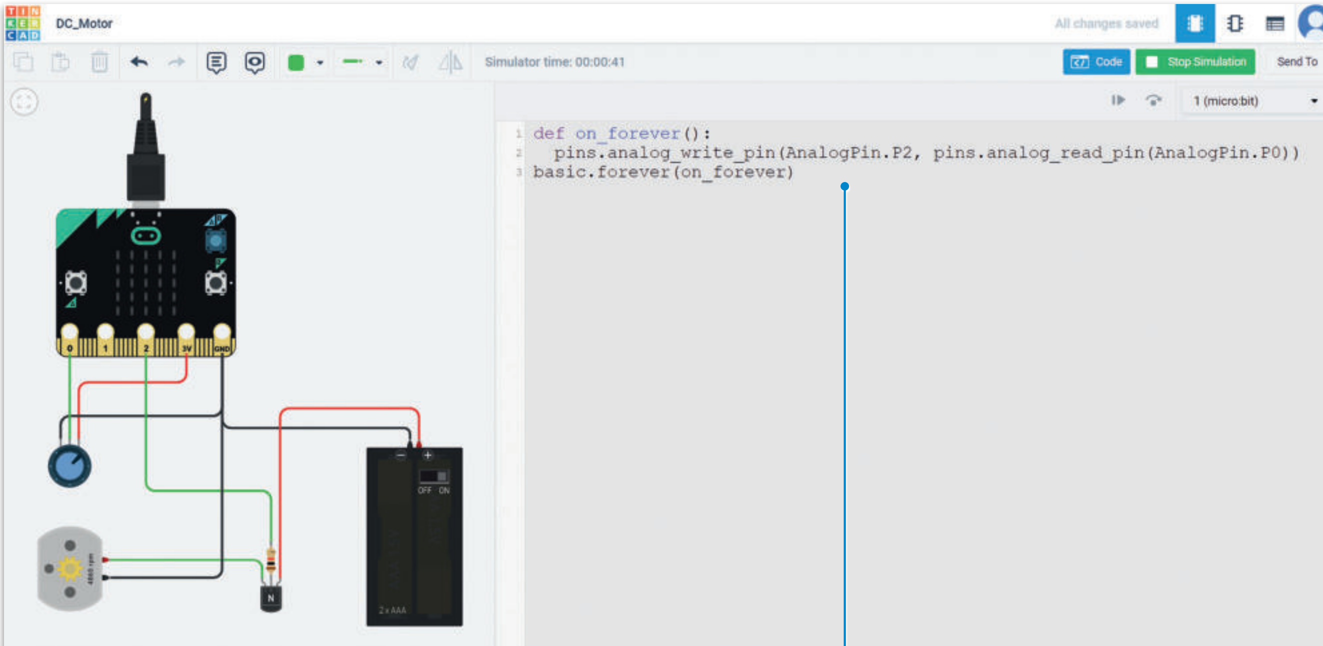


Figure 5.55: Test code

```
def on_forever():
  pins.analog_write_pin(AnalogPin.P2, pins.analog_read_pin(AnalogPin.P0))
basic.forever(on_forever)
```

Notice how the **DC Motor** rotates when the **voltage** applied is adjusted by the **potentiometer**.

