Capstone Portfolio

2025-2026

Grade 11- Semester 1

Development of an ATmega-driven multimeter from recycled E-waste materials

Group / 17207

TABLE OF CONTENTS

Team members and contact:

Mahmoud Walid Farag

Mahmoud.1724025@stemismailia.moe.edu.eg

Mohamed Mohsen Mahmoud

Mohamed.1724037@stemismailia.moe.edu.eg

Ziad Hossam Ramadan

Ziad.1724061@stemismailia.moe.edu.eg

Ziad Masoud Khalaf

ziad.1724062@stemismailia.moe.edu.eg

Introduction

Egypt is a country with rich, abundant resources, but it faces a set of complex challenges that threaten its sustainable development and hinder its progress in key sectors such as the economy, agriculture, and industry. These challenges, known as Egypt's Grand challenges, require urgent attention and innovative solutions to ensure that this country's long-term growth. The 11 Grand Challenges identified by Egypt are

- Improve the use of alternative energies.
- Recycle garbage and waste for economic and environmental purposes.
- Deal with urban congestion and its consequences.
- Work to eradicate public health issues and disease.
- Increase the industrial and agricultural bases of Egypt.
- Address and reduce pollution fouling our air, water, and soil.
- Improve use of arid areas.
- Manage and increase the sources of clean water.
- Deal with population growth and its consequences.
- Improve the scientific and technological environment for all.
- Reduce and adapt to the effects of climate change.

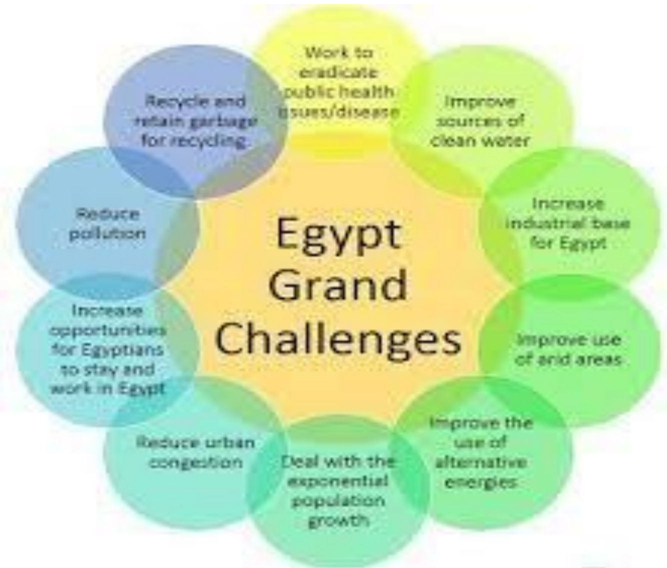


Figure 1 Illustrates all Egypt Grand Challenges

Each of these challenges presents obstacles to Egypt's development. Pollution and Poor waste management, for example, threatens both human health and natural resources, While limited science and technology availability slows down industrial growth and innovation.

This capstone focuses on four of the most critical challenges where innovation can create massive and measurable impact: **recycling garbage and waste for economic and environmental purposes, addressing pollution fouling air, water, and soil, improving the scientific and technological environment for all,** and **reducing and adapting to the effects of climate change.**

By tackling these areas, Egypt can enhance economic productivity and public health, while advancing in innovation and technological sectors, laying the foundation for a sustainable and beneficial future.

Chapter 1

Present and justify a problem and a solution requirement

Egypt Grand Challenges.
Problem to be solved.
Research.
Other Solutions Already Tried.

Egypt Grand Challenges

1) Improve the scientific and technological environment for all

Overview

Before we explore this grand challenge, there are two main things you need to know: **GDP,** or the Gross Domestic Product, and **R&D**, which is the Research and Development.

What is Gross Domestic Product (GDP)

GDP measures the overall economic activity of a country by calculating the market value of everything produced domestically in a given time, which is a standard of quarter. This metric helps to improve the economic performance, where rising GDP often means more jobs. The table below explains how the GDP is calculated. *(Callen, T. (2025)*.

Figure 2 Illustrates the definition of GDP

GDP Calculation Approaches	Description	Example
Production	Sums value-added (sales minus intermediate inputs).	Flour (input) subtracted from bread sales.
Expenditure	Total final spending: consumption + investment + government + net exports.	Household buys TV; government funds education.
Income	Total earnings: wages + profits.	Employee salaries from factory production.

R&D refers to the innovative efforts by companies or governments to expand the knowledge and apply it to new or enhanced products, services, or processes. It includes basic research, like exploring concepts without any applications, or the applied research, where its target is leaning towards applying this to real-world applications. Businesses invest in R&D to stay competitive; for instance, a tech company might develop better recycling methods for e-waste. While expensive and risky, R&D boosts productivity and economic growth. Companies like Amazon spend billions annually on R&D to innovate. (Kenton, W. (2025, March 28).

In Egypt's context, GDP provides a benchmark for R&D investment, typically expressed as a percentage, to evaluate commitment to innovation. Low R&D to GDP ratios may limit progress in areas like e-waste recycling for scientific tools. Enhancing R&D could address grand challenges by forcing to use of reusable tech from discarded devices, conserving resources, and reducing pollution.

Egypt's efforts to provide its scientific and technological landscape are connected with economic metrics like Gross Domestic Product (GDP) and Research and Development (R&D) spending, which provide the insights that can be used later in resource allocation for innovation. Furthermore, R&D refers to the systematic, creative work undertaken to increase knowledge and devise new applications, though it involves high costs, time, and risks with no guaranteed returns. Investing in R&D could return benefits for sectors like tech. Examples include Amazon's $88.54 billion R&D spend in 2024 for innovations in e-commerce and cloud computing, or Apple's $29.915 billion in 2023 for product enhancements. In Egypt, R&D as a percentage of GDP highlights investment in science.

Moreover, these concepts frame Egypt's push toward sustainable development. As of 2023, Egypt's R&D is about 1.03% of GDP, up from 0.91% in 2021, yet below the global average of 2.4-2.75%. This supports strong research output, ranking Egypt 24^{th} globally with 44,219 publications The ICT sector grows at 16% annually, contributing 5.8% to GDP, fueled by over 2 billion dollars in investments. STEM initiatives, like the Egypt STEM schools project, address education gaps where only 16.88% of graduates are in science and engineering

Causes

Egypt's efforts to improve its scientific and technological environment are caused by interconnected causes that limit innovation and resource allocation. These causes not only limit technological advancement, but also cause more problems, like e-waste management, where stronger R&D could enable prototypes from discarded devices for labs in biology or physics.

Figure 3 Represent the amount of electronics wasted

1-Low investment in Research and Development

The low R&D funding in Egypt restricts the capacity for innovation, as the resources are very limited. This low investment comes from the competing national priorities, including high public debt, which is around 90% of GDP in recent years, and social spending, which take out the percentage of R&D. For instance, Egypt's R&D spending grew from 0.19% of GDP in 1999 to 0.92% in 2020, but remained below the global average of 2.4%, leading to insufficient infrastructure for technological applications like e-waste recycling.

2-Brain Drain of Skilled Professionals

The continuous emigration of talented individuals, which is driven by poor working conditions, makes Egypt drain, particularly in STEM fields. 64.9% of nurses have migration intention. Egypt loses an estimated 20,000 skilled workers annually, including 66.4% of Physicians. This then leaves Egypt without any talented workers, or even very few.

3-Weak University-Industry Collaboration

Egypt's university-industry collaboration is hindered by several factors, leading to limited innovation and technology transfer. This affects the scientific environment by causing innovation and technology transfer to be stopped or delayed. This then affects the scientific environment and the development of practical tools. Data from surveys and studies show high relevance of these barriers, often rated above 80% by firms.

Impacts

Now, let's discuss the serious problems Egypt might face if its scientific and technological environment isn't improved. It looks at how a weak science and tech sector could hurt the economy, or drive people to leave, and damage the environment.

1-Economic Depression

If Egypt doesn't fix its science and tech issues, the economy could grow slowly and rely more on imported goods. As of this moment, R&D spending is only 1.03% of GDP in 2023, much less than the global average of 2.4%. This has kept Egypt at 86th place in the 2024 global innovation index, which means fewer jobs and products. Without change, high-tech manufacturing might not grow, which will risk a GDP growth rate stuck at 2.5% instead of the needed 5.7%. *(World Bank Open Data*. (n.d.)

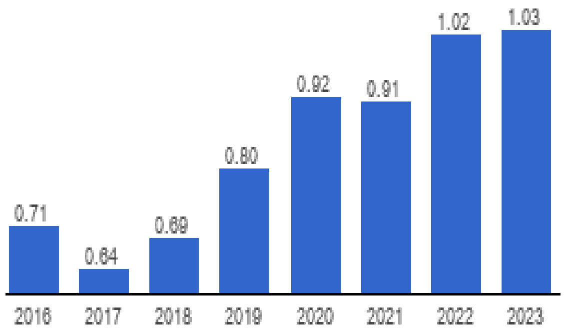


Figure 4 Represent the amount of R&D spent in Egypt

2-Worse Brain Drain

Without better opportunities in science and tech, more skilled Egyptians will leave for other countries, which would cause worse brain drain, as about 20,000 people emigrate each year. If this continues, youth Unemployment could rise to 20%, and the economy might lose 5.7% of GDP for every 1% increase in those skilled workers leaving. (*Egypt Youth Unemployment Rate 1960-2024*. (n.d.)

3-Increased Environmental Damage

Poor technology will make it harder to handle climate change and waste, which is known will lead to more pollution and resource shortages. Without new solutions, crop yields drop 15% for wheat and 28% for soybeans by 2050, not to mention water needs, which


Figure 5 Shows environmental damage due to poor technology

also might be damaged and drop. (Tigchelaar, M., Battisti, D. S., Naylor, R. L., & Ray, D. K. (2018)

2) Address and reduce pollution fouling our air, water, and soil.

Overview

Pollution adds harmful materials and pollutants to the environment, which cause negative effects on the environment that can include chemical materials, waste products that affect living organisms, ecosystems, and the quality of the environment. The balance of the natural world would be disrupted by introducing elements that don't exist naturally, which leads to environmental and health problems.

There are many types of pollution, for instance, air pollution, water pollution, soil pollution, and others.

Solving and reducing the problem of pollution is considered one of the most important things that should be done soon. Therefore, research was conducted on each type, its causes, and ways to solve it. *(Pollution and waste: air, water, and soil | Knowledge for policy*. (2025).

Air pollution

Air pollution is considered one of the biggest problems that faces the world in the current time, especially the urban areas, which causes many harmful effects on human health.

Figure 6 Represents air pollution

The reports of The World Health Organization refers to that more than 90% of the 7 million deaths happens in these areas as a result of the exposure to fine particles in polluted air, air pollution is a very important factor for noncommunicable diseases, accounting for more than a quarter of adult deaths 45% of COPD, 30% of lung cancer, 28% of heart diseases and 25% of stroke, Air pollution also case communicable diseases at a percentage of 52% such as acute lower respiratory infections. (State of Global Air. (2021)

What are the reasons for air pollution?

The biggest reason that air pollution causes human activity, that instance artificial processes for producing gases and particles that are suspended in the atmosphere, which affects the quality of inhaled air. The increase in the concentration of the number of pollutants has been linked to effects on human health and the environment.

Impacts

- **<u>Causing health problems, for instance:</u>**

1. Respiratory problems such as coughing, asthma, bronchitis, and lung problems.
2. Cardiovascular diseases cause an increasing risk of heart attacks.
3. Cancer: it can cause lung cancer.
4. Brain and nerve damage: Many pollutants, like lead, affect the nervous system

Premature death: Millions of deaths happen each year because of air pollution.

- **<u>Causing environmental problems, as:</u>**

1. Causing damage to plants as it reduces photosynthesis and slows the plant growth.
2. Damage the soil and seas as (SO_2) and nitrogen oxides mix with water vapor to form acids. (*Air Pollution and Your Health*. (2024).

Water pollution

Water is affected by many factors that cause its pollution. It's a serious phenomenon that causes a decrease in the quantity of drinking water, which is our resource from rivers, lakes, and underground water.

Figure 7 Represents water pollution

Water pollution is caused because of throwing waste into water resources; every year, 20 million people die from poisonings, which are caused by contaminated water, including more than 5 million children. One report in the United States showed that about 45% of the streams, 47% of the lakes, and 32% of the bay water are polluted. Water pollution affects organisms such as fish. Nathanson, J. (2018).

What are the reasons for water pollution?

Climate change, which means the rising temperature and changing precipitation patterns, can make water pollution worse by increasing the frequency and intensity of storms, flooding, and droughts. These changes can lead to higher pollution concentrations and reduced water quality.
Deforestation, which means cutting down forests near water bodies, leads to soil erosion, which can be carried into rivers and lakes.

Impacts

• Affect human health:

1. Water pollution causes many diseases, for instance: cholera, typhoid, and dysentery.
2. Industrial pollutants (arsenic, lead, pesticides) in drinking water can cause health problems such as cancer, organ failure.
3. Swimming or fishing in polluted water can lead to skin infections, respiratory problems.
4. Pollutants can contaminate seafood and crops irrigated with polluted water, introducing toxins into the human diet.
   Environmental impacts:
5. Aquatic ecosystem damage: Pollutants such as heavy metals, plastics disrupt the natural balance of rivers, lakes, and oceans.
6. Toxic substances can kill fish, amphibians, and aquatic plants, leading to reduced biodiversity.
7. Excess nutrients (especially nitrogen and phosphorus from fertilizers) cause algal blooms, which deplete oxygen and create dead zones where few organisms can survive. (*The Effects of Water Pollution: Human Health and*

Environmental Impacts • Environmental Studies (EVS) Institute. (2024, June 16).

Soil pollution


Figure 8 Represents soil pollution

Soil pollution refers to the destruction of land that can be used constructively through human activities, either directly or indirectly. At present, 300,000 hectares of UK land are thought to be contaminated with toxic elements such as lead and arsenic, and the same is true for other industrialized countries that are most affected by those gases, and developing countries are steadily moving in this direction. It has many negative effects, for instance, climate change, negative impact on human health, and loss of soil fertility. (*Guide to soil pollution: How to prevent and monitor*. (2023).

What are the reasons for soil pollution?

• Industrial Waste: Throwing industrial waste into the soil causes soil destruction.
• Deforestation: cutting down forests causes a shortage of plants and green areas.
• Extreme use of fertilizers and insecticides: using fertilizers and insecticides is the main reason that causes soil pollution, because they are chemicals that are put in the soil

Impacts

1- Contamination food crops with toxic chemicals affecting human health
2- Disruption of the ecosystem because plants are affected, which are dependent on animals that eat plants
3- Desertification occurs because plants and trees die or do not live long, so the place changes to a desert, affecting the environment and increasing climate change
4- Reduced agricultural productivity because the plants are being polluted, which causes them not to perform as they should, and by reducing productivity, it affects the economy in a harmful way
5- Release harmful gases like methane, which is a greenhouse gas that plays an important role in global warming and climate change

3) Reduce and adapt to the effects of climate change.

