DIVE INTO THE WORLD OF

Citizen Science

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Preface

Dear reader, whoever you might be.

I am glad this book found you, and I hope you will find yourself in it.

Its content is perhaps a little unusual, and so is its goal. It is intended as a light read – a theoretical and practical introduction to the world of experimentation and discovery, of the world around us and of ourselves. It is suitable for almost all ages, although it will perhaps have greatest impact on children and young adults (12 years old and up).

Through its narrative and methodologies, it seeks to help young people articulate bigger questions, and find a way of approaching and answering them through analytical (deconstructive) and constructive tinkering. It also hopes to encourage adults to examine topics and practices mostly neglected and sometimes forgotten – that is, to find their inner playfulness by (re)discovering science and rethinking perspectives on the things we take for granted. In addition to those who are open to a little self-learning and discovery, the book might also serve as a teaching aid to youth workers in STEAM (Science, Technology, Engineering, Art & Mathematics), as well as general educators who wish to incubate the development of analytical, critical and constructive thinking skills in young people. It looks to do so not by being a source of definitions and a 'dry read', but by planting seeds from which curiosity grows, and being a tool for developing better tools along the path of self-learning and of co-creation of a sustainable future.

And that would be its basic philosophy: seeking to inspire citizens not to conform to existing global challenges (such as climate change, environmental pollution, inequalities, etc.) or non-stimulative environments and communities, but to grasp the problems, reform, (re)invent and build a better future. Do not forget that citizens such as you are the ones who build and make society.

The content itself is made to be read in any way you like. Feel free to read the book from cover to cover, skim through it, or jump directly to any chapter that takes your fancy. There is only one thing I would kindly ask of you: don't just read without trying out the practical part. Knowledge without application has little meaning, while real comprehension does not come from taking theory for granted, but by diving deeper into the topic, all hands in.

Don't be scared of making mistakes or making a mess. Self-learning comes from the process of experimentation, mess is a fertile ground for creation, and mistakes are a surefire way of ensuring that the end result is as good as it can be.

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Introduction

1.1 The Playground of Citizen Science

1.1.1 DISCOVER

In nature, every being, organism and cell comes into existence without knowing its environment and its working mechanisms; it then seeks to live, find positive stimuli, a hospitable environment and directions in which to grow. This is something worth thinking about, isn't it?

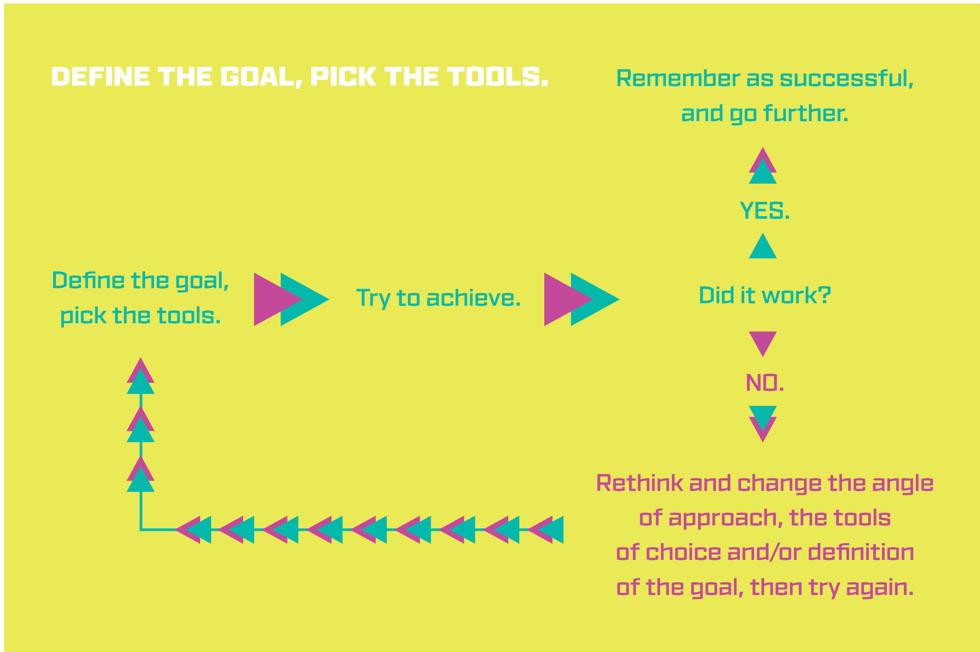
We could say the most important tools for fulfilment come in the form of:

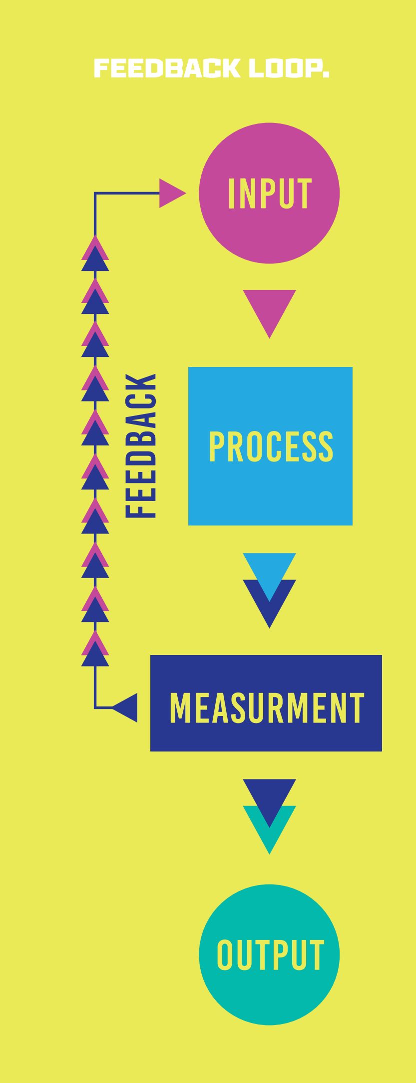
- the ability and skill to explore and analyse the environment, whatever it might be (in search of hospitable and stimulative conditions),
- the ability to critically compare findings, pick the best and avoid the negative,
- the ability to make the most use of what one has at one's disposal (for construction and growth).

Science and engineering are nothing more than human manifestations of these phenomena. They have evolved into a form that can be shared with others, which allows us to keep building and refining, and to achieve more as individuals and as a human collective.

The natural, innate way of doing science and engineering is deeply embedded in all of us, as that core method of experimentation: trial and error.

If we simplify this process, we can see that it is rooted in the most innate and basic mechanisms of control found in all self-controlling living systems, and recreated through engineering in all artificial automatic control systems – something called a 'feedback loop' in the science of cybernetics. This process re-





lies on feeding data that has been produced back into itself, learning from its trials and errors, to produce the desired outputs.

But first, let us go back and try to grasp what science is in general terms.

Most dictionaries would say that **science** is a systematic and methodical approach to understanding the natural world through observation, experimentation and the formulation of testable explanations or theories. It represents a systematic way of acquiring knowledge, organising information and making predictions about the world and about the objects, subjects and phenomena within it.

At its core, science as a discipline is based on the principles of empiricism (the idea that all learning can only come from experience and observation) and the practice of objectivity. Objectivity approaches the study of the world with an unbiased and impartial mindset, seeking to uncover truth based on evidence rather than personal beliefs or opinions.

This is a truthful explanation, but it's a bit dull, isn't it? What it does not contain is any sense of the **spark and drive of science**. Why should we relate to and care about science? Well, the answer is that a core of science is embedded in all of us as a natural principle – one of the innate mechanisms of exploring and understanding, even though we might not be aware of it. We could say that science is a tool we are born with, and that it is up to us whether we want to use and develop it.

Since we could say science (as a tool) is in all of us, it is not surprising that many people practise science.

Some people specialise in practising science. These **professional scientists** employ various methods and processes to investigate and understand the natural world, and do so as their job.

Some people seek to practise science non-professionally – perhaps for personal development or as a way of spending their free time constructively. These are **citizen scientists**.

From this we can cook up a wide definition of a scientist as an individual who practises science and follows scientific methodology.

The **scientific methodology** usually comprises these elements:

- **OBSERVATION**
  Scientists observe phenomena in the world, making note of patterns, behaviours, and events.

- **QUESTION**
  Based on their observations, scientists formulate questions that seek to explain or understand the phenomena they have observed.

- **HYPOTHESIS (THEORETICAL IDEA OF PROBABLE CONCLUSION)**
  Scientists propose theoretical, untested explanations or hypotheses that can be tested through further investigation. A hypothesis is a proposed explanation that can be supported or refuted by testable and measurable evidence.

- **EXPERIMENTATION**
  Scientists design and conduct experiments to test their hypotheses. Experiments involve manipulating variables and measuring outcomes to determine cause-and-effect relationships.

- **DATA COLLECTION AND ANALYSIS**
  Scientists collect relevant data during experiments or through other means. They then analyse the data using statistical methods and other techniques to draw meaningful conclusions.

- **CONCLUSION**
  Based on the analysis of the data, scientists reach conclusions about the validity of their hypotheses. If the data supports the hypothesis, it may become a theory or a well-established explanation. If the data does not support the hypothesis, scientists may modify or reject it, and then go on to develop new hypotheses for further investigation.

These elements of professional science usually follow the sequence listed – but not always. Sometimes questions do not come directly from the object of focus or the domain of science itself, but through inspiration – seeing similarities, perhaps, or seeking connections with other objects and domains. **Making connections** (correlation) and comparing the comparable and the incomparable are therefore important processes.