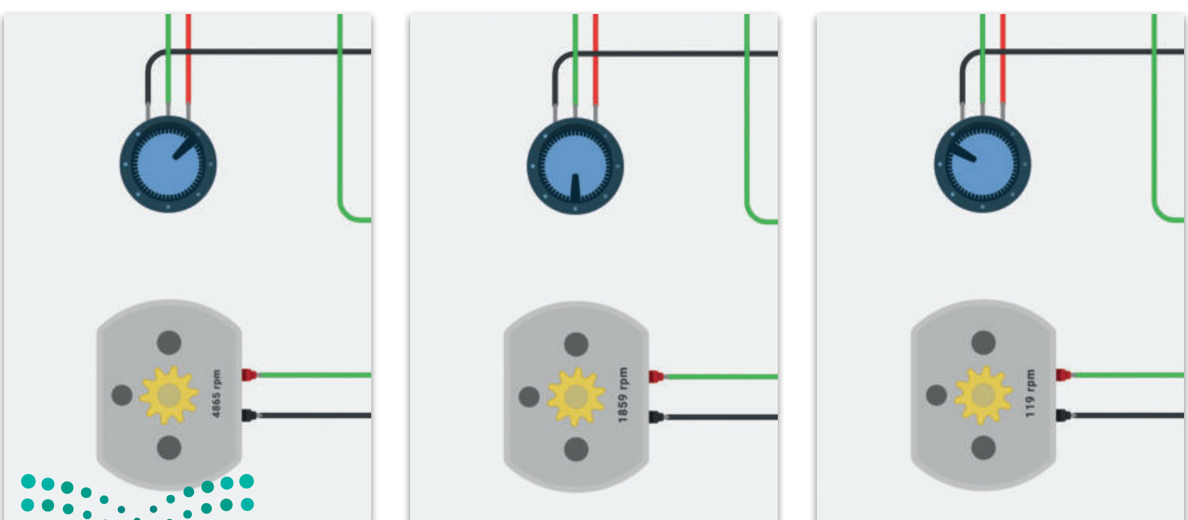


Figure 5.56: Adjusting voltage with the potentiometer

Exercises

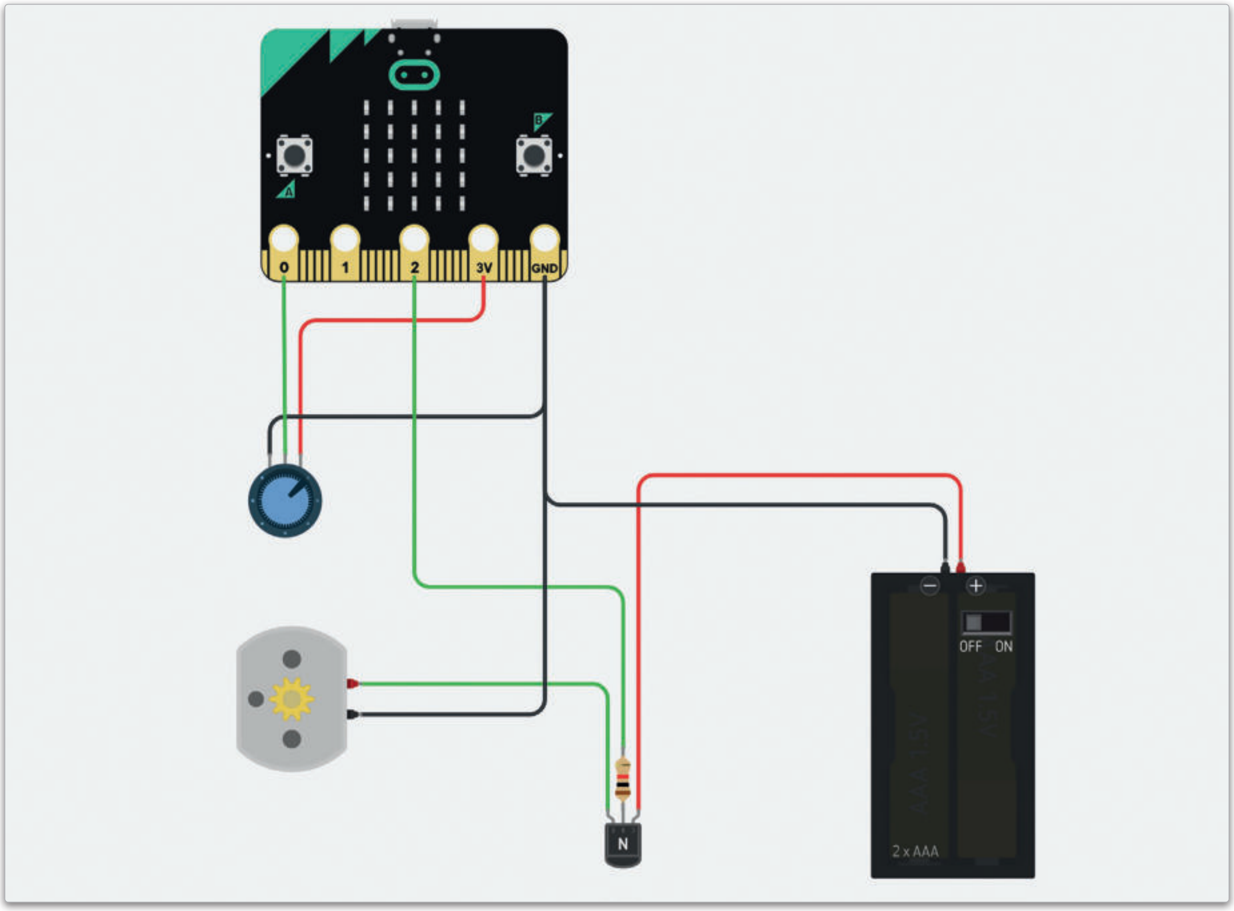
1. What is a linear potentiometer? What is the main difference between a linear and a rotary potentiometer?