Overview

Climate change refers to major changes in the way in which the weather works all around the world. Global warming is the biggest part of this, which means that the atmosphere becomes warmer as it holds onto more heat from the sun. The Earth's atmosphere acts like a cozy blanket, which keeps the right amount of warmth around us. Humans have been making changes that put an extra blanket around the Earth, which makes it too warm. This extra warmth messes up a lot of things, for instance: when the oceans get warmer, bigger storms are made as hurricanes and typhoons, and as the ice at the North and South poles melts as the weather is too warm, as a result of that the sea level rise, which cause many crucial results such as floods in many places which people live, it will cause disappearing of many coastal cities *What is Climate Change?* (2023).

From the major things that cause climate change, for example, the increase in Greenhouse gases, which affect the Earth's energy balance and climate, the Sun is considered the primary energy source for Earth's climate. Some of the incoming sunlight is reflected into space, especially by bright surfaces such as ice and clouds, the rest of the incoming sunlight is absorbed by the surface and the atmosphere. A lot of the absorbed sunlight is reemitted as heat (longwave or infrared radiation). Normally, the atmosphere in turn absorbs and reradiates heat; any disturbance to this balance of incoming and outgoing energy will affect the climate. For example, small changes in the output of energy from the Sun will affect this balance directly. If all heat energy emitted from the surface passed through the atmosphere directly into space,

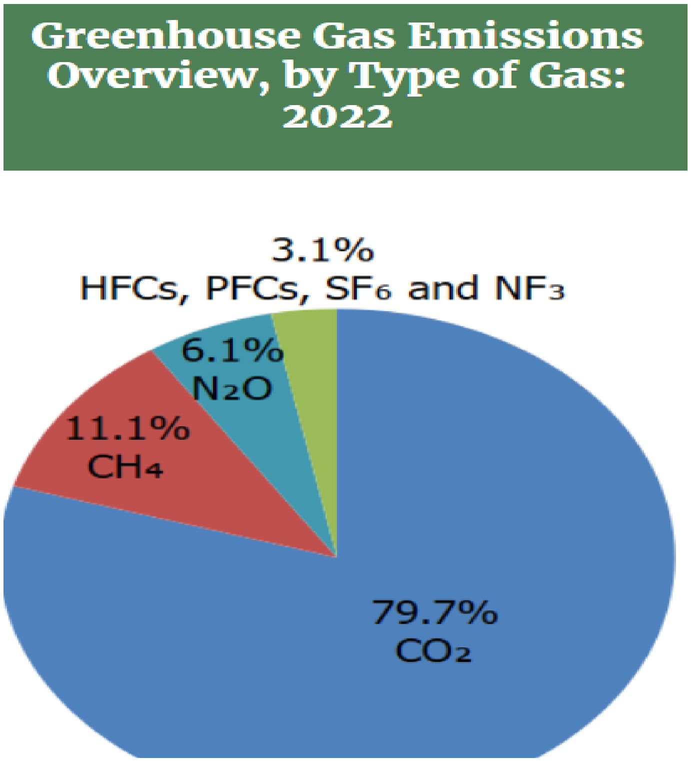


Figure 9 Represents percentages between different greenhouse gasses

Earth's average surface temperature would be tens of degrees colder than today. Greenhouse gases in the atmosphere, including water vapor, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), make the surface much warmer as they absorb and emit heat in all directions (including downwards), which keeps the Earth warm. Without these gases, life couldn't have evolved on our planet. The increase in the percentage of Greenhouse gases in the atmosphere makes it harder and more effective at preventing heat from escaping into space. When this happens, Earth gets warmer until a new balance is established. The Royal Society. (2024). Royalsociety.org; The Royal Society. United States Environmental Protection Agency. (2025, January 16).

Causes

1. Generating power: A lot of global emissions are produced from generating electricity and heat by burning fossil fuels. Most electricity is still generated by burning fossil fuels, which produces carbon dioxide and nitrous oxide – powerful greenhouse gases that blanket the Earth and trap the sun's heat, as it was mentioned previously.

2. Cutting down forests: cutting down forests to make farms or pastures, or for any other reason, makes a lot of emissions, like the cut trees, which release the carbon they had been storing. Each year, approximately 10 million hectares of forest are destroyed.

3. Using transportation: Most cars, trucks, and most transportation modes work by burning fossil fuels, which makes transportation a major source of greenhouse gases.

Impacts

1. Hotter temperatures: As the greenhouse gas concentration rises, the global surface temperature increases.

2. Increased drought: climate change is changing water availability, making it scarcer in more regions, which leads to a high risk of agricultural droughts affecting crops and ecological droughts.

3. A warm, rising ocean: when the Earth's surface becomes warmer, a lot of ice will melt, which causes an increase in the sea level which causing the sinking of many coastal cities. (United Nations. (2022).

4) Recycle garbage and waste for economic and environmental purposes.

Overview

Recycling garbage and waste is a process of collecting, sorting, and transforming old materials without changing the nature of these materials, turning them into new ones that can be used in different products. Recycling gives materials such as paper, plastic, wood, and much more a second life. These processes save the environment as they reduce pollution as they reduce the volume of waste. Beyond its important role in saving the environment, recycling garbage and waste generates great economic value. It supports local industries with recycled materials at low prices. The reused items are being used over and over instead of being disregarded, benefiting the environment, society, and the country. (Britannica. (2020).

Figure 10 Different recycling material

In 1970, on Earth Day, recycling garbage, waste was taken seriously by all the governments in the world, and rising awareness among people all over the world. Later, there were some organizations started by the United States to spread recycling between the 1980s-1990s. The rates of recycling garbage are constantly increasing all over the world, and in Egypt, it reached 37% of recycled materials in 2024, and the government aims to increase it by 60% by 2027. The rest of the percentage is either openly burned or discarded. (*Egypt Targets 60% Waste Recycling Rate by 2027*. (2025, June 18).

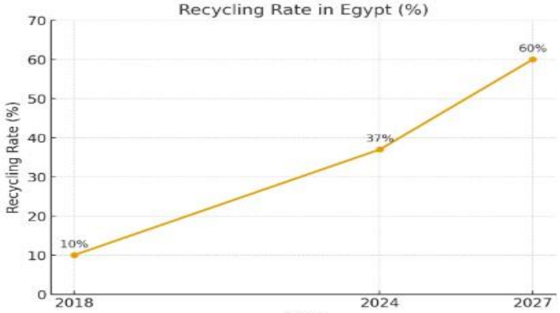


Figure 11 Illustrates the amount of recycling rate in Egypt in future

Types of recycling garbage

1- Mechanical recycling

Mechanical recycling involves sorting, collecting materials then cleaning them to turn them into new materials.

2- Chemical recycling

Known as advanced recycling, it is simply turning the materials into their original state of chemical components to make a new one.

3- Energy recovery

This process is mainly about using old materials or waste as a fuel to generate energy. For example, biomass energy uses the waste of animals, and by burning it, it generates steam that makes the turbines revolve to generate energy.

4- Organic recycling

This process turns waste food such as bananas into something useful into something rich in nutrients, and contains valuable products for plants.

There are two processes inside these types known as upscaling and downscaling. Upscaling is about turning old materials into something with equal or higher value; however, downscaling is the opposite, it turns a product into something with lower value. (Britannica. (2020).

Causes

1- Public unawareness

Most people do not know how important recycling is in developing the country, or they do not know where to recycle their items or waste.

2- Weak infrastructure

Developing countries do not yet have a recycling system. This means you do not find bins with a sign of plastic to throw plastic in it or anything like that, so most people do not know how to recycle. Even worse, some areas do not contain recycling bins at all. So there have to be sorting recycling systems to make it easier for people to recycle their items.

Figure 12 Represents different types of wastes being recycled

3- High costs

Recycling garbage and waste systems cost a lot of money, so most governments do not prioritize investing in technology to recycle old or used materials.

4- Cultural and social habits

Most people prefer to use new products, not recycled products, so the demand for recycling products is low. Most recycled items do not compete with new items, even though they are cheaper, but people do not trust recycled products.

5- Limited policies

Limited policies result in old ways of disposal of materials, such as open burning, which not only wastes the material value of becoming something new, it also increases the pollution in the air, so there must be restricted laws that punish people who do not care about their environment.

Impacts

1- Economic costs

Materials that are not recycled are considered an economic loss because they could be new materials that could be used in local industries at low prices. (The World Bank. (2018b, September 20).

2- Unemployment

The recycling sector could create hundreds of jobs, such as maintaining the systems of recycling systems. The unemployment rate is not increasing in Egypt right now, but it could be much better. The jobs that can be possibly created in the recycling sector can add millions to the GDP

3- Air pollution

Burning waste results in air pollution because of the increasing percentage of CO2 and other toxic chemicals in the air, which can result in respiratory illness. Most of the chemicals, such as CH4, that result from burning waste are greenhouse gases, which play an important role in increasing the temperature, global warming, and climate change in general. Burning waste results in 5% of emissions of greenhouse gases

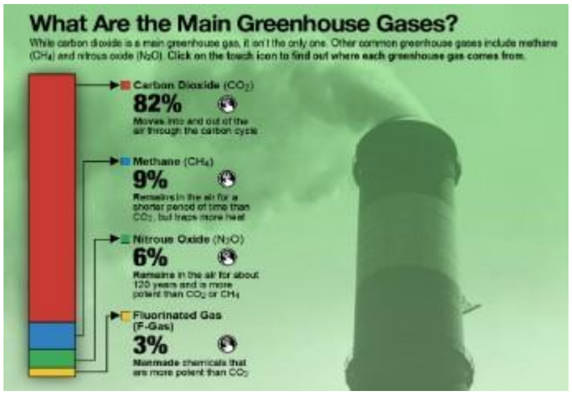


Figure 13 Illustrates main greenhouse gases and their percentages

4- Water pollution

Disposal of waste in oceans, lakes, and seas puts the lives of marine mammals in constant danger, as plastic does not decompose in water. Disposal of thermal wastes kills all the life in the ocean as the solubility of oxygen decreases with increasing temperature, so fish and other marine organisms cannot take oxygen in the water, as there is none. Water pollution also affects the life of humans, as dirty water or polluted water can cause many diseases in the human body, such as cholera.

Figure 14 Shows water pollution

5- Landfill space crisis

The world generates lots of waste, and without recycling, the landfills are filling faster than they should be.

Problem to be solved

Overview

Egypt has been stopped so many times, yet it keeps on pushing. Later, an agenda was created, establishing goals to be reached and problems to be addressed. Two of the most important and emphasized challenges are as follows: the need to improve the scientific and technological environment for all, including students, researchers, and even ordinary citizens, while also addressing the problem of waste, recycling it to help achieve economic and environmental goals. These two challenges reflect Egypt's national vision, which aims to achieve sustainable progress through innovation. However, the country continues to face an imbalance between advancing technology and maintaining environmental stability. Egypt's technological growth remains limited by unequal access to scientific resources.

Figure 15 Illustrates an example of a lab

Furthermore, two interconnected problems highlight this imbalance: the rising cost of laboratory equipment and the growing collection of electronic waste. Laboratory equipment costs have increased globally, with prices rising by an estimated **7-20%** in just the past few years. In Egypt, this issue has been even more magnified, due to the devaluation of the Egyptian Pound, which went from roughly 30 EGP/USD in early 2023 to over 50 EGP/USD by 2024, in addition to the inflation that peaked at 38% (Hossam Mounir. (2024, June 10). These factors have made lab equipment inaccessible for many schools and universities. Moreover, Egypt generates over 690 kilotons of e-waste annually, the highest total in Africa, while only 0.1% is formally collected or recycled. This leads to the

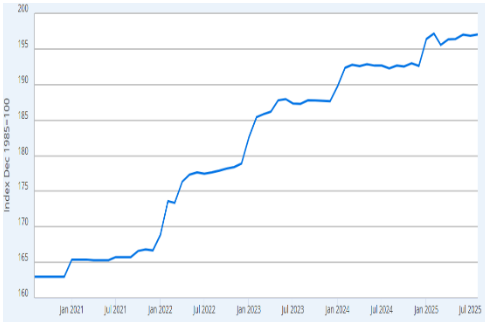


Figure 16 Graph shows the percentage of increasing in lab prices

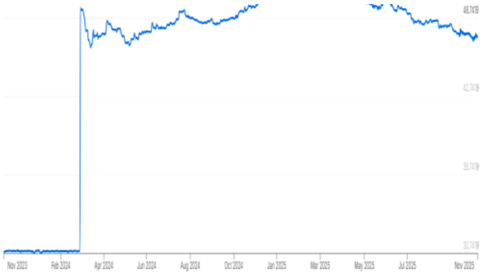


Figure 17 Graph shows the percentage of devaluation of Egyptian pound

release of heavy metals and toxins into the soil and water, worsening the pollution of air, water, and soil, and public health, and putting public health in more danger. Together, these issues create a cycle where technology both fuels and suffers from unsustainable practices.

To sum up, rising costs of laboratory equipment in Egypt have limited access to scientific experimentation, which has led to a shortage of innovation. Science was once for everyone; now it has become something only those with resources could explore. This equality is intended to be rebuilt by transforming electronic waste into more affordable scientific tools, improving the scientific and technological environment, and addressing pollution and e-waste issues. This process is achieved by tackling equipment inaccessibility through e-waste reuse, supporting sustainable resource management, and reinforcing Egypt's scientific and educational landscape.

Positive Consequences

1. Enhanced Innovation and scientific access

Reducing the cost barrier between laboratory equipment and students or researchers will significantly enhance innovation by enabling many more practical learning experiments. Enabling Egypt's technology to advance at a much higher rate.

2. Improved Green economy and job creation

Job creation could be improved by creating an e-waste recycling sector, which then enhances material recovery. Studies estimate that for every 10000 tons of refurbished e-waste, about 296 jobs are created. Egypt introduces roughly 1.1 million tons of electronic devices annually, meaning that scaling the formal recycling sector could offer over 30000 jobs. This aligns with global models showing recycling can cut the waste management costs by 20% while integrating informal workers into formal employment.

3. Environmental recovery

Preventing toxic pollution and enabling efficient metal recovery are all done by proper e-waste management. Studies show that only 20% of Egypt's waste is recycled properly. Recycling 1 million laptops annually can save enough electricity to power homes. This recovery affects the environment, making it to be such cleaner. (US EPA. (2019, May 17).