There is a saying: "We shouldn't compare apples and pears". But that just isn't true. When comparing apples and pears, we can discover more about both fruits than we can when we compare apples with apples, pears with pears. It is important to correlate – and to develop the skills of correlation.

It is important to knows that we can sometimes also find questions, new knowledge and ideas for experiments in pure data – such as in the hybrid field of data science, which represents one of the newest branches on the science domains tree.

In addition to good methodologies for learning, science teaches us about **knowledge itself**. It teaches us not to take knowledge (and things) for granted, since it considers knowledge to be dynamic, and subject to change and revision when new evidence emerges. This process of self-correction and refinement contributes to the cumulative advancement of scientific understanding over time, and to the growth of the body of human knowledge itself.

Science shares another interesting characteristic with living organisms by being **organic**. Science encompasses a wide range of disciplines (including physics, chemistry, biology, astronomy, geology, psychology and many others), which grow and branch out just like a living tree. Each field of science has its specific methodologies and areas of focus, but they all share a commitment to the systematic study of the world and what it contains, and a desire to uncover and explain underlying principles and processes.

Ultimately, science is a powerful tool for human progress, driving innovation, technological advancements and a deeper understanding of the universe and of our place within it. It provides a reliable and evidence-based framework for exploring and explaining the phenomena that shape our world.

1.1.2 CITIZEN SCIENCE

As we pointed out above, there are people who choose to practise science and scientific methodology in a non-professional capacity and and/or get involved in the process of professional science as citizens. As a group, they form the body of citizen science.

Citizen science, also known as community science or public participation in scientific research, is a collaborative approach to professional scientific inquiry or hobbyistic practice in which members of the general public (citizens not academically trained in science) actively contribute to scientific research projects. It can involve engaging non-professional scientists in various stages of the scientific process, including data collection, hypothesis production, experimentation, analysis, data interpretation and producing conclusions. On occasions, such non-academically trained individuals can, if they have developed sufficiently through self-learning and scientific experimentation, produce scientific research comparable in quality to the work of professionals – and even take it a step further into true (patentable) inventions. Perhaps the most shining example of an ideal citizen scientist, innovator and inventor would be Hedy Lamarr, with her impressive body of work in various fields of science, or that genius for the ages Leonardo da Vinci, who helped lay the foundations of several fields of science through self-learning by experimentation.

The concept of citizen science is founded on the belief that scientific research should not be limited to the realm of professional scientists and researchers. Instead, it recognises that individuals from diverse backgrounds and with different levels of

We should compare apples and pears.

expertise can make valuable contributions to scientific knowledge and understanding.

We should not forget that no father or mother of a scientific discipline has been formally educated in that discipline – simply by virtue of the fact that the discipline did not exist until they turned up. As they were giving birth to the field, they were citizen scientists in it.

It is therefore no surprise that citizen scientists today are involved in almost all domains of science – collecting environmental data, identifying species, monitoring bird populations, tracking weather patterns, analysing astronomical images, analysing water quality, solving problems of protein folding (necessary for developing solutions to target and eradicate diseases, as well as create biological innovations), and so on.

In citizen science, as in professional science, we distinguish between two main practices of research and experimentation: individual **do-it-yourself (DIY)** and collaborative **do-it-with-others (DIWO)** experimentation.

The concept of citizen science is founded on the belief that scientific research should not be limited to the realm of professional scientists and researchers.

'Sam svoj majstor',
1st issue, 1975.

The professional scientific community derives several **benefits from citizen science**. Researchers are able to gather large amounts of data over large geographical areas and extended periods, something that would be otherwise challenging or impossible to achieve. This process helps scale up data-collection efforts, leading to a richer and more comprehensive understanding of various phenomena.

Citizen science also fosters public engagement with science, and promotes scientific literacy in citizens and communities. By actively participating in research projects, individuals gain hands-on experience and develop a deeper understanding of scientific processes and concepts. Citizen science empowers people to contribute to important societal issues, and increases their appreciation of scientific inquiry; it can also actually strengthen connections between scientists, the public, policymakers and industry, and foster collaboration and dialogue. Professional researchers benefit from the expertise and local knowledge of citizen scientists, while citizen scientists gain insights into the professional scientific community's work, and can contribute to real-world scientific advancements.

In recent years, technological advancements have played a significant role in expanding the scope and impact of citizen science. The widespread availability of smartphones, internet access and data-sharing platforms has facilitated the participation and collaboration of citizen scientists on a global scale.

Overall, citizen science offers a collaborative and inclusive approach to scientific research, harnessing the power of collective intelligence, and contributing to a more informed and engaged society. Through the diversity of individual backgrounds, citizen science has the potential to address complex scientific and social challenges, and to drive meaningful change in the world.

1.1.3 DIY ENGINEERING

Practical **engineering** utilises knowledge to design, create and construct tangible outputs; and just as citizen science relates to professional science, there are some interesting cultural practices that relate to engineering fields. Prominent examples include the **do-it-yourself (DIY) repair cultures** found in socialist and communist countries. These often emerged from necessity, because local resources were scarce. Their goal was to utilise these resources to the maximum.

DIY repair cultures were common in the former Yugoslavia (1945–1992) and are very much part of society in present-day Cuba. Their approaches to DIY repair differed slightly, whether they involved buying sustainable domestic products at an economical price (e.g. items from recycled and/or affordable and sustainable local materials) or avoiding wasteful consumption and related unsustainable practices. The DIY culture became quite rooted in Yugoslavia, and was further fostered through 'Sam svoj majstor' and similar magazines, which gave practical detailed instructions on how to build and repair household items – and even how to build houses themselves.

At its core, maker culture encourages individuals to become active participants in the process of making things (and making things better) rather than simply being passive consumers.

While Cuba followed a similar path, economic constraints mean that the country's repair culture has become unique and recognisable, with highly innovative ways of repurposing items in DIY engineering and for repair. Its aesthetics have famously become an essential part of everyday life.

These examples are interesting in the context of the relatively recent public policies on sustainability, such as the United Nations Sustainable Development Goals (UN SDGs), which see global resources as limited and as things that must be cherished if we are to live comfortably. If you are interested in the subject of the problem of resource scarcity and responsible consumption and production, it is important to mention that one of the current UN SDGs is precisely 'Responsible consumption and production', which has been recognised as a global challenge we need to solve as citizens.

Emerging relatively recently, in the 2000s, and swiftly gaining public attention, **maker culture** is a cultural movement similar to repair culture and related to citizen science. It is a social movement that emphasises DIY and hands-on learning, exploration and creation, a global community of individuals who engage in various creative activities, such as designing, building, tinkering, inventing and prototyping, and often leveraging technology and digital fabrication tools.

At its core, maker culture encourages individuals to become active participants in the process of making things (and making things better) rather than simply being passive consumers. It values creativity, collaboration, and the sharing of knowledge and skills. Makers embrace an open mindset, seeking to learn and experiment with different tools, materials and techniques.

'Make:',
1st issue, 2005.

The key characteristics of maker culture include:

- **DIY MENTALITY:** Makers are driven by a desire to create and build things on their own, seeking to acquire skills and knowledge through hands-on experience.
- **OPEN-SOURCE PHILOSOPHY:** Makers often adapt, freely sharing their ideas, designs and projects with others. They value collaboration, and believe in the power of collective creativity and the freedom of knowledge and learning.
- **MODERN TECHNOLOGY:** Maker culture embraces the use of modern technologies, including 3D printers, laser cutters, microcontrollers and robotics. These tools enable makers to bring their ideas to life and rapidly prototype their creations.
- **INTERDISCIPLINARY APPROACH:** Maker culture often encourages the blending of different disciplines, bringing together people from diverse backgrounds, such as artists, engineers, designers, programmers and hobbyists, who exchange ideas and skills.
- **PROBLEM-SOLVING AND INNOVATION:** Makers often tackle real-world problems, seeking innovative and creative solutions. They embrace a hands-on, iterative approach to design and development, learning from failure and embracing the spirit of experimentation.

The maker movement has had a significant impact on education. It has encouraged a shift towards more practically minded, project-based learning approaches, and fostered the development of contemporary STEAM (Science, Technology, Engineering, the Arts and Mathematics) education by adding the joys of creating, tinkering with and exploring the world through a hands-on and collaborative approach.

STEAM = Science, Technology, Engineering, the Arts and Mathematics

'Maker Faire' events are worth mentioning here. These are maker innovation, creation and practice fairs which, through the interactive public engagement of makers, contribute to the development of STEAM at local and international levels.

We should also mention the characteristics and specific places for maker culture – **hackerspaces** and **makerspaces** – which are physical locations where individuals can gather to collaborate, share resources and work on projects. They are mostly open to the public, and typically provide access to tools, equipment and a supportive community.

The maker movement has gained recognition in education as a way of promoting hands-on, project-based learning. Makerspaces began appearing in schools, colleges and libraries, providing students with opportunities to explore STEAM subjects and develop practical skills.

Another related practice is **biohacking**, which refers to the practice of DIY research in biology and biological engineering (biotechnology). It is perhaps one of the youngest and most cutting-edge practices of science-related DIY engineering and, as such, is not well defined in literature. It has different meanings to different people and practitioners. The common philosophy lies in open-sourcing – which is enabling free access to biological and biological engineering knowledge, which is often jealously guarded by academic/science publishing systems (closed to general citizens) or by patents on natural biological mechanisms and resources.

Biohacking communities often share knowledge by organising workshops, lectures, conferences, exhibitions and similar public events, seeking community engagement and engaging in open-door practices.

Many members of the community build affordable DIY tools, such as microscopes, for exploring biology, and share open-source knowledge with the community. Usually expensive tools therefore become more affordable to the public, providing everyone (not just the privileged few) with the opportunity to learn.