2. Find the most common example of a device with linear potentiometers. Why do you think we use this type of potentiometer for this device?

3 Examine the following circuit and its code carefully and find the problem.

What do you need to do to fix it?

```
def on_forever():
  pins.analog_write_pin(AnalogPin.P1, pins.analog_read_pin(AnalogPin.P0))
basic.forever(on_forever)
```



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4 In the previous circuit, why do we use the functions `pins.analog_write_pin` and `pins.analog_read_pin` instead of `pins.digital_write_pin` and `pins.digital_read_pin`?

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5 How are NPN transistors used in an electronic circuit? Describe how the NPN transistor works.

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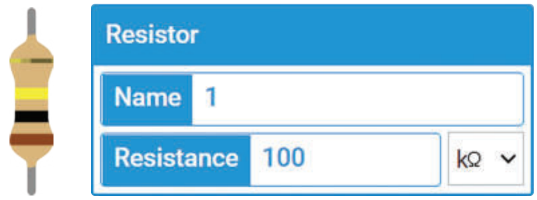
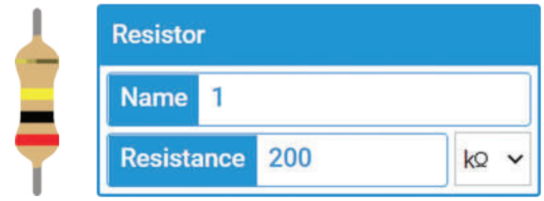
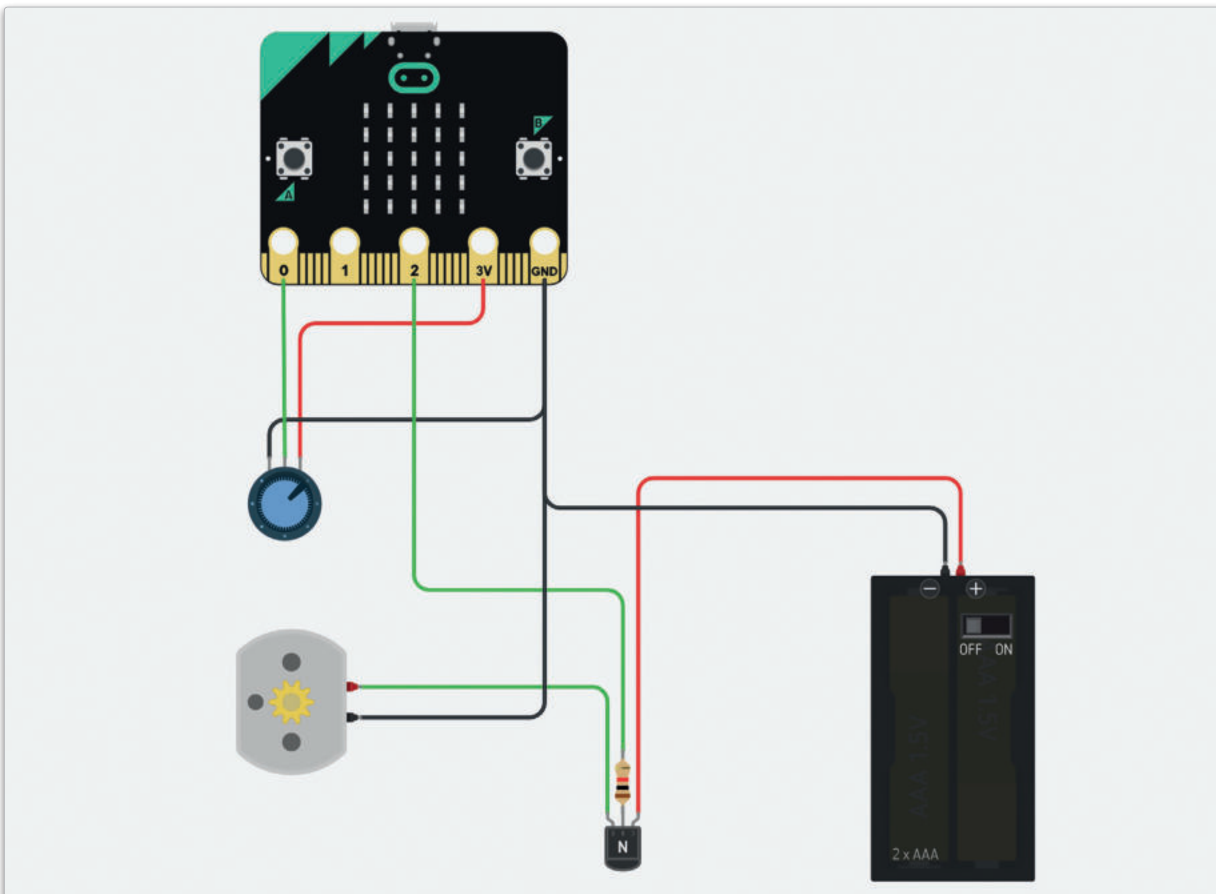
6 In the last project of the lesson, change the resistor value to 100kΩ and then to 200kΩ. How does this change affect the DC Motor?