Negative Consequences

1. Decline in Educational quality.

If laboratory equipment prices remain high, the scientific education gap in Egypt will widen. Increase equipment import costs dramatically, cutting research budgets and delaying laboratory upgrades. Educational programs that depend on laboratory practice have observed a great decline in performance quality by up to 25% when access to experimental resources is restricted.

2. Economic loss

This failure to recycle Egypt's e-waste annually wastes valuable metals, including gold, silver, and palladium. This is worth over 150 million USD per year in materials that are recyclable. Moreover, high laboratory imports costs drain foreign currency, slowing the projected 9.9-16.8% annual growth rate of Egypt's lab equipment market. This leakage undermines national efforts toward research.

3. Public health crises

Exposure to e-waste burning increases disease among workers and residents. Research across Africa reports that 21.6% chronic obstructive pulmonary disease (COPD) rates and 7.1% asthma cases among e-waste recyclers; these causes contribute to health issues, which are caused because of the inhaled toxins and particulate matter. In Egypt's informal e-waste sectors, this could expose tens of thousands of urban recyclers to respiratory and neurological disorders each year. Issah, I., Arko-Mensah, J., Agyekum, T. P., Dwomoh, D., & Fobil, J. N. (2022).

Research

The first step to solving Egypt's problems that prevent Egypt from achieving a faster pace of development is by collecting information about the linked topics related to the problem and the solution to develop the best possible solution

Topics:

- **Microcontrollers (Solution related)**
- **Pyroelectric meter (Solution related)**
- **Evolution of lab equipment (Problem related)**

- **Properties of plastic (Prototype related)**

1)Microcontrollers

A microcontroller (MCU) is a small chip designed to control specific tasks in an electronic system. It combines the functions of a central processing unit (CPU), memory, and input/output interfaces, all in a single small chip. A typical microcontroller consists of a Processor Core, Volatile, Non-Volatile Memory, Input/Output Peripherals, and various communication interfaces. (*PIC MICROCONTROLLER ARCHITECTURE*. (2017, May 10), *Embedded Systems - Architecture Types*. (n.d.).

Figure 18 Shows a picture of microcontroller

Computational Architecture and instruction set design

Microcontrollers have two main architectures, the Reduced Instruction Set Computing (RISC) and Complex Instruction Set Computing (CISC), both represent two fundamental approaches to microcontroller processor design.

1. RISC Architecture: The RISC microcontrollers execute most instructions in a single clock cycle, providing fast performance and predictable timing.
2. CISC Architecture: The CISC supports complex instructions per cycle but requires more clock cycles to perform and execute.

To illustrate, in Fig.01, this is a **C++** code, where the code creates three variables, then gets the sum of the first two variables, stores it in the third variable, and finally returns the value. Let's now tackle how both the **RISC** and the **CISC** will handle this type of code.

1. RISC
    a. Load Variable a
    b. Load Variable b
    c. Load Variable c
    d. Add them. Store the result in c
    e. Return
2. CISC
    a. Read from the memory
    b. Add
    c. Return

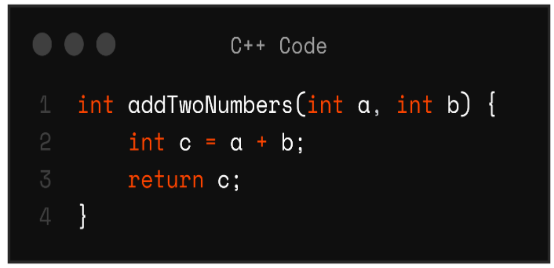


Figure 19 Illustrates the difference between RISC and CISC architecture

Notice here in the **RISC** steps, the steps have been broken into small chunks, while in the **CISC,** there are fewer steps, but each step is a big step. For example, the first step, which is *read from the memory*, this step consists of three steps: reading variable a, reading variable b, and reading variable c.

So, the conclusion is that **RISC** will be much faster in doing those instructions per one cycle of the clock, while **CISC** will have more cycles to perform one instruction.

The choice between **RISC** and **CISC** will affect the system performance, power consumption, and code density. The **RISC** architecture tends to consume less power due to the simplicity of the instructions' execution, while the **CISC** consumes more power and produces more heat. (GeeksforGeeks. (2018, July 23)

Memory architecture: Harvard Vs Von Neumann

The main memory architectures are the Harvard Architecture and Von Neumann Architecture, which shape how the microcontroller deals with the instructions. Harvard architecture is a computer architecture which is characterized by the separation of memory and instructions. Unlike the Von Neumann architecture, where both instructions and data share the same pathway.

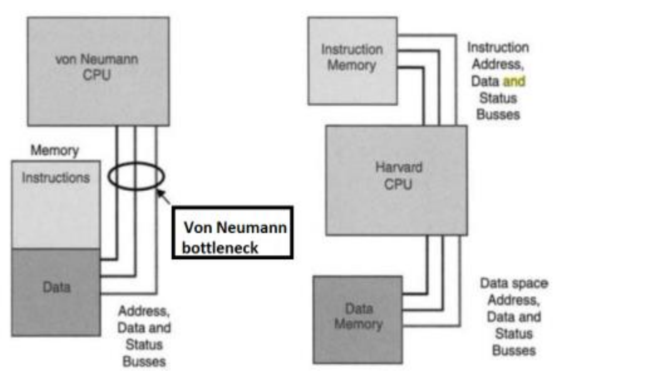


Figure 20 Illustrates the difference between Harvard and Neumann memory architecture

Harvard Architecture contains the following:

1. Instruction Memory: This memory is only used for the program code. Its separation from data memory prevents any malfunction that could happen, which would then overwrite the instructions during the computation, while also allowing the process unit to prefetch instructions without data access.
2. Data Memory: The data memory is used for storing variables, results, and operational data. Also, one other use for the data memory is to read the instruction fetches, optimizing the parallelism of the process pipeline.
3. Separate Buses: The buses are like pathways. Here at Harvard Architecture, there are two separate buses: one for the program's instructions and another for the data. The program instructions' bus deals with the instruction memory and reads/writes the instructions, while the data bus deals with the data memory. This separation reduces the bottlenecks of the shared memory architectures.
4. Processing Unit: The central processing unit (CPU) is the main brain that acts by executing the fetched instructions from the instruction memory via the instruction bus, decoding them, and performing operations using the data bus.

The advantages of this architecture are Increased Performance, Security, and Reliability.

Furthermore, the Von Neumann Architecture is a foundational model for digital computers in which a single memory space stores both program instructions and operational data. Unlike Harvard, which separates them into two separate buses, the Von Neumann Architecture uses a shared bus to access instructions and data, which results in a simpler hardware design but introduces certain performance constraints.

The Von Neumann contains the following:

1. Single Unified Memory: Which holds both the program instructions (Code) and data (Variables, Arrays, Sensor inputs), reducing the hardware complexity, but can cause memory access conflicts later.
2. Central Processing Unit (CPU): Which includes an Arithmetic Logic Unit (ALU) and, Control Unit. The task is to fetch the instructions and access the data from the same memory using a shared bus, executing the operations sequentially.

3. Input/Output Interfaces: The data of the devices, like the sensors or the actuators, flows on the same shared bus to the memory under the CPU control.
4. System Bus: A single bus handles both instruction fetches and data reading/writing. The shared nature of the bus creates what is often called the von Neumann bottleneck, where the CPU must wait if the bus is busy transferring data or instructions.

This architecture offers some great advantages, but at the same time, it has a trade-off, which is the Von Neumann bottleneck, making it unreliable most of the time when paired with a low-cost microcontroller. (GeeksforGeeks. (2020, May 13).

Instructions set and clock cycles per instruction

The **Clock Cycles Per Instruction (CPI)** metric defines how many clock cycles are required to execute an average instruction. Understanding the **CPI** is essential for performance prediction. The following equation gives you the number of seconds it would take to execute a specific instruction:

$$\text{Average Instruction Exectuion Time} = \text{CPI} \cdot \frac{1}{\text{Clock Speed}}.$$

Where the **RISC** processors typically achieve CPI values near 1.0, meaning that the instruction completes per clock cycle, the CISC processors may require 3-5 or more cycles for the complex instructions, making timing less predictable.

Memory types and data storage.

Microcontroller systems utilize different memory types, and each type has distinct properties affecting system design.

The first type is **Volatile Memory**; the second one is **Non-Volatile Memory**.

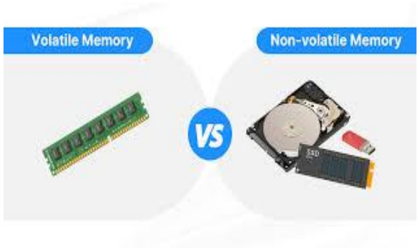


Figure 21 Shows Comparison between volatile and non-volatile memory

1. RAM (Random Access Memory): Also called **Volatile Memory**, used for temporary data storage during program execution, including variables. RAM provides fast read/write access but loses all data upon power loss. Microcontroller RAM sizes typically range from kilobytes (8-bit MCUs) to hundreds of kilobytes (32-bit MCUs)
2. Flash Memory: Also called **Non-Volatile Memory**, this is used for storing applications, firmware, and constant data.
3. EEPROM (Electrically Erasable Programmable Read-Only Memory): Non-Volatile memory supporting byte-wise read, write, and erase operations. EEPROM allows precise control of individual bytes, making it ideal for configuration data, calibration values, and non-critical sensor logs.

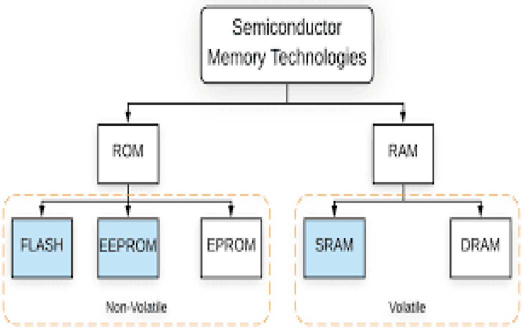


Figure 22 Illustrates all memory technologies

The **Memory Trade-Off**: System designers must balance memory types based on application requirements. (GeeksforGeeks. (2018b, September 10).

Data bus architecture and communication

Bus width and addressing capacity

The addressed bus width directly determines the addressable memory space,

Following this equation.

$$\text{Addressable Memory} = 2^{\text{Bus Width}}$$

For example, an 8-bit microcontroller with 16-bit addressing can access about 64 KB, whereas another 32-bit microcontroller with 32-bit addressing can access about 4GB. This fundamental constraint impacts system scalability and peripheral count. (*Addressable Memory - an overview | ScienceDirect Topics*. (n.d.).

Data Bus communication protocols

Different communication protocols serve distinct purposes. There are a total of four different protocols: **UART**, **I2C**, **SPI**, and **CAN**.

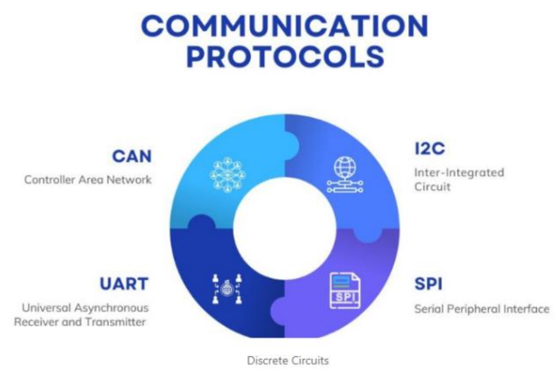


Figure 23 Represents all types of communication protocols

1. **UART** (Universal Asynchronous Receiver/Transmitter): An Asynchronous serial protocol is used for point-to-point communication. Operates independently without clock synchronization, simplifying hardware but limiting speed.
2. **I2C** (Inter-Integrated Circuit): Synchronous protocol with clock and data lines, supporting multiple devices on a single bus. The shared bus architecture here reduces component count but introduces bus capacitance limitations affecting maximum transmission distance.
3. **SPI** (Serial Peripheral Interface): SPI achieves higher speeds than I2C with lower latency, making it suitable for high-speed sensor interfaces and SD card communication.
4. **CAN** (Controller Area Network): A Different signal protocol defined in ISO standards, particularly for automotive applications. But the speed here is reduced and limited, making it suitable for distributed embedded systems and industrial networks.

The protocol selection has many trade-offs. If speed is targeted, then **SPI** is the right choice, while if long Distance is targeted, then **CAN** will be a great choice. (Communication network protocols. (2023).

2)Pyroelectric Meter

Overview

A pyroelectric meter is a device that measures infrared radiation or laser pulse energy using pyroelectric detectors, which rely on the pyroelectric effect in certain crystals to generate an electrical signal from temperature changes caused by absorbed light. These detectors produce a voltage or current proportional to the rate of temperature change. Making them ideal for pulsed energy rather than continuous energy sources.

Pyroelectric sensors

A pyroelectric sensor detects changes in temperature using special materials that create an electric charge when heated or cooled. In other words, it is a device that senses movement or heat through temperature changes. Moreover, there are some takeaways for this sensor, such as:

- These sensors only detect moving heat sources, making them ideal for motion detection
- Pyroelectric sensors convert the reading of temperature changes into electrical signals, enabling fast and accurate readings
- Compared to thermopile sensors, the pyroelectric sensor is better at detecting quick temperature changes

A pyroelectric sensor works because of special materials. These materials have a special property; they generate an electric charge when their temperature changes. This happens because the atoms inside the crystal shift slightly when heated or cooled, which later causes a slight voltage to appear across the material.

Pyroelectric effect

The pyroelectric effect is used to describe how certain material generates an electric charge when their temperature changes. To illustrate, when a pyroelectric material heats up or cools down, its atoms' arrangement changes or shifts. This shift causes a temporary electric polarization, which later produces a slight voltage across the surface of the material.

Pyroelectricity works because the material's crystal structure lacks a center of symmetry. This unique structure allows the material to develop polarization changes. This change forces any free charges to move, creating an electrical current.

The following formula is used to describe the pyroelectric current:

$$I_p = \eta \cdot P \cdot A \cdot \frac{dT}{dt}$$

Here, the I_P stands for current, and η is the absorption coefficient, P is the pyroelectric coefficient, A is the electrode area, and the fraction at the end is the rate of temperature change. This formula shows that the faster the temperature changes, the stronger the electric signal.

Components

A pyroelectric sensor contains several important parts that work together to detect temperature changes. Each part has its own function, which later enables the sensor to read accurate and reliable readings. Main components include:

1. Pyroelectric Material: This is the heart of the sensor; engineers often use materials like **Lead Zirconate.**
2. Electrodes: Thin layers of metals such as titanium that collect electric charge from the pyroelectric material.
3. Substrate: The substrate supports the sensor and holds all the layers together. Many sensors use **Silicon or Aluminum oxide**. Aluminum oxide prevents any heat escape, which makes the sensor more sensitive.
4. Optical Filter: This filter is used to prevent any other kind of light from entering the sensor; only infrared light will enter.
5. Signal Processing Circuit: This part takes the very tiny electric signals from the sensor and makes them strong enough to be measured.