1.2 Why Citizens Science in Youth Work

When we decided to start this project, we knew, we were doing something controversial. Bringing citizen science into youth work is crucial for fostering a generation that is engaged, informed, and capable of contributing to the global challenges they will inherit.

The importance of integrating citizen science into youth work can be understood through several dimensions:

A. EDUCATIONAL ENRICHMENT
Citizen science offers a unique educational experience that complements traditional classroom learning, but also complements the youth work settings, which are usually more focused on soft skills. It provides young individuals with hands-on, practical learning opportunities that enhance their understanding of scientific concepts and methodologies. By participating in real-world scientific research, youth can develop a deeper appreciation for the sciences, improving their analytical, critical thinking, and problem-solving skills. This practical approach to learning makes science accessible and engaging, potentially sparking a lifelong interest in scientific exploration and discovery.

B. EMPOWERMENT AND OWNERSHIP
Involving young people in citizen science projects empowers them by giving them a sense of ownership over their learning and contributions to society. This empowerment fosters a sense of responsibility towards addressing global challenges such as climate change, biodiversity loss, and pollution. As they witness the impact of their contributions, young individuals are motivated to become proactive agents of change, understanding that their actions can make a difference in the world.

C. BUILDING COMMUNITY AND COLLABORATION
Citizen science projects often require collaboration among participants, researchers, and sometimes, international teams. This collaborative environment teaches young people the importance of teamwork, communication, and the collective pursuit of knowledge. Through these projects, young people can connect with peers and mentors with shared interests, fostering a sense of belonging and community. These experiences help them develop interpersonal skills that are valuable in every aspect of life.

D. ENHANCING ENVIRONMENTAL AND SCIENTIFIC LITERACY
Citizen science projects, especially those focused on environmental monitoring and conservation, enhance participants' environmental and scientific literacy. Young individuals learn about the complexities of ecosystems, the importance of biodiversity, and the impacts of human activities on the environment. This knowledge is crucial for developing informed active citizens who can make responsible decisions and advocate for sustainable practices.

E. **CAREER EXPLORATION**
For many young people, participation in citizen science projects provides a window into the world of scientific research and various STEM careers. It allows them to explore their interests and passions within these fields, potentially guiding their educational and career paths. Experiences gained through citizen science can enrich their resumes and college applications, setting the foundation for future opportunities in STEM.

F. **INCLUSION**
One important thing we noticed on the way is as well how citizens science as a methodology can be very inclusive element. We tend to talk in youth work about the inclusion when we talk about vulnerable groups, growing up in hard situation or facing different abilities. Inclusion in citizen science extends beyond supporting vulnerable groups to encompass young individuals with exceptional intellectual curiosity, who might feel misplaced in traditional educational settings. These young people possess a deep thirst for knowledge and engagement, often seeking challenges and opportunities for exploration that go beyond what standard curriculums offer. They are often excluded from their peers due to the need for more explanations, deeper research and curiosity, which is as well putting them in the excluding position as it's hard for them to find the company. Citizen science provides an invaluable platform for these individuals, allowing them to apply their talents to genuine scientific research and innovation.

Incorporating citizen science into youth work is not just about engaging young people in scientific research; it's about preparing them for the future.

Intellectually curious young people benefit from the stimulation that citizen science projects offer, engaging deeply with complex topics that satisfy their need for discovery. These projects connect their advanced abilities to tangible societal challenges, giving them a sense of purpose and contribution. Such engagement can be particularly validating for those who feel isolated due to their unique interests, embedding their efforts within a global context of scientific inquiry.

Furthermore, participating in citizen science helps these young individuals to develop crucial social skills and emotional intelligence through collaborative work with peers, mentors, and professionals. This not only aids their personal development but also helps them find a sense of belonging within a community of like-minded individuals. Leadership roles in these projects can foster self-confidence and resilience, encouraging them to pursue STEM careers where their talents can be further nurtured.

The customizable nature of citizen science allows for personalized learning experiences, catering to the specific interests and capabilities of each participant. This ensures that learning remains relevant and engaging, encouraging continuous intellectual growth.

Incorporating citizen science into youth work is not just about engaging young people in scientific research; it's about preparing them for the future. It offers them the tools, knowledge, and experiences needed to navigate and contribute to a rapidly changing world. By fostering a generation that values science, collaboration, and community, we equip them with the ability to face global challenges with innovation, resilience, and hope.
The natural, innate way of doing science and engineering is deeply embedded in all of us, as that core method of experimentation: trial and error.

1.3 Possibilities – The example of Hedy Lamarr

We can find amazing examples of citizen science and engineering from inspiring individuals. They range from globally renowned figures such as Leonardo da Vinci (1452–1519), with his experiments and discoveries in anatomy and engineering, to more contemporary examples such as Rita Levi-Montalcini (1909–2012), who won a Nobel Prize for her discovery of nerve growth factor (NGF), which was based on the experiments she carried out in an improvised bedroom neurobiology lab in Turin at the height of World War II.

But perhaps the most illustrative example comes from the unlikely citizen scientist and engineer Hedy Lamarr* (1914–2000), a Hollywood Golden Age beauty who spent her spare time between shooting movie scenes doing experiments and tinkering with science and engineering in an improvised lab in her on-set trailer.

Hedy Lamarr's story is testament to the transformative potential of curiosity and ingenuity, and the potential an individual can achieve through self-learning. Born Hedwig Eva Maria Kiesler in Vienna, she demonstrated an insatiable thirst for knowledge from a very young age. Her early experiments with dismantling and reassembling household gadgets foreshadowed her future as a pioneering inventor. Despite lacking formal scientific training, she possessed an innate aptitude for understanding complex concepts, and a relentless drive to push the boundaries of what was possible.

Lamarr's most renowned innovation came during World War II when she, along with composer George Antheil (1900–1959), devised a groundbreaking frequency-hopping spread spectrum technology by combining mathematics, radio technology engineering and concepts found in the mechanisms of musical instruments (specifically, the piano). This invention, initially intended to aid the war effort by creating secure torpedo guidance systems whose signal could not be cracked and scrambled, laid the groundwork for modern wireless communication technologies, including Bluetooth and wi-fi. Yes, you read that right: wi-fi, the thing that enables all our gadgets to access the internet today. Lamarr's brilliance not only revolutionised military tactics, but also paved the way for countless technological advancements that continue to shape our interconnected world in the twenty-first century.

It is important to point out that inventions in the field of radio communications technology were not her only playground. She experimented with bionics, which is the construction of artificial systems inspired by living organisms – specifically, translating the aerodynamic body shape of fish and birds to aircraft design – and with chemistry, patenting an innovative approach to making concentrated soft drinks.

* To honour this remarkable individual, we invite you to do some self-exploration on your own. Use the wi-fi that Hedy gave us and do a bit of internet research on her inventions and motivations, as well as on the remarkable works of Rita Levi-Montalcini and Leonardo da Vinci. We are sure you'll find some personal motivation there.

Central to Lamarr's success was her unwavering belief in the power of hands-on experimentation and the value of learning through trial and error. She was unafraid to dive into unfamiliar domains through self-learning, often teaching herself new skills and disciplines along the way. Her story serves as a reminder that innovation knows no bounds and that anyone, regardless of background or formal training, can contribute to scientific progress through sheer determination and a willingness to take risks.

Moreover, Hedy Lamarr's journey underscores the importance of amplifying the voices and contributions of women in science. She persevered in the face of systemic barriers and societal expectations (on what a Hollywood actress should and should not do, for example), and managed to leave an indelible mark on the history of technology. Her legacy serves as a beacon of inspiration for aspiring female scientists, reminding them that their ideas and insights are invaluable assets to the scientific community.

In embracing the spirit of do-it-yourself exploration championed by Hedy Lamarr, we are encouraged to embrace our innate curiosity, to question the status quo, and to pursue our passions with unwavering determination. Her story challenges us to push beyond the boundaries of what is known, to boldly venture into uncharted territories, and to harness the power of innovation to shape a brighter future for the generations to come.

Leonardo da Vinci

Rita Levi-Montalcini

Hedy Lamarr

DIY tinkering spaces/ household laboratories

Every invention requires a place of birth. In citizen science, these are often household laboratories or 'DIY tinkering spaces'. Depending on what you are interested in and what resources you have at home, these spaces can come in a variety of forms. The trend among citizen scientists in the US is to turn garage spaces into tinkering spaces and DIY laboratories, while in people Europe seem to be keen on using kitchens for biological experimentation. But sometimes, a small corner in any room is more than sufficient. The first lab of Gjino – one of the authors of this book was exactly like this: an old, unused wooden cabinet repurposed into a bedroom workbench and storage space for all my improvised research tools and materials. So if you decide to go a bit more seriously into citizen science, we invite you to be creative with your creative corner – customise it to your needs and desires. A DIY tinkering space or household laboratory is your gateway to a world of endless innovation and boundless curiosity.