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Project

1 ***Microcontrollers are*** *used to implement autonomous electronic systems. An example is a fire alarm system that detects a fire and emits an alarm signal for evacuation.*

2 ***Design and*** *implement an electronic circuit with a microcontroller such as micro:bit, that can be used as a fire alarm system. Write the code required for the microcontroller to activate the alarm under specific conditions such as a temperature increase.*

3 ***In addition*** *to indicating with an alarm sound, indicate the danger of fire with a visual signal. Use appropriate symbols or text for hearing impaired people.*

4 ***Extend your*** *design to check for unusual light intensity levels in the environment. High temperatures and extreme brightness are indicators of a fire inside a building.*

5 ***Simulate and*** *troubleshoot your circuit design with Tinkercad Circuits. Are you using the minimum electronic components required? It is important to design electronic circuits with the minimum number of components for simplicity, cost efficiency and low power consumption.*

Wrap up

Now you have learned:

- > about external components used in a microcontroller circuit.
- > how different components affect circuit logic.
- > to program the micro:bit microcontroller with Python.
- > to use temperature and light sensors in micro:bit.
- > to design microcontroller circuits to implement in real-life scenarios.
- > how a potentiometer regulates voltage in an electronic circuit.
- > to implement circuits with transistors.
- > how to use a transistor to amplify voltage in an electronic circuit.
- > how to use a DC motor as an actuator for movement.

KEY TERMS

DC motor	Microcontroller	Potentiometer
FOV (Field Of View)	Piezo buzzer	Servomotor
LED matrix	PIR sensor	

وزارة التعليم
Ministry of Education
2023 - 1445

Python programming prerequisite

Programming is one of the most important skills that should be acquired by students enrolled in Computer Science and Engineering pathway, as it is a requirement for a number of curricula in this pathway, including the Engineering and Data Science curricula. To facilitate the student's acquisition of Python programming basics, the following content is designed to be accessible by scanning the QR code for each topic. The student is advised to make a time plan to complete the reading of these units with the help of the suggested durations in the table below. The student can also put a tick mark (✓) to mark the completion of each unit.

Unit	Suggested duration	QR Code	Did you complete the unit?
1. Introduction to Python	One day		
2. Input-Output and Mathematical Operations	One day		
3. Conditional Statements	Two days		

Unit	Suggested duration	QR Code	Did you complete the unit?
4. Loops and Functions	Two days		
5. Lists, Tuples and Python Libraries	One week		
6. Dictionary, Nested Lists and Data Files	One week		
7. Advanced Data Structures and Recursion	Two weeks		
8. Introduction to Object Oriented Programming	Two weeks		