Conclusion

The pyroelectric meter depends on the pyroelectric sensor, and its function is to capture pulses of temperature changes, which helps in many applications, such as motion sensing in malls or fire detection systems. The pyroelectric meter only provides a way to measure infrared radiation when pulsed.

3)The evolution of lab equipment

The laboratory equipment has undergone remarkable transformations through history. This transformation happens from simple tools, which are used in rudimentary experiments, to sophisticated devices harnessing cutting-edge technology. This evolution began in

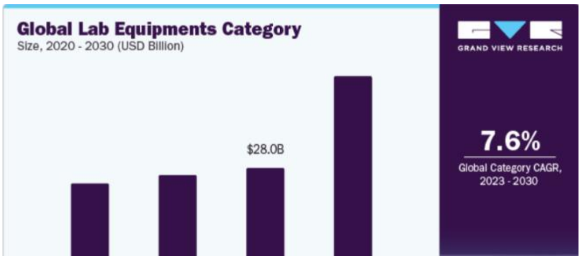


Figure 24 Illustrates the global increasing of lab prices

the 19th century when scientific inquiry transformed from basic, qualitative observations to more quantitative assessments. In the past, labs were often equipped with simple and basic equipment, for instance, beakers and flasks, which are considered the infrastructure for experimental chemistry. With the introduction of the scientific method, a lot of instruments, such as thermometers, became very crucial, which allowed scientists to measure and analyze with precision. This led to the need for more reliable and accurate instruments, such as the invention of the microscope, for instance, which revolutionized biology by unveiling the microscopic world. This helped us in understanding the cellular structures and paved the way for future innovations in lab technology. In the early 1800s, the development of the spectroscope opened new paths in chemistry and physics, enabling researchers to analyze the compositions of substances through light spectra. As we moved into the present day, the rate of evolution in labs has accelerated. Modern labs now benefit from state-of-the-art technologies that enhance research capabilities across multiple disciplines. Instruments like high-throughput sequencing machines and nuclear magnetic resonance (NMR) spectrometers have redefined the boundaries of what's achievable in genomic studies and molecular analysis. As there is a fantastic evolution in lab equipment, there is a major increase in the costs of this lab equipment from the past; the global lab category is predicted to grow at a CAGR of 7.62% from 2023 to 2030. Growth of the category can be attributed to factors such as a rise in investments and funding for research & development activities in the biotechnology and pharmaceutical sectors

In terms of end-user industry, the healthcare sector has the highest revenue share of 43.08% amongst other sectors.

The sector is one of the largest users of the industry's products because of the growing need for diagnostic testing, medical research, and pharmaceutical creation. The global lab equipment category was valued at USD 28.03 billion in 2022. The growth of laboratory equipment services is strongly correlated with the growing need for equipment. Thus, the category

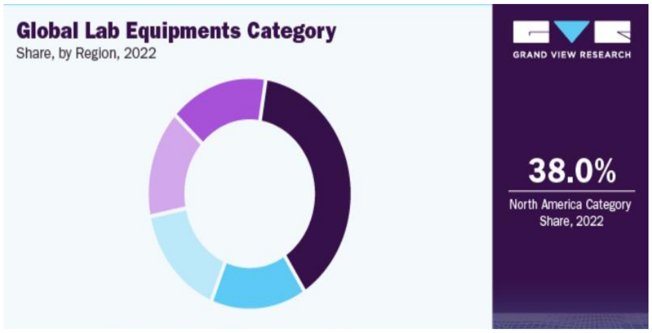


Figure 25 Represents growth in labs in certain regions

will rise as a result of the increasing requirement for the prompt and accurate identification of illnesses. In addition, it is anticipated that the global incidence of acute and chronic illnesses, which may call for laboratory equipment, will speed up the category's overall expansion. The need for cell media, gloves, Petri dishes, test tubes, and other consumables for cell culture is enormous. Besides, the need for laboratory disposables, such as cell culture media, is also anticipated to rise in light of the increased emphasis on personalized treatment and the expanding usage of cell-based therapies.

The North America region dominates the category, holding 38% of the global market share.

4) Properties of Plastic.

In our prototype, plastic is chosen to be the cover of our device as it has many abilities that make it the best choice for this position, from these abilities:

- **Impact resistance**
  It refers to the ability of an object to absorb sudden force as (hit, drop, or collision) without affecting this material as the plastic can absorb shocks and protect the device from any sudden forces, as plastic flexes and bends instead of cracking, there is a scientific base to this phenomena as plastic is made of long polymer chains that can stretch, this allows plastic absorb impact energy through chain mobility, giving plastic high hardiness.

- **Lightweight**
  Plastic keeps the device light and easy to carry, as it has low density compared to other materials like acrylic. This is related to it is made of light atoms (C, H, O) and has free molecular packing, giving it a density of around 0.9 -1.4 g/cm^3.

- **Electrical Insulation**
  Plastic is considered one of the safest covers as it covers our electrical device without any risk of any electrical shock, as plastic doesn't conduct electricity, because it has no free electrons. It is formed from a covalent bond; because of that, plastic is the best electric insulator cover for an electrical device.

- **Corrosion resistance**
  It refers to the ability of material to resist chemical degradation or rusting when exposed to water, oxygen, or other conditions. Plastic has high corrosion resistance as it doesn't rust or oxidize when exposed to moisture, sweat, or oxygen. The scientific base behind this point, it is a chemically stable polymer, unlike metals, plastics do not undergo oxidation, electrochemical corrosion.

- **Thermal insulation**
  It means the ability to resist heat transfer. Plastic is a good thermal insulator as it protects from feeling excessive heat from the device's internal components. Plastic has low thermal conductivity (around 0.1–0.4 W/m·K); its molecules are held together in a way that doesn't allow heat transfer.

- **Cost Effectiveness**
  The ability to be produced and manufactured at relatively low cost, plastic reduces the overall cost of devices while maintaining high quality, as it comes from petrochemicals and is produced through highly efficient processes like polymerization. It also requires low energy.

- **Aesthetic Flexibility**
  It refers to the ability of material to be easily colored, textured, and finished in many styles, but it was chosen to have the transparent shape to show the internal parts of our device to show the circuit and other important things.

- **UV and Weather Resistance**
  The ability to resist degradation from sunlight, heat, and outdoor conditions, plastic prevents discoloration, cracking, and weakening over time. This returns to the ability of plastic to absorb and neutralize UV energy before it breaks chemical bonds.

- **Noise Resistance**
  Noise resistance is the ability of a material to absorb and reduce sound waves or decrease vibration transmission, plastic has this ability as it is made of long polymer chains that can move vaguely when energy hits it which causes, **viscoelastic behavior** which is the combination between viscosity

and elasticity, **energy absorption** as vibration lose energy as heat in the plastic, **lower acoustic resonance**, plastic don't ring**.**

All of these abilities make plastic the best choice to be the cover of a device

Other solutions already tried

1)Generating electricity in Sweden:

Overview

In Sweden, there is much of non-recycling waste, so they use it to generate electricity by burning it to produce steam that makes turbines revolve.

There are nearly 35 plants in Sweden that do the same thing, and they remove around 6-7 million tons each year (*Swedish Waste Management 2023)*. The system generates approximately 20 TWh of energy each year (*Waste incineration in the Nordic countries*. (2021).

Figure 26 Recycling plant in Sweden

Around 5% of the households benefit from this electricity, and 20% benefit from its heat.

This process serves as an energy source for Sweden and a waste management tool, as it reduces the amount of waste in landfills. In Sweden, there are a lot of recycling processes. This one is done when there is no other option to remove this waste.

There are many processes after burning to not hurt the environment, including cleaning systems to remove the toxic particles in the air and acid gases.

Sweden, Norway, Iceland, Denmark, Finland. All these Nordic countries use this process to remove the non-recyclable materials.

Mechanism

There are many phases to produce energy from waste, starting with

1- Collecting and sorting

This process includes collecting all sorts of non-recyclable and harmful materials from the plant. Anything that can be recycled again does not go to the plant because, as mentioned above, it is the last option for recycling.

2- Combustion

After gathering the materials for the plant, they put the waste into a bed furnace with a high temperature between 850 °C and 1450 °C to generate steam.

3- Generating electricity

This process depends on steam to revolve the turbines that are connected to massive generators.

4- Flue-gas treatment

There are filters used to reduce the harmful gases from going to the atmosphere, including filters that remove acid gases and toxic particles in the air. These systems contain fabric filters and activated carbon absorption.

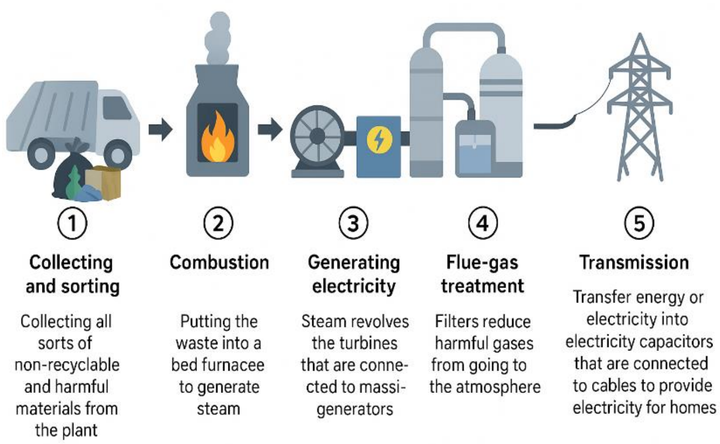


Figure 27 Illustrate the process of turning waste to energy

5- Transmission

They transfer energy or electricity into electricity capacitors that are connected to cables to provide electricity for homes. (Gomstyn, A., & Jonker, A., 2024, June 19)

Points of strength

1-Minimal landfill use

This process in Sweden makes less than one percent of waste end up in a landfill, which increases the percentage of empty land in Sweden

2-Stable energy supply

By making the turbines spin so the generators generate much electricity, which is equal to 19.5TWh every year, supplying lots of homes with electricity.

3-Circular Economy Integration

Metals, coal, and bottom ash can be reused in local facilities, which makes them affordable for the process of manufacturing process in Sweden.

4- High efficiency

Total energy produced from both heat and power can reach 95% which is a very high efficiency.

5-Increasing imports of waste

Norway takes over 2 million tons from countries such as the United Kingdom or Norway, so it pays Sweden money to get rid of their waste. (*Swedish Waste Management 2023)*

6-Creating jobs and improving the economy

This process creates a lot of jobs, and nearly 27,000 workers work in the waste management industry, although it helps the economy by providing electricity, heat, or even materials to local industries. (ReportLinker. (2024). *Forecast: Employees in Sewerage, Waste Collection and Management Services Sector in Sweden 2024 - 2028*.)

Points of weakness

1-Overcapacity import dependence

This means that there are countries that import large amounts of waste, making Sweden only able to recycle theirs. For example, Sweden can hold up to 6.3 million tons of waste with stops and improvements of their plants, but there more sent over 6.8 million tons 2020 of waste to be burned and produce electricity. Sweden also relies on these countries to make the plants full of the waste. (*Waste incineration in the Nordic countries*. (2021).

2- High fossil fuel emissions

Even so, there is an advanced cleaning system, but still, there are fossil fuel emissions, for example, CO2. This happens when waste is burned to create steam for the turbine.

3- High capital cost

Building and maintaining such plants, with, for example, their cleaning systems, is expensive.

4-Impact on higher-level recycling

Some analysts say that if there is an easy door or way to get rid of all waste by burning, then all people or the government will use it, impacting the traditional ways of recycling.

5- Public concern

There are lots of people who are feared of this process, creating some resistance to it because, for instance, they are feared of air pollution created by CO2 emissions or even loss of materials because these plants burn lots of waste.

2)Arduino lab kits

Overview

Arduino lab kits are a prior solution to the problem of increasing the cost of labs in schools or generally. Arduino lab kits are a functional tool to be used in experiments or labs instead of heavy or expensive devices or equipment because they provide simplicity and are very cheap, providing the core of affordability and simplicity without sacrificing the core of education. (Kushner, D. (2011, October 26).

Figure 28 Shows an Arduino lab kit

Arduino lab kits contain a microcontroller board, sensors, motors, LEDs, and connecting wires, allowing anyone to create something or simulate any experiment, from simple ones, for example, a circuit explaining Ohm's law, to complex ones, for example, automated systems.

These kits can also be used to build lots of projects by students throughout the year, and they help them to understand the practical experiment with ease.

Arduino lab kits were first developed in Italy in 2005 as an easy tool to help people use it instead of complex devices, as it is user-friendly and anyone can use it if they have simple background knowledge about electronics. Now, Arduino lab kits have reached more than 5000 schools, impacting lots of people nearly one million people globally.

Arduino lab kits can be used for the long term because they do not wear out over time. Arduino lab kits can benefit a student individually or a school for experiments or a lab to test something. (Administrator. (2019, November 10).

Mechanism

The mechanism of using Arduino lab kits in general is as follows

1- Installing

Install everything on the main board and make sure it is installed correctly, including sensors, cables, and more.

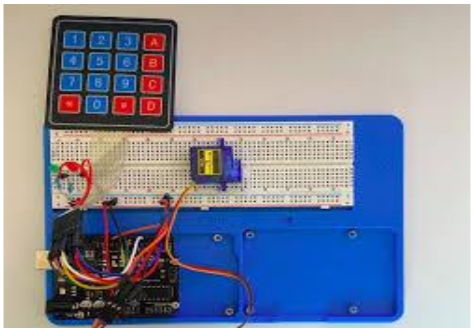


Figure 29 Represent how work with an Arduino

2- The input (sensing)

After installing the components, these components will gather data for you from the physical environment, for example temperature sensor measures the temperature of the current room.

3- The processing

After gathering the data from the sensors, the user writes a code or program on a computer or uploads it to the main board by a microcontroller. This code is written in programming languages, for example, C++ and Python. The code that the user writes defines or sets the roles of the data or the information coming from the sensors, for example, if the temperature is high, turn on the fan.

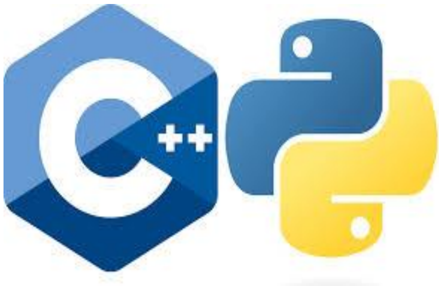


Figure 30 Represent the most famous languages to code with

4- The output

After writing the code to display the output under certain conditions. The output can be on a digital LED screen, for example, a sensor that measures how clean the air is, or a physical act, for example, spinning the fan. All the components are connected by jumper wires, which are flexible electrical cables with a solid pin at each end, acting as temporary bridges because they carry electric signals between components.