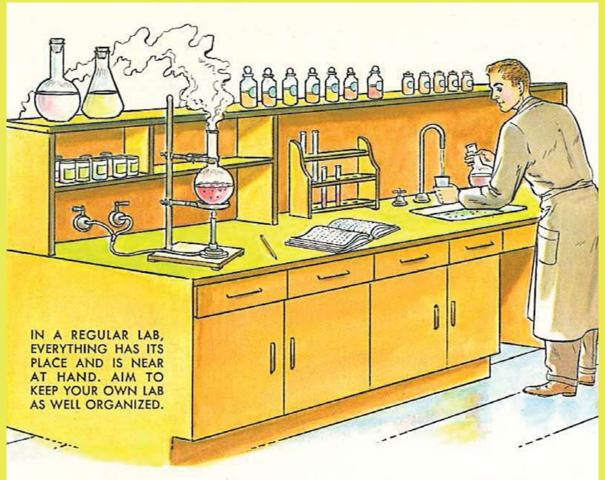
Workspace

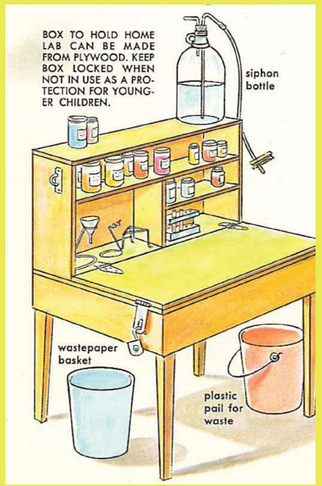
Since we are all unique, with different interests and desires, it is not easy to describe an average tinkering workspace or household lab. Depending on your interests and needs, you can customise it to best fit your current field of study. If you decide to explore the realm of chemistry, it will have to be customised to ensure that you can work safely with chemicals, with easy-to-clean surfaces that do not absorb liquids. Be sure to put it in a nicely ventilated space as well (next to the window is fine). The same goes for biology, as things can get smelly. If you are looking to experiment with modern engineering, such as 3D printing, it might be better to work in a room other than the bedroom – the hum of 3D printing can become annoying after a while. The possibilities are vast and endless.

So before constructing your creative corner, put it on paper first. List what you think you will need, sketch the layout, think about safety and be sure to know the limits. Start small and let it develop gradually. For example, if you're into biology, a basic microscope will be more than enough to kick start your citizen science research; if electronics are your thing, a cheap multimeter, a soldering iron, a few screwdrivers and some old electronics to disassemble will set you on your way.

Start small and let it develop gradually.

Here's a lovely example of a DIY chemistry lab from 1960. Various designs can be found online – just find one for the domain you're interested in.





Regular chemistry lab (left) vs. a small, improvised DIY chemistry lab (right)

(Illustration from The Golden Book of Chemistry Experiments, 1960)

2.2

Safety

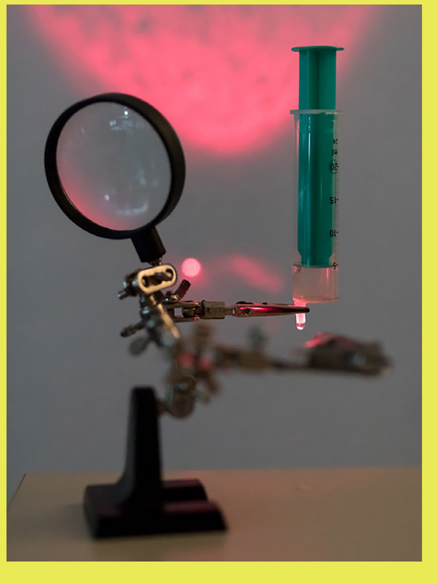
It is better to be too careful than not careful enough.

Ensuring personal protection and safety in a workspace is paramount in any scientific endeavour, particularly in environments where DIY experimentation with biological, chemical and electrical materials is to take place. Before embarking on any project, it's crucial you wear the appropriate gear: safety goggles to shield the eyes from chemical splashes and flying debris, lab coats or aprons to protect against spills and splatters, and gloves to protect the hands from hazardous substances (although beginners should avoid those, generally speaking).

It is essential that you adhere to strict safety protocols and warning signs. Chemicals must be clearly labelled and properly stored. When working with electricity, it is imperative that you use insulated tools and equipment, and deploy proper wiring techniques, to prevent electrical shocks and fires. It is best practice to have all electric appliances in your DIY lab or on your workbench connected to a central switch that you can easily turn off in case of emergency, and to have a small fire extinguisher to hand nearby. You should also have a small basic medical kit containing plasters, bandages, etc. Even the most careful professionals can injure themselves.

The general rule is to always play it safe. It is better to be too careful than not careful enough.

By integrating personal protection and safety practices into every aspect of their work, DIY scientists not only protect themselves, but also create a culture of safety that benefits the entire community. Again, do your research on safety before carrying out any experiments.



Affordable commercial microscope/digital magnifier (left) and DIY water drop microscope projector (right)

2.3

Basic equipment

Embarking on a DIY science journey, whether in biology, chemistry or electronics, requires a solid foundation of basic equipment to facilitate experimentation and innovation.

At the heart of any DIY laboratory is a versatile workbench – a sanctuary where ideas take shape and discoveries unfold. Here, an array of essential tools and instruments stand ready to assist in the pursuit of knowledge and creativity.

As we have already pointed out, the tools and materials you require differ greatly depending on your needs and interests. It would be impossible to list them all, so we will mention just a few of the most common ones. We will also give you pointers to some tutorials on how to make your own.

Keeping a laboratory log is common practice in all good labs. It is essentially a simple book in which you enter your notes, and is the most essential piece of material in your thinking space. Making good research notes is the best way to self-learn science and engineering.

2.3.1 WET LAB EQUIPMENT (BIOLOGY AND CHEMISTRY)

The tools most usually encountered in biology and/or chemistry labs are:

- a microscope and related consumables (glass slides) for studying the smallest objects
- (today there are many affordable ones, both digital and classic optical)
- a magnifying glass (for studying the surfaces of large objects)
- tweezers, scissors, scalpel and a chopping board for preparing samples for study
- a wide variety of containers, such as glass jars for collecting your samples and objects of study (you will use these things very often)
- a hotplate for cooking and heating
- volumetric glassware (glass cylinders, pipettes, droppers, etc.)
- glass containers (jars, etc.) that can be sterilised

If you decide to pursue research in microbiology, you will also need:

- a DIY Bunsen burner (e.g. a portable gas camping cooker) for sterilising tools and making sterile microenvironments for microbiology experimentation
- sterilisation equipment for liquids and tools: a pressure cooker (DIY autoclave) for sterilising liquids and metal and glass tools, or a microwave oven (for sterilising liquids) + a regular oven (for sterilising metal and glass tools)

For those who decide to go deeper into the field of serious biotechnology at some point, there are affordable educational tools such as PCR kits (e.g. PocketPCR by GaudiLabsor or PCR by OpenPCR), and even DNA/RNA sequencers (Oxford Nanopore), that can be used to explore the mysteries of the biological world.

Again, it is not easy to list everything, so we encourage you to do your own research. Explore the literature to find out what will meet your needs.

RECOMMENDATIONS

If you're starting out with DIY chemistry, we would recommend the classic Golden Book of Chemistry Experimentation (1960) by Robert Brent, which is available from the Internet Archive (https://archive.org).

For DIY biology and biotechnology, you could try the online Hackteria wiki at https://hackteria.org/wiki/Generic_Lab_Equipment (where you'll find amazing tutorials on how to make your own microscope cheaply from an old webcam, for example).

MATERIALS

Materials for DIY biology and chemistry experimentation are all around us. We invite you to be creative and explore. Read the labels on products in grocery stores, as you'll be able to find most of the materials and reagents there.

Weak acids and bases/alkalis are among the reagents most commonly used in biology and chemistry labs, and can be found in vinegar, lemon juice, sodium bicarbonate and baking powder, for example. Polar solvents are easy to get hold of (water, alcohol), while Zippo fluid, easily available from your local corner shop, makes a good non-polar solvent for DIY chemistry experiments.

DIY cabbage juice pH meter.

In biology, dyes and stains are often used to colour and analyse samples. You can also find those easily find on the retail market: methylene blue, for example, which is used to colour cell nuclei and cytoplasm, and malachite green (for colouring endospores, pollen and fungi) can both be found in pet shops as anti-fungal agents for aquariums.

Next to acids, bases, solvents and stains, the most common tools in biology and chemistry labs are those used to measure pH. We can measure pH value (how acidic/basic a substance is) with digital or chemical pH meters. But one of the best and most fun to play with is a pH meter you can make yourself, from cabbage juice. So here's the recipe.

TUTORIAL: DIY CABBAGE JUICE pH METER

YOU WILL NEED

- Red cabbage
- Blender or food processor
- Strainer or cheesecloth
- Clear glass or plastic container
- Distilled water
- Something acidic and basic to test it with
  (e.g. drop of lemon juice as acid, a drop of soap as base)

STEP 1:
Chop the red cabbage into small pieces and place them in the blender or food processor.
Add enough distilled water to cover the cabbage pieces and blend until smooth.

STEP 2:
Strain the cabbage mixture through a strainer or cheesecloth to remove any solids, leaving the purple cabbage juice behind.

STEP 3:
Pour the cabbage juice into a clear glass or plastic container.
Note the colour.

STEP 4:
Place a teaspoon of cabbage juice in a glass, add a drop of lemon juice and stir.
Notice the change in colour.

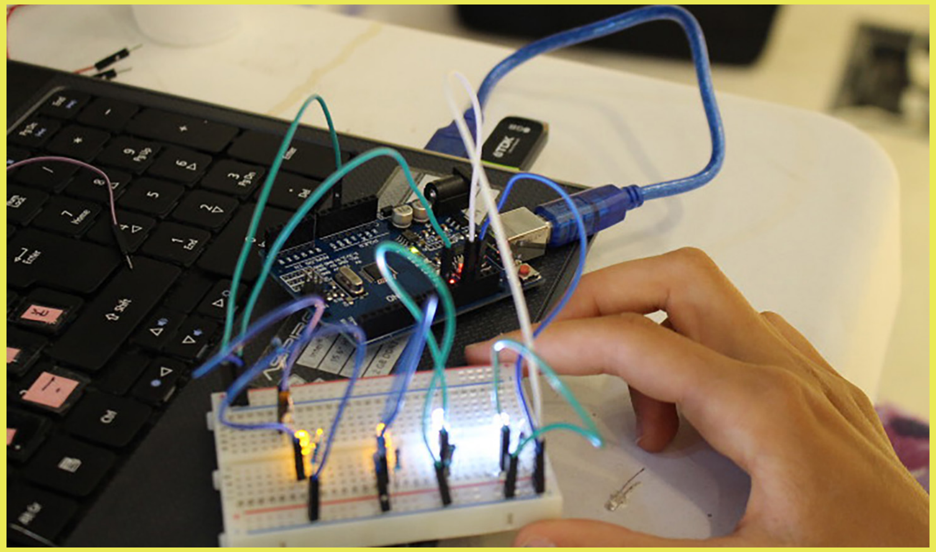
STEP 5:
Place a tablespoon of cabbage juice in a glass, add a drop of liquid soap and stir.
Notice the change in colour.

2.3.2 ELECTRICAL AND ELECTRONIC EQUIPMENT

In the field of electronics, soldering irons, multimeters and breadboards are essential. These enable circuits to be studied, assembled and tested with precision and accuracy. People who experiment with digital electronics often also use DIY experimental microcontrollers (such as Arduino, Raspberry PI, ESP, MicroBit, etc.).

There are so many good, detailed DIY electronics tutorials out there that it would be rather redundant for us to provide you with one as well. But to get you started, we would recommend the book "Make: Electronics" by Charles Platt and the Instructables website (https://www.instructables.com/).

As an interesting study example, we give you one tutorial in electronics on how to make your own DIY Arduino/ESP-powered environmental data collector.

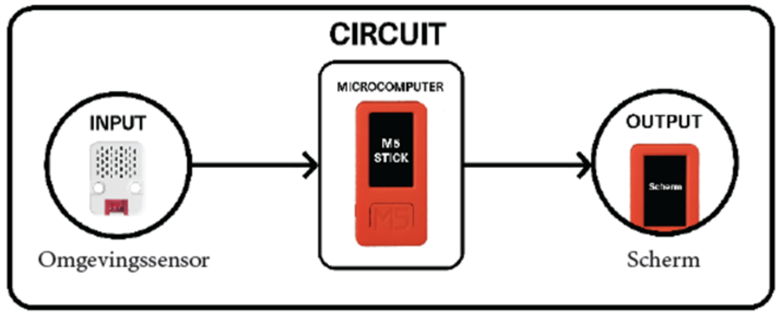


Arduino Uno-compatible microcontroller (controlling LED lights)

TUTORIAL: ENVIRONMENTAL DATA VISUALIZER WITH M5STICK

How can we know at a glance if our houseplants are enjoying themselves well? We make things easier for ourselves by programming a circuit with an environmental sensor and screen. That way we communicate with our plants via a screen and meet all our plant's needs.

In this tutorial we'll show you how to capture and visualize data coming from an environment sensor on a microcomputer called an M5stick Plus. We'll also use a cable to connect it to a computer that uses UI Flow to code our M5stick and the sensor. For this, we use the following input-output circuit:



Connect your M5Stick or other M5Stack device to your computer with a suitable USB type C cable and follow the following instructions to connect it to your computer and the coding program, UI Flow: https://docs.m5stack.com/en/quick_start/m5stickc_plus/uiflow

On the bottom left corner of the UI Flow window on your computer, check that the M5stick is properly connected to the M5Stick!

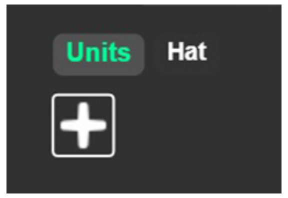
STEP 1: ADDING THE ENVIRONMENT SENSOR

First physically:

- Connect your environment sensor to the bottom of the M5stick with a Grove cable; this sensor will serve as an input in our project.

Secondly digitally:

- Add the sensor in our program by clicking on Units (1) en then on the + symbol (2).

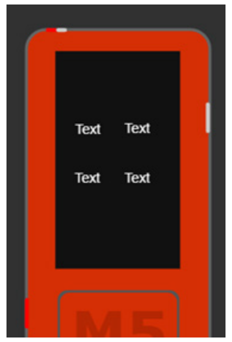


- Select the environment sensor in the list of sensors (you can find the exact sensor name on the back of the sensor).
- Click on 'OK' to finalize adding the sensor.

STEP 2: VISUALIZING THE DATA OF THE SENSOR

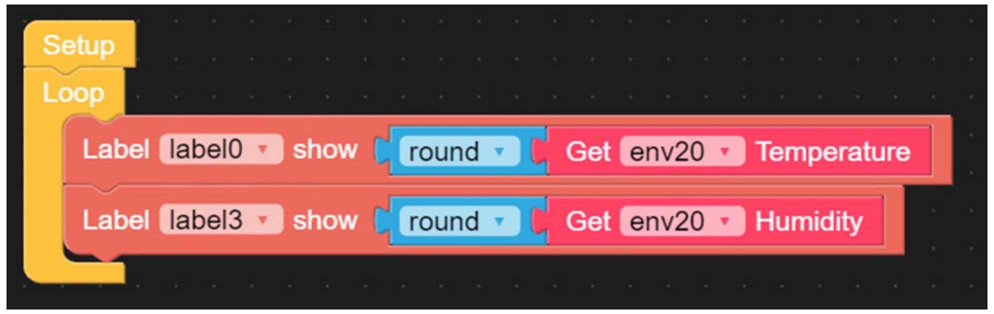
- Add a label from the left-hand side by clicking and dragging it onto the virtual screen of the M5stick.

- You'll see some options to edit your label appear on the right. (if not, click the label)
- You can duplicate the label by double clicking on it. Do this 3 times.
- Make a grid of 4 labels as seen on the picture.



- Change the text of the labels on the right so they say "C (Temperature)" & "% (Humidity)". These labels will not change as they are only here to express the units of the data.
- You can drag codeblocks from different categories to the empty field on the right. Find the following codeblocks in the corresponding categories: Event - Units - Math - UI > Label

- Place the Loop-block under Setup
- Place the rest of the blocks in the following structure:

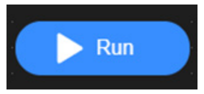


Watch out! make sure the label names in your code blocks match your left labels.

STEP 3: TESTING THE SENSOR

- Press the play button in the top right corner (newer versions of the program have a Run button in the bottom right)


Old version



New version

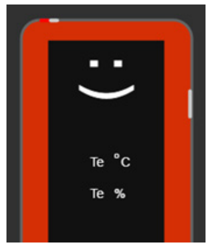
- You can blow on your sensor to see if the data changes on the screen of your M5Stick.

How do we turn our M5Stick into a creative representation of our little plant? Using the screen, we give our plant a face to express itself; code animations using the steps below:

STEP 4: ADDING A FACE

- Add 2 more labels and rotate them 90°
- Place them below each other and replace the text of the top label in ":" and of the lower label in ")".
- Lastly change the font size to 72

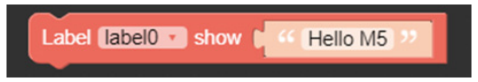
You should have something that resembles this:



STEP 5: ADDING MORE CODEBLOCKS

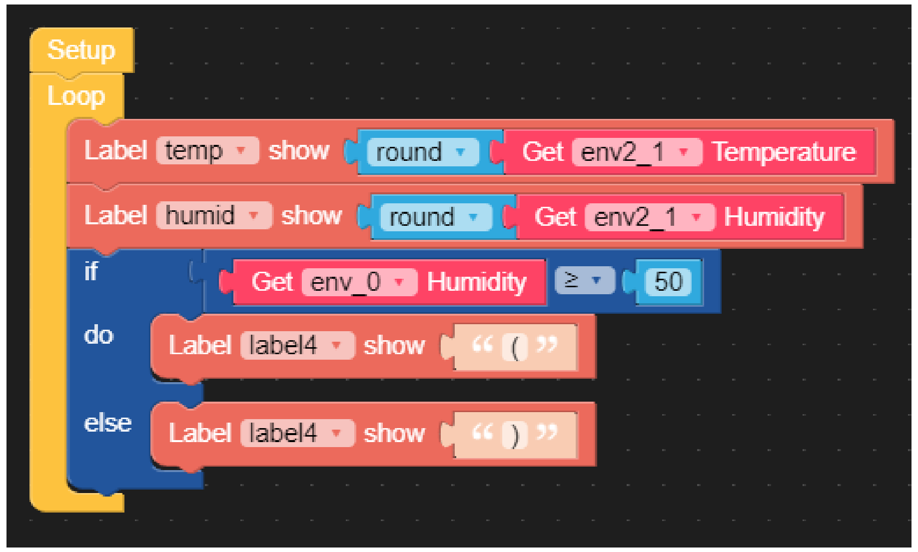
- Find the following codeblocks in the corresponding categories:
  Math - Logic

- Duplicate the following block twice:



- Duplicate this block once:

- Now that you have all the necessary codeblocks rearrange them to achieve the following result:



STEP 6: RUNNING YOUR CODE ON THE MACHINE

- Test your code again by pressing the Play/Run button
- Blow on your sensor to see if your smiley changes on the screen of the M5Stick.