Points of strength

1- Low initial investment

A single Arduino lab kit costs nothing compared to specialized lab equipment because it costs nearly 1000 L.E., while specialized lab equipment that can only be used for one thing costs thousands.

2- Replacement Savings

If one part or component is destroyed or broken, it can be replaced easily without worrying about the cost, because, for example, sensors cost around in average 100 L.E.

3- Scalable Project Complexity

Suitable for levels beginning with simple projects, for example, applications on Ohm's law, into complex projects, for example, automated systems

4- Simplified Programming Environment (User-friendly)

The Arduino integrated development environment is straightforward to install and use for all people, and writing syntax only requires background knowledge of C++

5- Long-Term Usability

A single kit can be used for a long period of time, as the Arduino lab kit does not wear out, and it can be used on different projects and by multiple people, as the board is designed to withstand repeated use. Shinde, S. (2023, January 25).

Points of weakness

1-Weakness in processing power

The power of microcontrollers or the memory is pretty slow, making it unsuitable for large amounts of data, complex data, and advanced algorithms.

2- Lack of high precision

The built-in components of the Arduino kits and sensors are used for general use, but for high-precision engineering numbers or advanced scientific research, you cannot rely on the Arduino lab kit.

3- Computer dependency

Every kit needs a computer to install everything on the Arduino with the integrated development environment (IDE) installed, so you can code

4- Damaged components

With the wrong use or not following instructions, you can damage the components, especially the sensors, pretty easily, so you will have to buy another sensor, or you can damage the entire board. So, if anyone is Arduino lab kit for the first time, he should look for an instructor to help how deal with it.

3)AMP robotics

Overview

Figure 31 Shows a picture in AMP robotics company

AMP robotics is a corporation that is the head I the field of AI and robotics for the recycling industry, which was started in 2014 by Matanya Horowitz. The company's task is to reuse the waste material, transform the economics of recycling, and improve its efficiency and accuracy to make a new, sustainable Earth. The major problem is addressing the inefficiency and danger of the old recycling sorting, which is often done manually on fast-moving conveyor belts. Their technology tackles this by using AI to identify materials and robotics to physically sort them. AMP's system is a powerful mix of artificial intelligence and high-speed robotics. (*AMP Robotics – Contrary Research Company Profile & Resources*. (n.d.).

AMP Neuron™: The AI "Brain"

- This is the company's branded AI platform that uses computer vision and machine learning.

- It trains millions of images of recyclable materials to know and classify objects based on their material type, for instance, PET plastic, HDPE plastic, cardboard, aluminum cans, shape, color, and even brand.

Neurons can differentiate between various types of plastic, paper, and metals with high accuracy, even finding specific products and packaging.

AMP Cortex™: The Robotic "Hands"

Figure 32 Represents the shape of AMP hands

• These are high-speed robotic arms (primarily the "Cortex-R") that perform physical sorting.
• Shown in real-time by the AMP Neuron AI, the robots use suction grippers to pick and place targeted items from the conveyor belt into the targeted bins.
• They are known for their speed (picking up to 160 items per minute, faster than humans) and for having the ability to work 24/7 in harsh, dusty environments. (Greenwood, M. (2019b, March 22).

Points of strength

1- Improved Sorting Accuracy and Purity:
The AI (AMP Neuron) can know materials with exceptional accuracy, differentiating between types of plastic, paper, and metals that are often puzzled by human sorters or traditional machinery. This leads to cleaner, higher-value bags of recyclables that fetch better prices on the market. (Ellen MacArthur Foundation. (2021, October 1).

2- Increased Recovery Rates:
The robots can reclaim valuable and specific materials that would be missed and sent to a landfill. This includes items like small electronics, coffee pouches, and specific high-value plastics, increasing the amount of material recycled.

3- High Efficiency and Speed:
AMP robots can pick and place objects at speeds reaching 160 items per

minute, exceeding human abilities. They can operate 24/7/365 without breaks. (Greenwood, M. (2019b, March 22).

4- Data Analysis for Facility Optimization:
This is an essential, observed advantage. The AI doesn't just control robots; it allows a real-time digital trail of everything on the conveyor belt. Facility managers gain data on material flow and high efficiency, allowing them to make smarter business and operational decisions.

5- Improved Safety:
Manual sorting is dangerous, involving sharp objects and hazardous materials. By automating the most dangerous sorting tasks, AMP's robots make facilities safer for humans, who can be reassigned to supervisory or equipment maintenance roles.

6- Financial Capability for Recycling:
Decreasing costs and increasing the value and volume of recovered materials make recycling greener. This is important for keeping recycling programs.

Points of weakness

1- High Initial Capital Investment:
A single AMP Cortex robot system represents a significant upfront cost, often hundreds of thousands of dollars. This can be a big barrier for smaller, municipally owned recycling facilities.

2- Technical Complexity:
While more reliable than humans, robots are complex machines that require special technical staff for maintenance and troubleshooting. A facility's IT also needs to support the AI systems.

3- Limited Flexibility for Certain Tasks:
While Artificial Intelligence is constantly learning, physical robot arms are best at picking up. They can struggle with tangled materials like plastic film, bags, or clothing, which require human intervention.

4- Job Displacement Concerns:
The primary economic driver is reducing labor costs, which naturally leads

to concern about job losses for manual sorters. The industry argument is that it creates higher-skilled jobs in robot operation and maintenance, but the transition can be difficult for the existing workforce.

5- Dependence on a Single Supplier:

Adopting AMP's ecosystem leads to "vendor lock-in." The facility becomes dependent on AMP for software updates, replacement parts, and special service, which can be a long-term risk.

4)Tesla’s recycling battery

Overview

Tesla’s materials in the lithium-ion vehicle and energy storage batteries are recyclable. Tesla has developed a closed-loop battery recycling system, which is designed to recover and reuse valuable materials from its lithium-ion batteries rather than sending them to landfills. The company says that 100% of the batteries are recycled, and that its process can recover up to 92% of key materials. (Recycle Technologies. (2023, May 22).

Figure 33 Shows a tesla battery

Mechanism

Before recycling, Tesla extends battery life by repairing, software updates, or second-life uses, for instance, energy storage. When a battery reaches end-of-life, it is safely removed and de-energized by certified professionals. Packs are taken apart into cells and modules. Non-cell materials (plastics, wiring, casings) are separated for further processing. The left things (black mass) (a mix of active material) are handled by two processes, which are pyrometallurgical and hydrometallurgical.

1- Pyrometallurgy is the melting of components to recover metals, for instance, nickel, cobalt, and copper.

2- Hydrometallurgy uses chemical leaching to extract lithium and other elements.

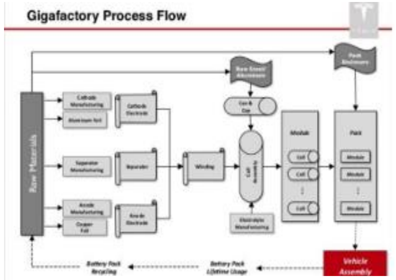


Figure 34 Illustrates the mechanism of how to make tesla's battery

The refined metals are returned to Tesla's Gigafactory production lines and minimizing the need for newly mined resources.
The recycling mechanism of Tesla closes the loop from production to reuse, reducing waste and environmental impact.

Points of strength

1- Reduce the need for raw material mucking, recycling battery recovery materials as lithium, nickel, cobalt, copper, etc. This reduces dependence on new mining operations, which have environmental, social, and geological risks.

2- By recovering materials and reusing them in a loop again, there's less waste, fewer materials going to landfills.

3- Cost savings and supply chain resilience, if anybody can recover materials and reuse them, the material costs will be reduced.

4- Supporting the second life use before full recycling and making sure of that.

Points of weakness

1- The complexity and the difficulty of battery pack design and materials, as they are built with many cells, various chemistries, modules, adhesives, electronics, and safety systems. These make sorting and material recovery more difficult and costly.
2- Safety risks such as recycling lithium-ion batteries pose inherent hazards: e.g., thermal runaway, fire risk, high voltage, and chemical exposure. (EPA. (2023, June 17).
3- Infrastructure and capacity limitations, although Tesla says 100% of scrapped batteries are recycled, much of the "recycling" to date has been from manufacturing scrap rather than large volumes of post-consumer (used vehicle) batteries. Also, globally, the infrastructure to handle large volumes of EV battery recycling is still maturing.
4- Economic viability and material value fluctuations, as the economics depend on the value of the recovered materials, the costs of the recycling process, and volumes of batteries needing recycling. If metal prices drop or if the battery chemistries move away from certain valuable metals, the incentive weakens.

5)Solar-Powered "Liter of Light."

Overview

Figure 35 Represent a photo of liter light

The Liter of Light (Isang Litrong Liwanag) is a global, commons movement that uses inexpensive, readily available materials to provide sustainable indoor lighting to communities with limited or no access to electricity. Its core innovation is an open-source design that is designed for a solar-powered light that is cheap, easy to build. The project takes the sunlight from daylight, stores the excess energy in batteries. This is the only solution to a 24-hour solar-power system. (*Solar energy to light up Egypt's poorest villages*. (2015), (*Liter of Light*. (2023, July 26).

The Components

1. A Plastic Bottle with a volume of about 1 liter: Acts as the "light bulb."
2. A Small Solar Panel: collects the sunlight during the day.
3. A Rechargeable Battery: Stores solar energy that the solar panel generates.
4. An LED Bulb: The light source, which is much brighter and more accurate than the original daylight.

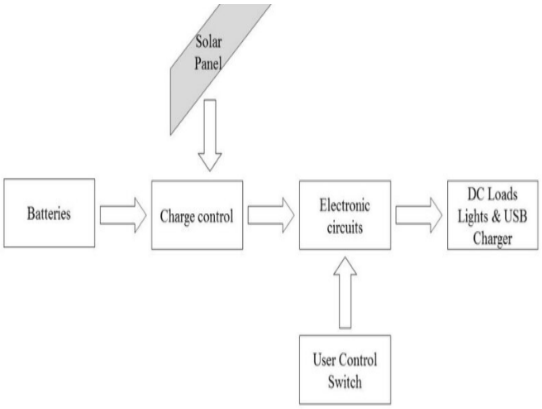


Figure 36 Illustrates all the components needed to make a liter light

5. Electrical Components: A simple circuit board that may include a sensor for automatic operation at sunset.
6. Exterior Casing: sometimes made from plastic or another clean material to protect the components.

Mechanism

1- In the day, the solar panels take the sunlight and convert it into electricity, then collect it in the battery.

2- At night, often automatically stimulated by a sensor, the battery powers the LED bulb from the energy which collected in the battery.

3- The LED bulb that is kept inside the plastic bottle, which distributes the light generally, to light a small home.

4- The difference from the Original "Liter of Light" was simply a bottle filled with light solution inserted into a roof, reflecting sunlight indoors. The solar version is a standalone, electrically powered light that works 24/7.

Points of Strength

1- It reduces the need to buy batteries for lighting. For families living on a few dollars a day, the money saved on kerosene can be sent towards food, education, or healthcare.

2- It is built from cheap, available components like recycled plastic bottles, small solar panels, and standard LEDs. This makes it cheaper than commercial solar lights and cheaper than the cost of kerosene.

3- The plans and building instructions are freely available. This "open source" model allows all individuals, groups, anywhere in the world to learn, build, and adjust the technology without paying fees.

4- The project doesn't just deliver lights; it trains local volunteers ("Light makers") to build, fix, and repair them. This creates green micro-entrepreneurs, builds local technical skills, and promotes a powerful sense of ownership and self-confidence.

5- It directly replaces kerosene lamps, eliminating internal air pollution from toxic gases, a big cause of respiratory diseases. It also removes the high risk of chance of fires and burns related to lightning.

6- The solution is double purpose for the environment, it uses clean, renewable solar energy to reduce carbon emissions and recycles the plastic waste (bottles), facing both energy poverty and plastic pollution at once.

7- It directly refers to the problem of "energy lack" by providing a necessary service—light and underserved communities. This allows important activities like studying at night and working safely after dark.

Points of Weakness

1- The light is a basic, low-power solution. It provides enough illumination for general indoor lighting, but it is not enough for tasks requiring bright, focused light, such as detailed artistic work or lighting larger communal spaces. Lacks a USB port for charging phones, an important feature available in commercial solar lights.

2- While the design is strong for its cost, the use of recycled bottles and exposed wiring can make the units exposed to damage from extreme weather and physical impact.

3- The solar version requires some complicated electronic components, like a PV panel, a battery, an LED, controller. Finding these parts is not easy to find them in our daily life.

4- The project often depends on grants, donations, and volunteer labor to initiate workshops and distribute lights. Creating a fully self-supporting.

5- The rechargeable battery is the component with the shortest lifespan of 2:4 years. When the battery dies, it must be replaced. Without a good system for collecting and recycling these spent batteries.

Chapter 2

Generating and Defending a Solution

Solution and Design Requirements
Selection of Solution
Selection of Prototype

Solution and Design Requirements

To create a successful prototype that solves the problem of the increasing lab equipment, several criteria must be put for the solution itself and the design of the shape it will resemble.

Solution requirements

1-Eco friendliness

The solution material must not harm the environment in any way. For illustration, any material that contains toxic chemicals or emissions will not be used, so the solution is clean to the environment.

2-Availability

The materials or the electric parts from which we will extract the components must be available in any circumstances, as choosing the correct materials plays a huge role in how effective the solution is.

3-Safety

Safety is a non-negotiable requirement. Particularly dealing with electronics and high-voltage parts, the solution must be safe for anyone using it, following the safety precautions.

4-Reliability and Durability

Reliability means that the device measurements are trusted for scientific calculations or researchers, and durability means the device can withstand repeated use and can work in an open-air environment without lowering the accuracy. The device can also work in different room temperatures without any errors.

5-Very Low cost

The device is all made with recycled materials, even the electronic parts. Bought from cheap places that sell recycled components at very low prices. The device is cheap according to any other device that is used for the same purpose, solving the increasing lab problem. Furthermore, the prototype is accessible or replicable in any school or any place in general, achieving the improvement of the scientific and technological environment for all.

6-User-friendly

The prototype should be accessible and easy to use for regular individuals, as it should not require experience or prior knowledge to operate it

Design requirements

1-Variety of applications.

The device that would be built will be used in the physics lab and fabrication lab, and it has many functions in these two labs. Its functions will be tested in these two labs, depending on the usage in each lab.