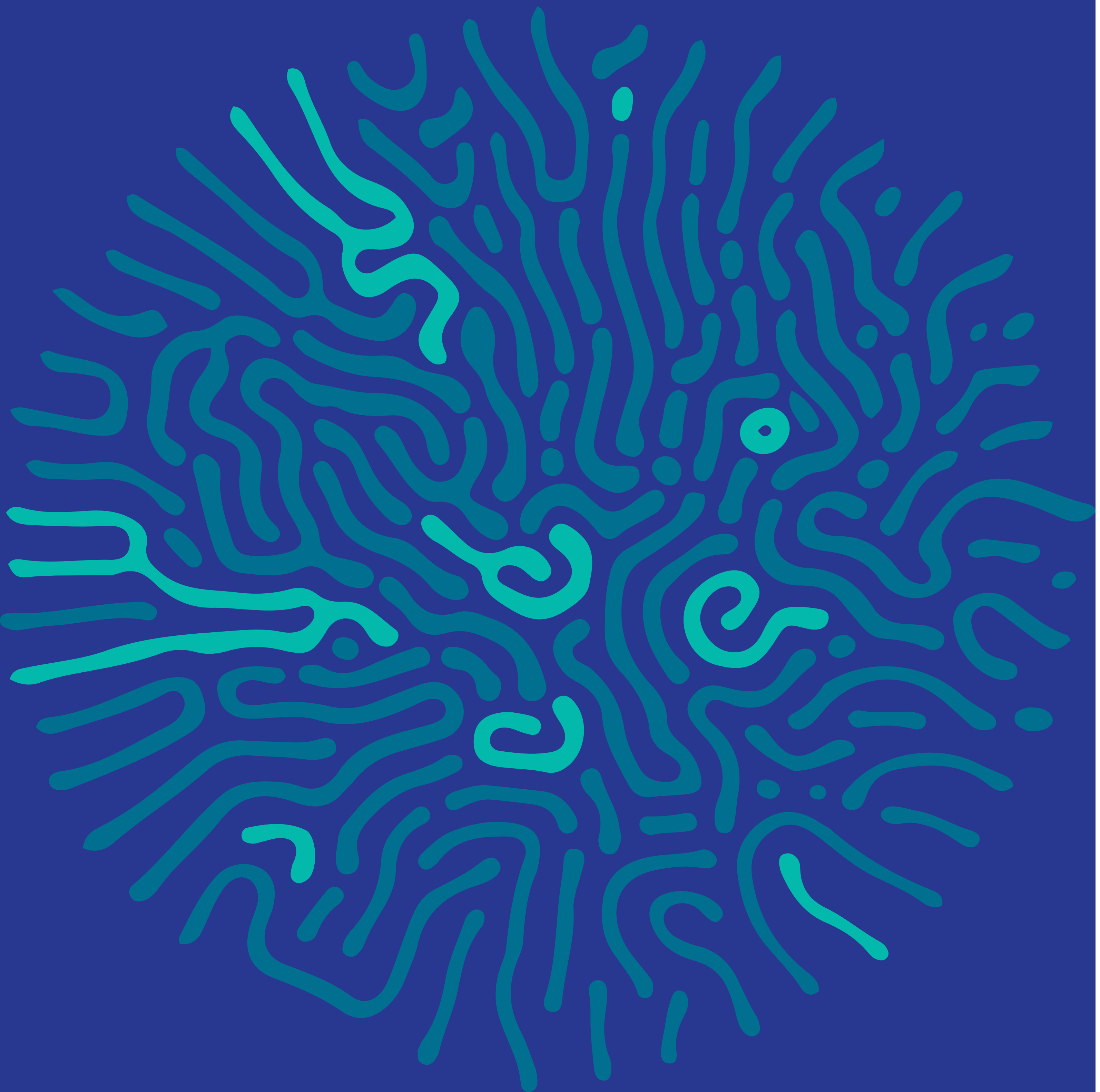
Congratulations you have now successfully coded an environment sensor!

See if you can add more components to your code such as:

- Try and store the data of the sensor
- Make an InternetofThings application that shows the data online so that you can check your plants conditions anywhere.

You can find a lot of documentation and code examples for all the different sensors that are available through the M5 website (https://docs.m5stack.com/en/uiflow/uiflow_home_page).

Explore



3.1

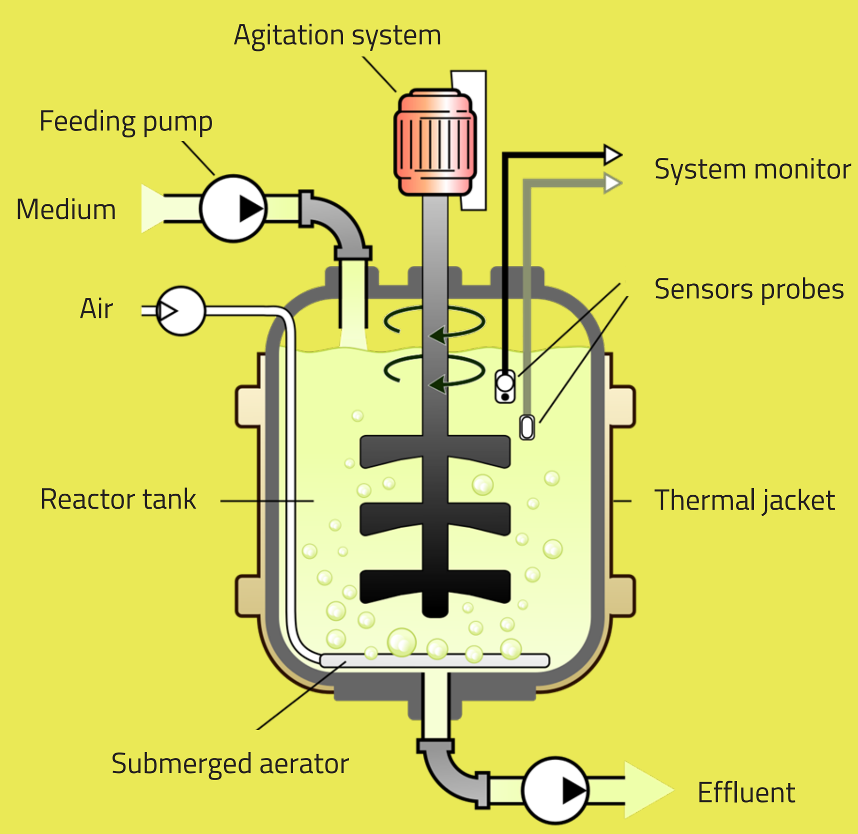
Open Environments, Natural Systems and the Cybernetic Approach

Most of the world around and within us can be seen as an open system – the human body, a specific organ, a single cell, a tree, a forest, a lake, the sea or planet Earth itself. In the realm of open systems, objects continuously interact with their environment, exchanging energy, materials and information. In living systems, this dynamic exchange often fosters adaptation and evolution, as systems respond to external stimuli to maintain stability and functionality. Whether it's the intricate web of ecosystems balancing nutrients and energy flow or the complex network of social interactions shaping human societies, open systems highlight the interconnectedness of all things.

By contrast, closed systems (such as engineered closed environments) provide a controlled environment in which internal processes unfold without external interference. This controlled setting allows for precise experimentation and analysis, enabling scientists to isolate variables and study fundamental principles in depth. Closed systems offer valuable insights into the underlying mechanisms of complex phenomena, from chemical reactions in a sealed chamber to the workings of a closed-loop feedback system in engineering.

A cutting-edge example of a closed system would be the Large Hadron Collider (LHC) built by CERN for subatomic particle research, or the bioreactor, which is an essential instrument in biotechnology and is a

A human body, a tree and planet Earth



Basic schematic of a common bioreactor (by Yassine Mrabet CC BY-SA 3.0 2009)

vessel containing finely controlled environmental factors (temperature, pH, gas concentrations, etc.) used for cultivating single cells and tissues in vitro, and for the production of biological compounds, living cells and derivatives.

By studying the interplay between objects and their environments, as well as the principles of cybernetics, scientists gain a deeper understanding of the fundamental dynamics that govern the world around us.

As the science of communication and control in systems, cybernetics bridges the gap between open and closed systems. It explores how feedback loops and regulatory mechanisms enable systems to maintain stability and achieve goals in both natural and artificial contexts. It provides a framework for understanding the processes of homeostasis, communication and control that underpin the functioning of complex systems, for example in the regulation of body temperature in living organisms and the design of autonomous robots,

By studying the interplay between objects and their environments, as well as the principles of cybernetics, scientists gain a deeper understanding of the fundamental dynamics that govern the world around us. This interdisciplinary approach not only sheds light on the intricacies of natural systems, but also informs the design of more efficient technologies and the development of strategies for sustainable living in an interconnected world.

3.2 DIY Case Study – Exploring an Open Environment of your Choice

Here we invite you on a small journey of exploration. We would like you to choose an open system, study it carefully and examine its intricate interconnections with the environment.

3.2.1 OBJECT

IDENTIFY YOUR INTERESTS

Consider your interests, passions and goals for the study. Are you intrigued by plant biology, fascinated by aquatic ecosystems or smitten with horticulture? Identifying your interests will help you select an object of study that aligns with your curiosity and objectives.

RESEARCH POTENTIAL OBJECTS

Conduct preliminary research on the various objects that you're considering studying. Learn about their characteristics, ecological roles, habitats and significance within the broader environment. Explore the diversity of options available, from individual organisms such as trees and plants to entire ecosystems such as gardens, ponds or forests.

ASSESS ACCESSIBILITY AND FEASIBILITY

Evaluate the accessibility and feasibility of studying each potential object. Consider factors such as proximity to your location, ease of observation and data collection, availability of resources and equipment, and any legal or logistical restrictions that may apply.

CONSIDER RELEVANCE AND IMPACT

Reflect on the relevance and potential impact of studying each object. Choose an object that not only aligns with your interests, but also contributes to broader scientific knowledge, conservation efforts or personal growth. Selecting an object with ecological significance or educational value can enhance the relevance and impact of your study.

FIELD RECONNAISSANCE

Conduct field reconnaissance visits to potential study sites to assess their suitability first hand. Observe the object's condition, surrounding environment, accessibility, and any potential challenges or opportunities for study. Take notes, photographs and preliminary data to inform your decision-making process.

SELECT YOUR OBJECT OF CHOICE

Based on your research, assessment and field reconnaissance, make an informed decision on which object to study. Choose an object that excites and inspires you, aligns with your interests and goals, and offers practical opportunities for observation, data collection and analysis.

Choose an object within an open environment that intrigues you. It could be a species of plant or animal, a geological formation, a body of water, or any other component of the ecosystem.

GIVE THE OBJECT A NAME

This might seem silly, but giving your object a name makes it more likely that you will connect more closely with it and have more motivation to explore. So we encourage you to do so.

A bush and a lake

PLAN YOUR STUDY APPROACH

Develop a study plan outlining your research objectives, methodologies, timelines and the resources needed. Consider the specific research questions you aim to address, the methods you'll use for data collection and analysis, and any permits or permissions required for conducting research at the chosen location.

RESEARCH – BEGIN YOUR STUDY

Once you've selected your object of choice and planned your study approach, begin your investigation with dedication. Implement your research plan, collect data, analyse findings and draw conclusions that contribute to your understanding of the object and its broader ecological context. Make sure you use your research log/diary – a notebook in which you can enter all measurable data, notes, ideas and thoughts.

Conduct comprehensive research on your chosen object. Gather additional information from reputable sources such as scientific journals, textbooks and academic publications. Learn about the object's characteristics, habitat, ecological role, interactions with other organisms, environmental factors affecting its survival, and any ongoing research or conservation efforts related to it. Map your findings in a notebook.

FIELD OBSERVATION

Visit the location at which your object exists in its natural environment. Spend time observing and documenting its behaviour, physical attributes and interactions with its surroundings. Take detailed notes, photographs and videos to capture your observations accurately.

DATA COLLECTION

Collect quantitative and qualitative data relevant to your case study. This may include measurements of environmental variables such as temperature, humidity and pH levels, as well as behavioural observations, population counts and habitat assessments. Use the tools you have at your disposal.

ANALYSIS

Analyse the data you've collected to identify patterns, trends and correlations. Consider how environmental factors influence the object's behaviour, distribution and survival.

Use scientific principles and analytical tools to interpret your findings and draw meaningful conclusions.

DOCUMENTATION

Compile your notes, observations, data and analyses into a comprehensive case study report of around two or three pages. Organise your findings in a logical manner: an introduction followed by sections on background information, methods, results, discussion and conclusions. Use clear and concise language, supported by visual aids such as charts, graphs and maps, to present your findings effectively.

PEER REVIEW

Introduce peers to your case study and seek their feedback. Constructive criticism is a great tool for learning. Incorporate their suggestions to improve the clarity, accuracy and rigour of your analysis in this case study and in your future work.

By following these steps, you can create a comprehensive case study exploration of an open environment object of choice, enriching your understanding of its ecological significance and contributing to scientific knowledge and conservation efforts.

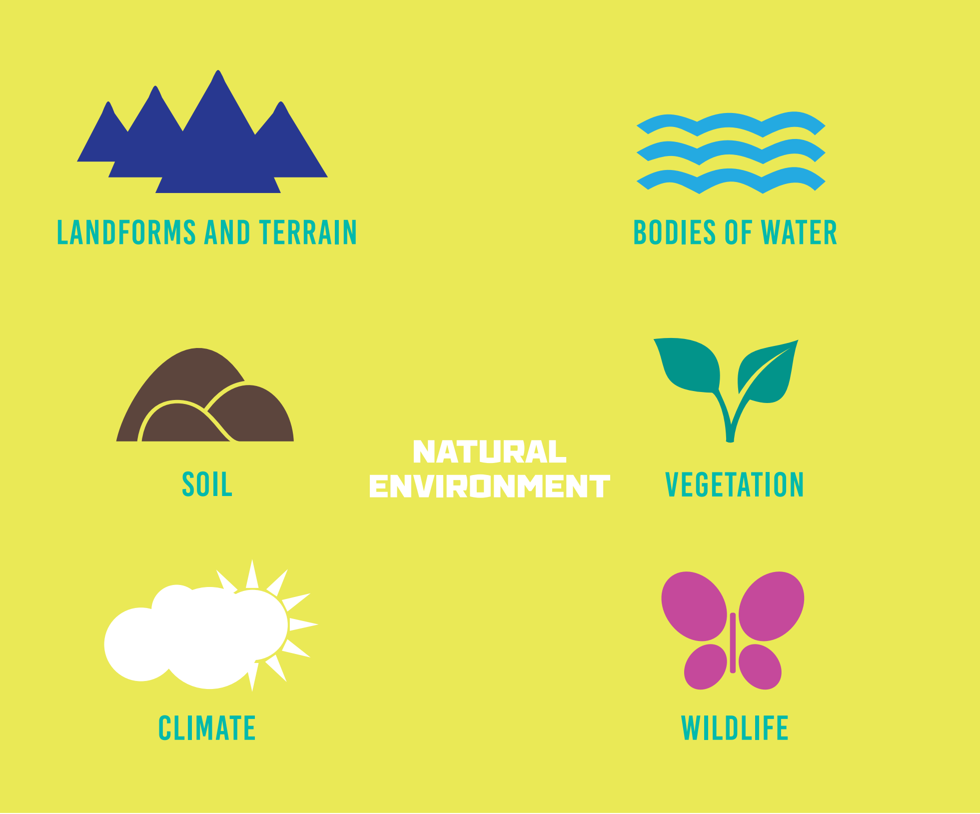
3.2.2 ENVIRONMENT

3.2.2.1 INTRODUCTION

The natural environment includes our planet's living and non-living components – the land, water and all living things. It includes everything from the highest mountains to the deepest oceans, from the tiniest microorganisms to the mightiest predators. This environment is always changing and full of life. It's not like a still picture, but more like a lively, moving scene that supports many different forms of life.

COMPONENTS OF THE NATURAL ENVIRONMENT

The natural environment isn't merely a collection of separate elements. Its main components interact with each other, shaping the kind of ecosystem that develops and impacts the lives of its inhabitants. It's like a well-coordinated team, where each part plays a crucial role in supporting life. For example, plants release oxygen through photosynthesis, supporting animals, while animals produce carbon dioxide, which is essential for the growth of plants. This interdependence stretches across all levels of the ecosystem.



VARIABLES FOR MEASUREMENT AND STUDY

To understand the natural environment, we rely on various variables, which are specific aspects or characteristics that can be measured and studied. These variables help us figure out how different parts of the environment are connected. Here are some key variables:

A. TEMPERATURE
Measures the warmth or coldness of the air, water or soil, and influences the behaviour and distribution of living organisms.

B. HUMIDITY
Reflects the amount of moisture in the air. It affects plant growth, animal behaviour and weather patterns.

C. PRECIPITATION
Includes rainfall, snowfall and other forms of water falling from the atmosphere. It is crucial for the water cycle and the sustenance of ecosystems.

D. WIND SPEED AND DIRECTION
Describes the movement of air. It impacts climate, plant pollination and the spread of seeds.

E. LIGHT
This tells us how much sunlight reaches an area. It is essential for plants to grow and for animals to find their way around. Different plants and animals need different amounts of light.

F. SOIL COMPOSITION
The composition and quality of soil are critical for plant growth and serve as a habitat for many organisms.

G. PH LEVEL
Measures the acidity or alkalinity of water or soil. It influences the types of plants and animals that can thrive in a particular environment.

H. POLLUTION LEVELS
Quantifies the presence of harmful substances in air, water or soil. Monitoring pollution helps protect the health of ecosystems and human populations.

I. BIODIVERSITY
Refers to the variety and abundance of living organisms in a given area. It indicates the health and resilience of an ecosystem.

J. VEGETATION COVER
Describes the density and types of plants in an area. It is crucial for understanding habitat quality and ecosystem services.

> Various variables help us figure out how different parts of the environment are connected.

By measuring and studying these variables, we gain valuable insights into the complex interactions that shape the natural environment. This helps us make smart and informed choices about taking care of our planet and using its resources in a way that keeps ecosystems healthy for as long as possible.

3.2.2.2 GUIDED OBSERVATIONAL STUDY QUESTIONNAIRE FOR "IN SITU" EXPLORATION

All variables influence each other and create an environment. Study the patterns of interdependence among the variables. (Depending on the object of observation you have chosen, you might not be able to measure all the variables.)

Each variable will be measurable by the DIY tool listed in 2.3 Basic equipment (e.g. temperature and humidity by Arduino/ESP equipped with a DHT11 sensor. The same goes for all observations and experiments.)

1. **Measure the variables throughout the day.**

Variable	8:00	12:00	16:00	20:00
Temperature				
Humidity				
Precipitation				
Wind speed and direction				
Light				
pH				

2. **Draw graphs of the data you have collected, with the x-axis being the time of collection and the y-axis being the data. Try to put more than one variable on the same graph to make it easier to visualise the interdependence of the variables (e.g. temperature and humidity).**

3. **What is the relationship between these variables? Have you noticed any rules in their behaviour?**

4. **Find a flower (daisy, dandelion, etc.). Notice the relationship between the amount of sunlight and whether the flower is open or closed. Why would the flower open and close depending on the amount of available sunlight?**

All variables influence each other and create an environment.