2-Recycled materials that are environmentally friendly

All the materials that will be used to construct our prototype must be from old devices or used materials, or discarded ones. The extraction methods will be documented. The materials will be friendly to the environment as they do not produce any emissions or cause pollution.

3-Calibration

The device is calibrated to produce accurate results for any amount; for example, the voltage measured and the calibration methods will be documented.

4-Transparent housing

The device should be well preserved in a transparent housing, and all the components can be seen inside. The transparent housing should protect the device from any environmental factors.

5-Data Sheet Showing Prototypes

The properties of the prototype are calculated, including the voltage operating value, the maximum drag electric current, the maximum operating power, the voltage, and the resistance reading range. These properties are calculated to make it safe and easy for anyone using it

6-Schematic Design for The Circuit

There should be a schematic diagram showing the internal and external components of the device, and it should include electrical circuits.

The schematic diagram acts as a map for anyone replicating our solution.

7-Accuracy

The prototype should produce accurate and precise numbers, and the error percentage should not exceed 5%. The volt, currents, resistance, power, and energy should be compared to another functional device or a known standard with relevant scientific references, for example multimeter. There should be at least five tests in real conditions, and the results should be put on a graph to show the relationship between the readings.

8-Comparison to a standard device

The prototype should be compared to a real device to measure the accuracy and any other properties between our prototype and the standard device

9-Portability

The device must be lightweight, easy to transport, and operate, as the mass and the volume should not exceed 0.5Kg and 0.003 m^3. The device can be recharged and works for a while without needing to connect it to a power source. This can allow the solution to be used in different spaces in field research or a shared lab.

10-Modularity

If anything happens to any component of the device, for illustration, one component is damaged and needs to be replaced; it can be replaced easily, and the device works perfectly.

11- Overcurrent protection

The device should not be damaged when high current flows through it. After high current flows to it, the device shuts down to protect itself, and this can be done by a special component called a fuse.

Selection of Solution

Figure 37 Represent a photo of multimeter

The proposed solution is making a multimeter, which is considered an electronic measuring instrument that merges a variety of measurement functions into one device, which can be used in electronics, electrical work, troubleshooting, and hobby projects. This device can measure voltage (V), resistance (Ω), and current (A). It often contains extra features like continuity checks, diode testing, and capacitance. This device uses internal electronic circuits to detect the electrical signal and display a number on a digital screen. Probes (red and black leads) connect the multimeter to the test points in a circuit. These probes are connected to the positive and the negative part of the device or the electric work that needed to be measured, this device provides accurate readings, gives easy reading that can be read from the digital display, it's safer and more reliable than older analog meters, and it's multiuse that can measure many electrical measurements, the digital measurements architecture of this device contain three major scientific subsystems:

1. **Analog Front-End (AFE):** that protects and prepares the signal, including precision resistors, MOSFET switching networks, Shunt resistors for current, Buffer amplifiers, and Overvoltage protection elements. AFE ensures the signal is safe and accurate before digital conversion.
2. **Analog-to-Digital Converter (ADC),** which is considered the heart of digital measurement. There are three major types of ADC:

    1. Dual **slope integrating ADC** → High accuracy, noise rejection
    2. Multi-**slope ADC** → Used in laboratory DMMs (very high precision)
    3. SAR **(Successive Approximation Register)** → Fast, efficient.

    The ADC changes the analog voltage into a digital number representing the measurements.

3. **Digital processing unit:** A microcontroller or DSP that performs digital filtering, calibration correction, and others.

This device gives measurements by using mainly laws such as $I = \frac{v}{R}$, $R = \frac{v}{I}$, and $v = R \times I$ These are considered the most important formulas that are used in having accurate readings. In this device, the way of connection differ from one function to another, for instance, in the voltage circuit the way of the connection is parallel as the voltmeter measures the potential difference between two points, voltage is the energy per unit charge, so the meter only wants to detect the difference between two points, connecting in parallel ensures the meter is across the component, without significantly altering the current in the circuit, in resistance circuit the way of connection is parallel (with power off) as a multimeter measures resistance by applying a small voltage and measuring the resulting current, it must be connected across the component to see the full voltage drop, and in current circuit the way of connection is series, as An ammeter measures the flow of charge (current) through a circuit.

To sum up, a digital multimeter is a very controlled system that changes electrical signals into digital data giving accurate output, as a result of all that this device was chosen to be our solution for our major problem instead of choosing pyroelectric meter, which measures power (energy) of the radiation pulses for instance from a laser, this device uses a pyroelectric sensor that detects the changes in the temperature when radiation hits the sensor, causing sensor get warmer, after detecting that change in the temperature, this change produces an electric signal such as voltage because of pyroelectric effect, this device has a lot of weakness points which make it from Prohibitions, for instance, it's very sensitive to vibration and noise, pyroelectric sensors respond to tiny changes in the temperature, which means that any mechanical vibration can affect the readings and the results, performing this device from E-waste material is very hard to be done, the core of the pyroelectric meter is a special crystal/ ceramic whose polarization shifts with temperature, to sum up this pyroelectric meter isn't universally applicable and matching the requirements in a DIY or low resource lab from E-waste is very complicated. Lastly, a multimeter is considered the best solution that matches design

Figure 38 Represents an image of pyroelectric meter

requirements, solves our chief problem, and is the best solution as a DIY prototype from E-waste materials.

Selection Prototype

The selected prototype that best embodies our solution is a breadboard that contains a microcontroller and other components that act like an Arduino system, paired with two circuits. The first circuit measures the volts from any device, and the second circuit measures the ohms of any resistor. And there is a housing made of transparent material.

Each part of the prototype will be explained in depth separately:

1-The breadboard with the microcontroller system

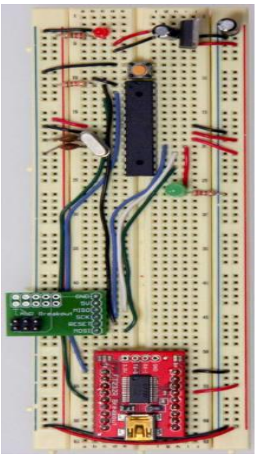


Figure 39 Represents the microcontroller system to operate it like Arduino

This system consists of two main parts:

1. Microcontroller (that acts as the brain, for example, ATMEGA)

2. Support circuit (Everything needed for the microcontroller to work perfectly, for example, resistors, capacitors, and a crystal oscillator)

The role of the microcontroller is to receive the code in C++, and you upload and run the code. The support system contains many components, for example voltage regulator, which lowers the amount of volts coming from the battery so the microcontroller receives what it needs. Filtering capacitors are placed beside voltage regulators to reduce noise and sudden voltage changes. The crystal oscillator sends the signal to the microcontroller, and this signal indicates that the microcontrollers need to finish this task or instruction at the correct speed. There is a reset button that resets the circuit. If anything goes wrong, you press it manually. There are many jumpers whose role is to connect between two points in a circuit to allow current to flow, and they act as bridges as they connect all the components with each other. Resistors are used in the circuit to protect it by limiting the amount of current that flows into it. To upload the code into the microcontroller, we used a component called FTDI that is connected to the breadboard and a USB that is connected to the laptop on which we code on and connect them to upload the code directly into the microcontroller.

2-Volt measurement circuit

This system contains a battery or object that is supposed to be measured. A resistor with a high resistance is linked to the circuit to limit the current, so the whole circuit is safe. Resistors to divide the voltage. Capacitors to smooth the noise. And then the code of the math is uploaded into the microcontroller to output the accurate measurements. There should be a calibration method to obtain accurate numbers if there are different amounts of volts to measure. This circuit works only on DC voltage, as AC voltage needs a bridge from DC to AC and more calculations in the code.

3-Ohmmeter measurement circuit

The system measures an unknown resistor by integrating a known voltage divider. A known resistor is used with a voltage divider. The microcontroller measures the voltage drop across any resistor by Ohm's law. The code measures the unknown resistor, and a calibration method is used to obtain accurate and precise outputs.

4-Housing

The prototype is protected by a plastic layer with low dimensions to make it portable, so the device can be used in scientific fields or shared labs. The plastic protects the prototype from sudden temperature changes because it affects the ohmmeter measurements.

The results the prototype should met:

1-The prototype error percentage does not exceed 5% and is accurate to standard device

2- The prototype mass is less than 0.3KG

3- The volume of the prototype does not exceed $0.003m^3$

4-The prototype materials do not produce any emissions, environmentally friendly and all materials are recycled

5-The prototype has variety of applications in the physics and fabrication lab

Chapter 3

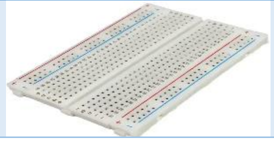
Constructing and Testing Prototype

Materials and method.
Test plan.
Data collection.

Materials and Methods

Materials

Table 1 (Materials)

Item	Source	Description	Picture
Breadboard	Fab Lab	A breadboard is a reusable, solderless platform to connect everything to.	
Jumpers	Fab Lab	It is a short length of conductor used to temporarily close or bypass a circuit connection.	
Old chip (ATMEGA)	Radio	The ATMEGA series is 8-bit AVR architecture microcontrollers	
Led	Old car toy	It is a semiconductor light source that emits light when current flows through it.	
Resistors	Power supply	It is a passive component that limits or regulates current flow in a circuit.	
Capacitors	Power supply	It is a passive component that stores electrical energy in an electric field.	
Fuse	Power supply	It is a component that protects the device from overcurrent	
Voltage regulator	Power supply	An integrated circuit that stabilizes voltage.	
Crystal oscillator	Radio	creates a precise clock signal	

Transparent housing	Old, discarded material in the home	To keep the prototype in it for protection	
Charge module	Old mouse	A module that manages the charging of a rechargeable battery	
LCD	Calculator	To display the results	

Safety precautions

1- Safety precautions are an essential part of the whole workflow of the prototype, and here are the precautions that the team ensured were followed.

2- Team members wear coats, googles, gloves, and closed-toe shoes to protect their feet from dropped tools and to prevent harm from materials, especially when dealing with the extraction of old devices.

3- When dealing with electric waste, assume the devices are live and unplug them for at least 24 hours before opening them to let the capacitors discharge. Remove batteries first, carefully, and watch out for any sharp metal or broken glass.

4- When dealing with a prototype, do not power it from an outlet; instead, power it from a small battery, about 5 volts.

5- Team members used the right tools for their purposes and covered them after use to prevent injuries.

6- Team members use the right devices or equipment under the supervision of the fabrication lab teacher or any teacher when working in a different lab other than the fab lab.

7- Team members leave all their things for illustration backpacks outside the working labs.

8- Team members behave well in the labs, which includes no horseplay, and everyone is focused on their tasks. If any team member notices anything wrong, they will report it to the teacher immediately.

9- Team members are educated on all emergency protocols, for example method of using fire extinguishers and their locations inside the school.

Figure 40 Following safety precautions

Methods

ATmega328 method

To make our device, many steps were followed, as shown below:

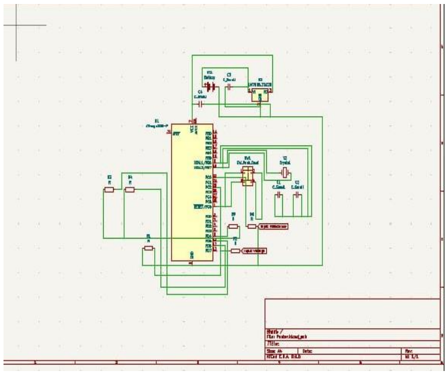


Figure 41 Represent schematic diagram

- The ATmega328 is inserted to facilitate each side of the pins being put on a separate breadboard rail.
- The 16 MHz crystal is connected between pins 9 and 10.
- One 22pF capacitor is connected from pin 9 to GND.
- The other capacitor is connected from pin 10 to GND.
- A 10KΩHe resistor is connected between the reset pin and +5V.
- A push button is added between the RESET pin and GND.
- VCC and AVCC are connected to the +5V rail.
- GND pins are connected to the ground rail.
- Input and Output capacitors are added to steady the voltage, and a 7805 regulator with a 9V source.
- An LED is connected to a 220 Ω Resistor to pin 13.
- LED anode with the resistor in pin 13.

- LED cathode with GND.
- TX of the FTDI is connected with RX of the ATmega328.
- RX with TX.
- GND with GND.
- DTR signal is connected to RESET via aμF Capacitor.

Voltameter methods

- An analog pin is selected on ATmega328 e.g., ADC0/ PD0.
- The input voltage is connected to the voltage divider.
- The voltage that is to be measured is connected to a resistor, which is connected to another resistor that is connected to GND (the point of connection between two resistors is called a junction).

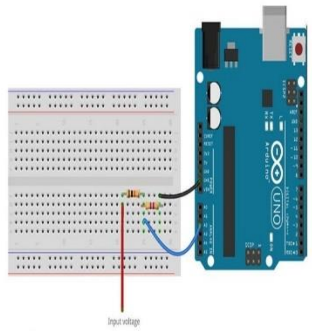


Figure 42 Illustrates voltameter methods

- The voltage shouldn't exceed 5V.
- A 100 μF A Capacitor is placed between the analog pin and GND.
- GND of the measured voltage is connected to ATmega328.

Ohmmeter methods

- Another analog pin is selected on ATmega328 e.g., ADC1 / PD1
- A known resistor is connected to an unknown resistor in series. Connect 5V to the known resistor with the unknown one to the GND.
- The unknown resistor shouldn't be connected to any external voltage.

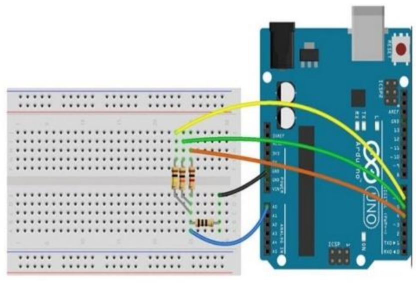


Figure 43 Illustrates ohmmeter methods

- GND of the series circuit is connected to ATmega328.

Test Plan

When the prototype is completed, several criteria must be met to determine its success. The criteria that need to be achieved are the design requirements, and they have to be tested.

Design requirements

1-Variety Of Applications

2-Recycled From E-Waste

3-Calibrated For Accurate Measurements

4-Transparent Housing for The Instrument

5-Data Sheet Showing Prototypes Voltage Operating Value, Maximum Drag Electric Current, Maximum Operating Power, Voltage Reading Range, Resistance Reading Range

6-Schematic Design for The Circuit

7-Accuracy Calculation: Maximum of ±5% Error and measure Voltage, current, resistance, power, and energy

8-Comparison to a Standard Device

9-Portable as it should have a mass and volume lower than 0.5Kg, 0.003$m^{3,}$ and is rechargeable

10-Modularity

11-Overcurrent Protection

Test plan

TP - 01: Voltage measurement

Requirement: The device must measure the voltage of different amounts of different objects with an average accuracy of at least 95%

Test steps:

1-Apply Known DC Voltages (1V, 5V, 9V, 12V)

2-Record prototype readings

3-Repeat the test many times to ensure consistency

4-Compare the results to the reference multimeter

Pass criteria: The device measures the volts accurately with at least an average accuracy of 95%

TP - 02: Resistance measurement

Requirement: The device must measure the ohms of different amounts of different resistors accurately, with an average accuracy of at least 95%

Test steps:

1-Connect known resistors (1000Ω, 5000Ω, 10000Ω)

2-Record device readings

3-Repeat the test many times to ensure consistency

4-Compare the results to the reference multimeter

Pass criteria: The device average ohms measured is within at least 95% accuracy

TP - 03: Current & Power Calculation

Requirement: The device measures the current, power, and energy after obtaining volts and ohms by Ohm's laws, with an average accuracy of at least 95%

Test steps:

1- Set up a simple resistive circuit

2- Measure V and R with the prototype

3- Let the prototype calculate I, P, and E by Ohm's laws

4-Repeat the test many times to ensure consistency

5- Compare I and P to values from a reference multimeter

Pass criteria: The device average results produced are at least 95%

TP - 04: Accuracy and precision

Requirement: The prototype is accurate, precise, and with consistent measurements. The error percentage does not exceed 5%

Test steps:

1-Take 5 repeated measurements of both volts and ohms

2-Calculate mean, standard deviation, and error percentage

Pass criteria: The device measurements through the five trials are accurate and consistent. The error percentage does not exceed 5%

TP - 05: Overcurrent protection

Requirement: The device should not be damaged when high current flows through the device

Test steps:

1-Intentionally short-circuit the output through the fuse

2-Verify fuse blows before any component is damaged

Pass criteria: The fuse blows, and no component of the device is affected, and the device works perfectly

TP - 06: Portability

Requirement: The device should have low volume and mass so it can work fine in shared labs or scientific fields

Test steps:

1-Weigh the prototype on the scale

2-Measure dimensions and calculate volume

Pass criteria: The device total mass and volume do not exceed 0.5KG and $0.003m^3$.

TP - 07: Transparent Housing

Requirement: There should be transparent housing that preserves the prototype from any sudden changes in temperature, and all the components of the prototype should be seen inside the housing.

Test steps:

1-Put all the prototypes inside the transparent housing

2-Visual inspection of all the components inside the prototype

3-Put the prototype in different room temperatures to measure if the temperature affects the prototype or not

Pass criteria: The prototype is well preserved, and all the components can be seen well from afar. The prototype is not affected by sudden temperature changes between different rooms.

TP - 08: Rechargeability

Requirement: The prototype should be portable, can be recharged, and work for a while.

Test steps:

1- Fully charge the internal battery
2- Operate Prototype until low power
3- Recharge and verify operation

Pass criteria: The prototype can work for a while without needing to be connected to source power for a while and when the internal battery is discharged, it can be recharged and work again.

TP - 09: Modularity

Requirement: The prototype components, when one is removed or damaged it can be replaced easily.

Test steps:

1-Remove/Replace one module
2-Verify the function after reconnection

Pass criteria: The prototype, after replacing one of the components, works perfectly, and the components can be removed easily.

TP - 10: Two lab applications

Requirement: The prototype should be tested in two different labs, which are the physics lab and the fabrication lab, with different usages according to the laboratory.

Test steps:

1-Ohm's Law Verification: Measure V, I, R in a circuit in the physics lab

2-Component testing: identify unknown resistor values and unknown battery properties in the fabrication lab

Pass criteria: The prototype is tested in both labs with different usages, and it works great. The device verifies Ohm's law in the physics lab and measures unknown resistors and batteries in the fabrication lab with accuracy.

Data Collection

After demonstrating the test plan, here are the tools used to measure the device and the systematic error of these devices:

Table 2 (Tools used)

Name	Usage	Systematic error	Picture
Multimeter	Used for measuring the voltage and the ohms of the circuit	$\pm 0.5\% + 2\ V$ $\pm 0.8\% + 2\ \Omega$	
Sensitive balance	Used for determining the accurate mass of the prototype	±0.5 mg	
Vernier caliper	Used for determining all the dimensions of the prototype	accuracy or permissible error often can be (±0.05 mm)	

As shown in the graph, the devices used in obtaining the results have high precision, resulting in high accuracy and precision.

After constructing the prototype, measurements were taken for both voltage and resistance. The results were recorded in these tables. Calibration was performed using a digital multimeter with stated accuracy of (±0.5% + 2) for voltage and (±0.8% + 2) for resistance. Through repeated calibration and careful component selection from e-waste sources, the prototype successfully achieved measurement precision comparable to commercial instruments.

Table 3 (Voltameter circuit readings)

Trial	Reference (V)	Reading (V)	Error (Absolute)
1	9	9.009	0.009
2	9	8.962	0.038
3	9	8.985	0.015
4	9	8.938	0.062
5	9	8.927	0.073
Total	45	0.197	

The average absolute errors for voltage (±0.35%) and for resistance (±1.98%) were calculated by summing the absolute error values of every individual trial error, then dividing them, the error lies within the calibrated multimeter's uncertainty range, confirming that the prototype voltage readings are accurate and reliable.

Table 4 (Ohmmeter circuit readings)

Trial	Reference (Ω)	Reading (Ω)	Error (Absolute)
1	10000	10160	160
2	10000	9539	461
3	10000	9927	73
4	5100	5150	50
5	5100	5150	50
Total	40200	794	

Negative Results:

1. Resistance measurements got significant drift (**±10%**) when operating in direct sunlight or elevated temperature environments.
2. Regular alkaline batteries drop voltage too often, causing measurement errors reaching up to (**±5%**).

Positive Results:

1- The prototype successfully achieved accurate and precise readings compared to a multimeter, as shown in Fig.44.

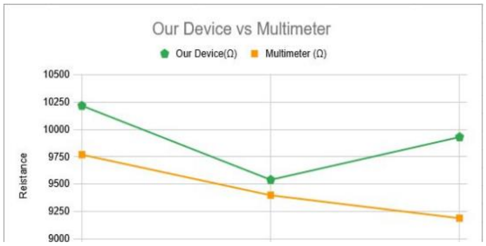


Figure 44 Represents our device versus multimeter readings

2- Modular design has been implemented, enabling all components to be replaced or upgraded using e-waste parts.
3- The final prototype meets the portability requirements, weighing only ≈0.3Kg and operating from a rechargeable Li-ion battery.
4- The prototype volume did not exceed $0.003m^3$

Addressing these negative results, the prototype was enclosed in a plastic housing to reduce any thermal fluctuations, and the power supply was upgraded to a Li-ion battery recovered from an RC car, eliminating any instability caused by alkaline cells.

Chapter 4

Evaluation, Reflection, Recommendations

Analysis and Discussion
Recommendation
Learning Outcomes
List of Resources

Analysis and Discussion

Reducing e-waste and assisting in enhancing the scientific and technical environment for everyone, this prototype tackles two important problems mentioned in Egypt's Grand Challenges. There are two main aspects of the issue. First, many schools and communities are still unable to afford high-quality laboratory equipment, leaving a gap in scientific education and creativity. Second, dangerous materials from the accumulation of electronic waste in landfills pollute groundwater and soil, posing a long-term threat to human health. The prototype offers sustainable solutions that reduce gaps in scientific instruments while utilizing e-waste from the environment by building a precision multimeter entirely from e-waste.

The prototype's main scientific base is developed on the concept of a voltage divider, and PH.2.04 to relationships from Kirchhoff's voltage law. Where the core measurement circuit consists of a resistor ladder network as shown in Fig.45, Kirchhoff's law states that the voltage summation across the circuit is equal to zero: $\sum V = 0$

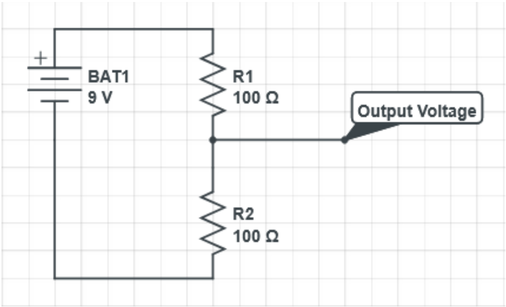


Figure 45 Illustrates Kirchhoff's voltage law

Assuming that the current is constant across the circuit, then the voltage passing through is. R_1

And R_2 is equal to IR_n, Forming the following law: $V_{in} - IR_1 - IR_2 = 0$

Solving for the current, it was concluded that it equals the following formula: $I = \frac{V_{in}}{R_1+R_2}$, using Ohm's law, the voltage running from R_2 is equal to IR_2So now the equation is equal $V_{out} = IR_2$, replacing the current value, the final formula of the voltage divider is obtained, equaling: $\boldsymbol{V_{out} = V_{in} \cdot \frac{R_2}{R_1+R_2}}$

This concept allows the circuit to safely measure voltages higher than the microcontroller's ADC (Analog to Digital Converter) and reach up to 30V. Moreover, the resistance measurement follows the same circuit but this time it's rearranged solved the unknown resistor R_x when placed in series with a known reference resistor $\boldsymbol{R_{ref}}$ $\boldsymbol{R_x = R_{ref} \cdot \frac{V_{Out}}{V_{In} - V_{Out}}}$

Many factors affect the precision and accuracy of measurements; the two critical factors are reference resistors used in the voltage ladder, and the accuracy of voltage readings, both could be fixed using calibration.

After tests, the prototype showed both positive and negative results. Positive results are as follows. The prototype worked accurately enough to meet the design goals, proving that e-waste can be used again to build a scientific tool. Moreover, after recording the voltage measurements, the average error was 0.35%, and for resistance, it was 1.98%. Both errors were well under the ±5% limit. This performance is nearly like regular multimeters, which are usually much more expensive. Also, the device is easy to carry, weighing only 300 grams. It can charge and discharge its lithium-ion batteries, and it can run for one day, which was calculated using the following formula: $\mathbf{t} = \boldsymbol{\frac{C \cdot DoD}{I_{Load}}}$

DoD, or depth of discharge, is usually about 80% for the maximum lifespan of the battery. The battery's capacity is 2400mAh. The current (I) is the amount of power the circuit uses. The circuit has LCDs, ATMEGA, resistors, and capacitors. The current running through the circuit is equal to 80 mA. Plugging these values into the equation gives us the time the battery will last:

$$t = \boldsymbol{\frac{2400mAh \cdot 0.8}{80mA} = 24\ hours\ \approx one\ day}$$

Moreover, there were some negative results that appeared in the stage of pre-testing the prototype, and each one was resolved through applied engineering. Primarily, the initial resistance measurements showed up to ±10% error. After troubleshooting, it was discovered that readings were influenced by thermal conditions, a phenomenon explained by the concept of temperature dependence of resistivity in **PH.2.03**, represented by the equation: $\boldsymbol{\rho(T) = \rho_0[1 + \alpha(T - T_0)]}$

Where $\rho(T)$ Presents the resistivity at a specific temperature. This fluctuation was addressed by enclosing the prototype within a plastic container, thereby minimizing direct thermal exposure and stabilizing its internal temperature.

A further negative outcome was the variability in readings, which was caused due to the lack of uniformity in e-waste components, resulting in an error margin greater than 8%. This issue was resolved by implementing **MA.2.01**, which involved establishing a linear function for the prototype calibration, utilizing the standard linear function for this purpose: $Y = mx + c$

And then solving to get the constants until the prototype is calibrated, taking the reference point as a calibrated multimeter, as follows.

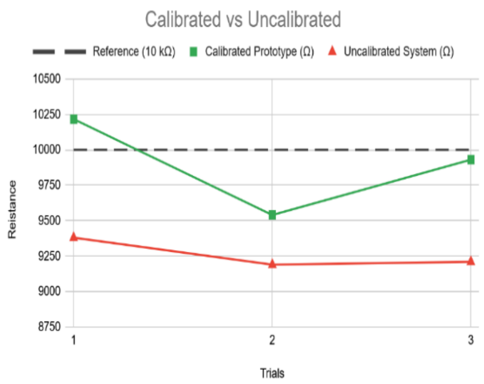


Figure 46 Illustrates the results of the device calibrated and uncalibrated

$$R_{cal} = \text{Calibration Scale} \cdot R_{raw} + \text{Calibration Offset}$$

His mathematical correction reduced the average resistance, as shown in **Figure 46**, by **68.8%** as shown in the following equation by applying **PH.1.01**.

$$\textbf{Error Reduction} = \frac{|\textbf{Uncalibrated Error} - \textbf{Calibrated Error}|}{\textbf{Uncalibrated Error}}$$

In summary, an additional problem was the inconsistent power supply when operating the prototype with alkaline batteries. This instability in voltage measurements led to inaccurate readings by the analog-to-digital converter (ADC), resulting in errors as high as 5%. This issue was resolved by using **CH.1.14** to study the electrochemical characteristics of batteries. Specifically, a Li-ion battery was extracted from an old RC car. This modification ensured a more stable output voltage and, more importantly, made the prototype portable by utilizing a rechargeable battery.

Recommendations

- Making an IOT platform by using Arduino ESP-32, which allows our device to connect to a mobile application for full control of its functions. The built-in Wi-Fi module in the ESP-32 enables continuous wireless communication between the device and the application.
- Making a full Energy-Monitoring System, instead of measuring V-I-R-P, making a complete energy monitoring platform that can be used in factories, research labs, smart buildings, and renewable energy systems. This includes Real-time energy analytics (Wh, kWh), Power factor measurement, Peak demand logging, Load profiling and forecasting, and Integration with smart grids.
- Integration with renewable energy systems, the large scale will support solar panel monitoring and battery health analysis.
- Represent our results of the prototype in the shape of graphs on the screen of the prototype.
- Reducing the error by using new branded capacitors and sensors.
- Create a simulation website which gives the students the ability to build virtual circuits, get predicted readings, and compare the expected results from the virtual circuit that they have been done by them with real device measurements.
- Adding a cooling system, as it’s very important in devices like our device to prevent any increase in the temperature of the internal parts and circuit.
- Add a buzzer, which acts as a sound alarm when, current is too high, the device is overheating, and others.
- Implementing a low-power sleep mode, to extend battery life.

Learning Outcomes

Chemistry

CH.2.05

Catalysts are helpers that speed up the chemical reactions by lowering the activation energy the reactions must climb, and this looks like our circuit, as a catalyst is a reaction helper, and our prototype is a measurement helper, making it easy to measure both ampere and volt without needing any prior experience. Another similarity between them catalyst lowers the energy barrier for reactions, and our circuit lowers the difficulty of measuring power. Catalysts give fast reactions, and our prototype provides precise and fast measurements on the LCD. To test both of them catalysts are tested by bubble experiments, and our circuit is tested by screen readings. To sum up, both of them make the job easier and faster.

Computer Science

CS.2.03

From understanding this learning outcome and how to code using MySQL, which has nearly the same syntax as C++. C++ is an important coding language as it serves as the brain of the electrical components connecting all, for example, connecting the sensor to the microcontroller and applying calculations to get the right result. MYSQL is similar to C++ in terms of data types. For illustration, the integers and floats work the same to obtain accurate numbers as they are similar across all Data types. They are similar in operators also, for example, arithmetic, comparison, and logical operators. Functions in both of them are similar, and the decision maker, for example if statement to use it to respond to respond to different situations.

Math

MA.1.02

In this learning outcome, we learned the standard deviation, which helps us understand how constant and reliable the readings from our multimeter are, which is very crucial when performing calibration. When we calibrate our device, we modify it so that its average reading matches the true value of a known reference. Nevertheless, calibration isn’t enough, a low standard deviation means ensures that our multimeter gives stable, repeatable measurements, so when it's calibrated, we can trust that feature readings will stay close to the true value, a high standard deviation, on the other hand, means the readings jump around a lot, even if the mean has been regulated correctly, in this case, our device may be calibrated in theory, but it isn't precise in practice. By calculating the standard deviation of repeated measurements during our multimeter project, we learned how much random error was present and how reliable the calibration truly was. As a final point, calibration corrects the accuracy, but standard deviation reveals the precision; both are necessary for a well-performing multimeter.

MA.2.01

From understanding this learning outcome and how to model with functions to reuse electric devices and obtain accurate results, because accuracy is one of the key design requirements, we focused on. Modeling with functions, I used a polynomial function to make sure I use the right variables and to obtain great results, and here is the equation of the polynomial function, which is ax3+ax2 +ax +b, and this equation helps me with lots of things, for example. Ensuring that the variables that I used, for example, volt and current, and others in the equation, are used to obtain accurate results. To use graphs of polynomial functions to represent the results we obtained and analyze them, and there are symmetric graphs which can be odd or even, to analyze the relation between the variables, for example, the relationship between current and voltage is a direct relationship.

Mechanics

ME.2.04

This learning outcome explains the law of conservation of energy, which is critical in designing the circuit. It explains how an ideal voltameter and ammeter work, as an ideal voltameter has infinite resistance and draws zero current, so it consumes zero power, $P=V^2/R\rightarrow 0$. An ideal ammeter has zero resistance and zero voltage across it, so it consumes zero power, $P=I^2R\rightarrow 0$. To minimize the energy transfer, there must be divider resistors and a shunt.

ME.2.05

Our device measures the power, and power is the amount of energy in a unit of time, and it is measured by P=V x I. The unit of power is in Watts, and there can be more variations of the power law, for example, $P = I^2 * R$ and $P = V^2 / R$. All these variations are derived from Ohm's law. Our hybrid system's main purpose is to measure the amount of power by making an ammeter and a voltmeter, and power increase by increasing either the voltage or the current, as the power is directly proportional to both of them.

Physics

PH.1.01.

In any electronic device, there is an error in the results and the readings; to evaluate the accuracy of any measurement, we rely on two essential principles, which are relative error and the percentage error law. The relative error law shows a difference between our measurements and the true measurements, which is given by:

Relative Error$=\frac{|M-T|}{T}$

(M, which refers to our measurement, T refers to the true value measurements).

This law gives us the ability to know and understand the size of the error, as we have put a design requirement that obligates us to ensure that the error doesn't exceed $\pm 5\%$.

The percentage error law relies on the same idea, with one difference, which is multiplying the relative error by 100% to make the principle as shown below:

Percentage error $=\frac{|M-T|}{T} x100\%$

These two laws are very crucial for judging measurement accuracy as they show how close a measurement is to its correct reading.

PH.2.02

Understanding this learning outcome mainly involves the microscopic vision of how electricity works and how repulsion and attraction between charges occur.

Coulomb's Law tells how to measure the electrostatic force between charges, and here is the law. $k * \frac{q_1 \times q_2}{r^2}$ K is the constant which equals $9*10^9 N/m^2*C^2$, the q1 and q2 represent the amount of the two charges, and r is the distance between them. Understanding electric fields as they are invisible lines around electric charges that exert a force on other one, and here is its law.

$E = \frac{Force}{Coulomb}$. Understanding how charges interact with each other is crucial to working with the circuit perfectly, so you do not mix the positive and negative poles and destroy or burn the circuit. Conservation of electric charge states that the total energy or charge in a closed system, like a circuit, must be constant.

<u>PH.2.03</u>

This learning outcome focuses on the dynamics and principles of electricity. Current flows in tubes, and here is its law $I = \frac{Q}{T}$, And there is resistance that opposes it, and the multiplication between them results in the volt, and here is its law. $V = \frac{j}{c}$, And that is Ohm's law. $V = I \times R$. Ohm's law states that whenever the volts or the current increase, the other one must increase because there is a direct relationship between both of them that results in a linear graph between them that comes out of the origin point. Electric Power is the rate at which energy is transferred in one second and can be measured by $P = V \times I$. In our device, these equations are needed to calculate the power by obtaining the volts and the amperes. Temperature plays an important role in terms of electricity, as increasing the temperature increases the resistance as collisions of the electrons increase. Theoretical results do not happen because there is an internal resistance that decreases the original voltage, and the new voltage is called the terminal voltage.

<u>PH.2.04</u>

In this learning outcome, we learned how to deal with circuits and types of circuits, which are series or parallel. The differences between them are that in a series circuit, the current is constant, but in a parallel circuit, the voltage is constant across all of it. In this learning outcome, there is how for calculating the resistance across the circuit. In series $R_S = \Sigma R$ But in parallel circuits $\frac{1}{Rp} = \sum \frac{1}{R}$ In designing the circuit there was used Kirchhoff's law of current (KCL) which states that at a point where three or more currents are flowing through it, the net current is equal to zero because there are currents that flow to the junction and there are currents that flow out of the junction. The current that flows to the junction is positive, and the current that flows out of the junction is negative in sign, not in amount. Kirchhoff's Voltage Law (KVL) states that the voltage across the circuit is equal to zero. There are two reasons for this. The first reason is that the resistors take up the volts created by the battery, and the second reason is that the battery creates volts, which can be positive or negative depending on the direction of the circuit that was analysed. These laws and claims were used to design the circuit of the prototype so that it can output precise numbers.

PH.2.05

From understanding this learning outcome and the importance of capacitors in a circuit, as they store the electric charge and release it later, in general, they act as a temporary energy container. This learning outcome was understood by us as how the capacitors recharge and discharge, and what controls the speed, which is the RC constant $\tau = RC$. This learning outcome explains how capacitors connect in series or parallel to get the right amount of capacitance and how to calculate voltage, charge, and energy in DC circuits. Understood the difference between inductors and capacitors, as inductors resist changes in current and store energy in a magnetic field around a coil $v = L\frac{di}{dt}$.Capacitors resist changes in voltage and store energy in an electric field between two plates. $i = c\frac{dv}{dt}$.

PH.2.07

In this learning outcome, we chose our solution from as the device that was chosen was a hybrid system that combines the functions of an ammeter and a voltameter, and multiplied the ampere and the volt to get the power. An ammeter and a galvanometer are nearly the same, as a galvanometer is more sensitive and measures a small amount of current, but an Ammeter with a low-resistance shunt placed in parallel, most current is bypassed, allowing measurement of a larger current. A voltameter is based on a galvanometer also but it has high resistance, so a small amount of current passes through, allowing for measuring the voltage. An ohmmeter is a device that contains an internal battery and measures the amount of resistance. The general idea of this learning outcome is to understand how magnetic fields interact with moving charges and current and how this interaction produces force, torque, and motion. All of these measuring devices that were mentioned above are built by controlling the torque by decreasing either the current or the voltage.

List of Sources in APA Format

1- *Callen, T. (2025). Gross Domestic Product: An Economy's All. International Monetary Fund.* *https://www.imf.org/en/Publications/fandd/issues/Series/Back-to-Basics/gross-domestic-product-GDP*

2- *World Bank Open Data. (n.d.). World Bank Open Data.*

https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?locations=EG

3- ITIDA - *Egypt's Thriving ICT Sector | Industry Outlook. (n.d.). Www.itida.gov.eg.*

https://itida.gov.eg/English/Programs/Industry-Outlook/Pages/default.aspx

4- *Egypt Youth Unemployment Rate 1960-2024. (n.d.). Www.macrotrends.net.*

https://www.macrotrends.net/global-metrics/countries/EGY/egypt/youth-unemployment-rate

5- *Pollution and waste: air, water and soil | Knowledge for policy. (2025). Europa.eu.*

https://knowledge4policy.ec.europa.eu/biodiversity/pollution-waste-air-water-soil_en#soil

6- *State of Global Air. (2021). Health Impacts of Air Pollution | State of Global Air.*

Www.stateofglobalair.org. https://www.stateofglobalair.org/hap

7- *Air Pollution and Your Health. (2024). National Institute of Environmental Health Sciences.*

https://www.niehs.nih.gov/health/topics/agents/air-pollution

8- *The Effects of Water Pollution: Human Health and Environmental Impacts • Environmental Studies (EVS) Institute. (2024, June 16). Environmental Studies (EVS) Institute.*

https://evs.institute/environmental-pollution-control-and-management/water-pollution-effects-health-environment/

9- *Guide to soil pollution: How to prevent and monitor. (2023). Basis-Reg.co.uk. https://basis-reg.co.uk/news/article/how-to-prevent-soil-pollution*

10- *The World Bank. (2018b, September 20). Global Waste to Grow by 70 Percent by 2050 Unless Urgent Action is Taken: World Bank Report. World Bank; World Bank. https://www.worldbank.org/en/news/press-release/2018/09/20/global-waste-to-grow-by-70-percent-by-2050-unless-urgent-action-is-taken-world-bank-report*

11- *US EPA. (2019, May 17). Electronics Donation and Recycling | US EPA. US EPA. https://www.epa.gov/recycle/electronics-donation-and-recycling*

12- *Issah, I., Arko-Mensah, J., Agyekum, T. P., Dwomoh, D., & Fobil, J. N. (2022). Health Risks Associated with Informal Electronic Waste Recycling in Africa: A Systematic Review. International Journal of Environmental Research and Public Health, 19(21), 14278. https://doi.org/10.3390/ijerph192114278*

13- *From Waste to Wealth - Sweden's comprehensive approach to Energy Recovery. (2025, March 10). Energimyndigheten.se. https://www.energimyndigheten.se/en/news/2025/from-waste-to-wealth---swedens-comprehensive-approach-to-energy-recovery/*

14- *Waste incineration in the Nordic countries. (2021). Norden.org. https://pub.norden.org/temanord2024-524/1-current-status-of-the-waste-incineration-sector-in-the-nordics.html*

15- *Administrator. (2019, November 10). Arduino - Revolution of hardware opensource - Woodpecker. Woodpecker. https://woodpeck.org/arduino-revolution-of-hardware-opensource/*

16- *Shinde, S. (2023, January 25). Why do We Use the Arduino Programming Language? How is it Helpful? Emeritus Online Courses. https://emeritus.org/blog/coding-arduino-programming-language/*

17- *Arduino. (n.d.). Arduino Docs | Arduino Documentation. Docs.arduino.cc. https://docs.arduino.cc/*

18- *Kushner, D. (2011, October 26). The Making of Arduino. IEEE Spectrum. https://spectrum.ieee.org/the-making-of-arduino*

19- *Arduino. (2025b). UNO R3 | Arduino Documentation. Docs.arduino.cc. https://docs.arduino.cc/hardware/uno-rev3/*

20- Ellen MacArthur Foundation. (2021, October 1). *Artificial intelligence for recycling: AMP Robotics*. Www.ellenmacarthurfoundation.org. https://www.ellenmacarthurfoundation.org/circular-examples/artificial-intelligence-for-recycling-amp-robotics

21- EPA. (2023, June 17). *Lithium-Ion Battery Recycling*. EPA. https://www.epa.gov/hw/lithium-ion-battery-recycling

22- *Liter of Light*. (2023, July 26). Unesco.org. https://www.unesco.org/en/articles/liter-light

23- GeeksforGeeks. (2018, July 23). *RISC and CISC in Computer Organization*. GeeksforGeeks. https://www.geeksforgeeks.org/computer-organization-architecture/computer-organization-risc-and-cisc/

24- GeeksforGeeks. (2018b, September 10). *Introduction to memory and memory units*. GeeksforGeeks. https://www.geeksforgeeks.org/computer-organization-architecture/introduction-to-memory-and-memory-units/

25- Communication network protocols. (2023). *Communication network protocols*. Farnell. https://dk.farnell.com/en-DK/communication-network-protocols-trc-ar

26- The Royal Society. (2024). *Climate change: evidence and causes*. Royalsociety.org; The Royal Society. https://royalsociety.org/news-resources/projects/climate-change-evidence-causes/basics-of-climate-change/

27- *What is Climate Change?* (2023). Warm Heart Worldwide. https://www.warmheartworldwide.org/what-is-climate-change1.html?

28- United States Environmental Protection Agency. (2025, January 16). *Overview of Greenhouse Gases*. US EPA. https://www.epa.gov/ghgemissions/overview-greenhouse-gases

29- United Nations. (2022). *Causes and Effects of Climate Change*. United Nations. https://www.un.org/en/climatechange/science/causes-effects-climate-change

30- GeeksforGeeks. (2022, February 20). *Microcontroller and its Types*. GeeksforGeeks. https://www.geeksforgeeks.org/digital-logic/microcontroller-and-its-types/

31- Ohm's Law. (2016). *Ohm's Law - University Physics Volume 2 - OpenStax*. Openstax.org. https://openstax.org/books/university-physics-volume-2/pages/9-4-ohms-law

32- United Nations. (2022, May 6). *Science, Technologies Can Transform Global Challenges, But Need to Be Accessible to All, Senior Officials Stress, as Economic and Social Council Forum Concludes | UN Press*. Press.un.org. https://press.un.org/en/2022/ecosoc7083.doc.htm

33- WHO. (2024, October 1). *Electronic waste (e-waste)*. Who.int; World Health Organization: WHO. https://www.who.int/news-room/fact-sheets/detail/electronic-waste-%28e-waste%29

34- GeeksforGeeks. (2024, July 22). *Master C++ Programming: A Complete Guide*. GeeksforGeeks. https://www.geeksforgeeks.org/blogs/master-cpp-programming-cpp-course/