3.2.2.3 EXPERIMENT: DIY LABORATORY SOIL COMPOSITION EXPERIMENTS

Soil, often overlooked but crucial to life on Earth, is a dynamic and complex mixture of mineral particles, organic matter, water and air. It serves as the foundation for terrestrial ecosystems, supporting plant growth and providing habitats for a myriad of organisms. Soil also plays a pivotal role in nutrient cycling, water filtration and carbon storage. Its properties vary widely across different regions and climates, influencing agricultural productivity, land use and even cultural practices. Soil health and conservation are vital for sustainable agriculture and biodiversity, and for mitigating the impacts of climate change. This makes it a precious and often undervalued natural resource.

One of the most important characteristics of soil is texture. Soil texture refers to the relative proportions of sand, silt and clay particles in a soil sample. These particles determine the physical properties of the soil, including its ability to retain water and nutrients, its aeration and its workability for plant roots. Sandy soils have larger, coarser particles, allowing for good drainage but often requiring frequent irrigation and fertilisation. Silt soils have intermediate-sized particles, offering better water retention and fertility. Clay soils, with the smallest particles, retain water exceptionally well, but can become compacted and poorly aerated. Understanding soil texture is essential for successful agriculture and gardening, as it influences plant selection and the need for soil amendments to optimise growth conditions.

Soil pH is also a very important characteristic. It greatly influences the availability of nutrients to plants – for instance, acidic soils may have limited access to essential nutrients like calcium and magnesium, while alkaline soils may lock up iron and other micronutrients. Understanding and managing soil pH is therefore crucial for optimising the health of crops and plants because it directly affects their ability to take up vital nutrients from the soil. Soils with a pH below 7 are classed as acidic and those above 7 as alkaline.

The last component of soil is biological. Soil is a bustling ecosystem teeming with a myriad of organisms, from microscopic bacteria and fungi to larger creatures like earthworms and insects. These soil organisms play essential roles in nutrient cycling, decomposition and the overall health of the soil. They break down organic matter (which releases nutrients for plants), improve soil structure and help control pests. Their contribution to the productivity and sustainability of terrestrial ecosystems is therefore indispensable.

In this experiment, we will determine the main characteristics of soil through three smaller experiments to determine soil type and composition, test the pH of the soil and carry out microscopic observation.

Soil samples.

YOU WILL NEED

- Soil samples
- Water
- Glass jar or measuring cylinder
- Cabbage juice
- Dropper
- Microscope
- Ruler

PART 1: DETERMINING SOIL TYPE AND COMPOSITION

STEP 1: PREPARE THE SOIL-WATER SOLUTION

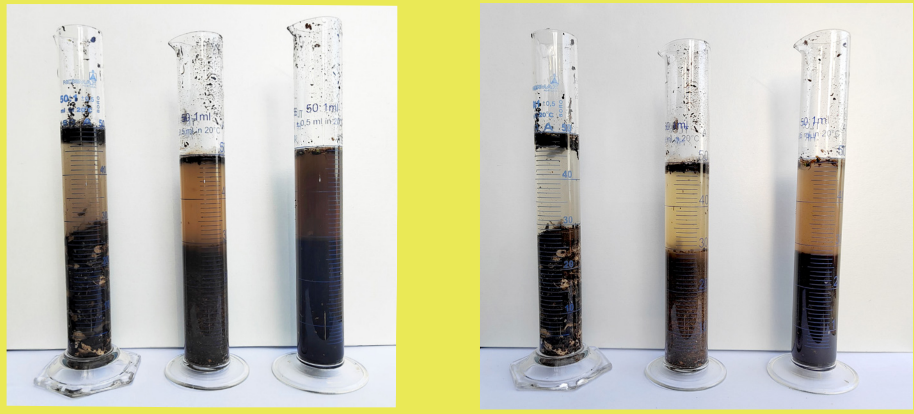
Mix a sample of soil with water in the jar and shake well to create a suspension. Transfer the mixture into a measuring cylinder, if you have one; otherwise, you can use a DIY alternative, such as a thinner jar or a cylindrical glass, and use a standard ruler for measurement.

STEP 2: LET IT SETTLE

Allow the mixture to sit undisturbed for a while (about 48 hours, or until the water becomes completely transparent again). Over time, the different particles in the soil will settle into layers. The first settled layer will be sand and the next one will be silt. The third layer (clay) will take the longest to settle.

STEP 3: OBSERVE MINERAL AND ORGANIC SEPARATION

Note that the settled layers primarily consist of mineral components, while the organic matter tends to float on top or remain suspended.



Water-soil solution in a jar.

STEP 4: MEASURE AND CALCULATE

Use a ruler to measure the volume of each layer in the jar. If you are using a volumetric cylinder, carefully measure the volume of each layer (sand, silt, clay). Record these volumes.

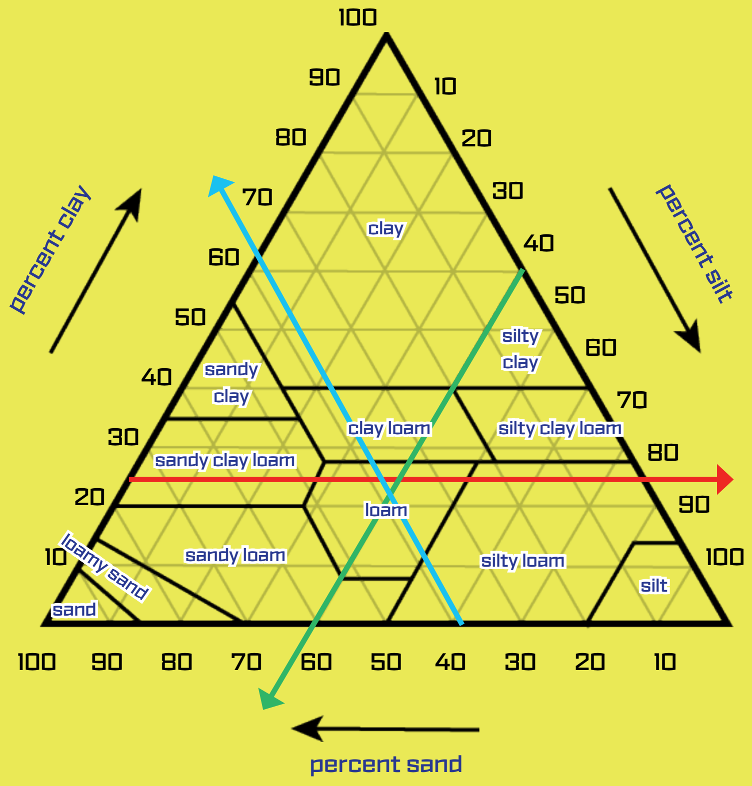
STEP 5: CALCULATE PERCENTAGES

Using the recorded volumes, calculate the percentage of each type of soil in the mixture.

$$\left(\frac{\text{VOLUME OF THE COMPONENT LAYER}}{\text{TOTAL VOLUME}} \right) \text{X } 100 = \text{PERCENTAGE OF THE SOIL COMPONENT (\%)}$$

STEP 6: USE THE SOIL COMPOSITION TRIANGLE

Refer to a soil composition triangle to determine the soil type based on the percentages of sand, silt and clay.



The soil composition triangle

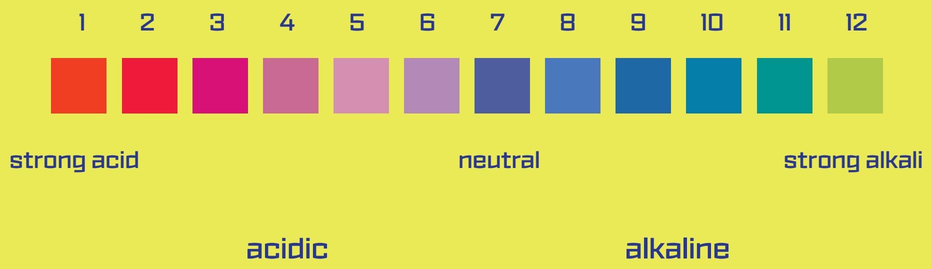
PART 2: TESTING SOIL PH

STEP 1: CREATE A CABBAGE JUICE INDICATOR

See Chapter 2.3.1.

STEP 2: APPLY CABBAGE JUICE

Place a small amount of soil in a dish and add some drops of cabbage juice. Observe any colour change. Pink to red indicates acidity, purple is neutral, while blue and green to yellow indicates alkalinity.



The red cabbage juice pH scale

PART 3: MICROSCOPIC OBSERVATION

This experiment requires a microscope with a minimum magnification of 40x, which means any microscope will suffice: a child's toy microscope, a professional microscope or a DIY microscope assembled from an old webcam or laser pointer (instructions can easily be found online from places such as https://hackteria.org/wiki/DIY_microscopy).

STEP 1: PREPARATION

Take a tiny amount of soil and place it on a microscope slide. Add a drop of water and cover with a coverslip.

STEP 2: OBSERVE UNDER THE MICROSCOPE

Examine the soil particles under the microscope. Note their shapes, sizes and structures. Try to use different magnification levels. Is everything inorganic and still, or are there live organisms 'running around'?

1. **How much time did it take for your sample to settle down?**

2. **Using soil composition analysis, determine your soil type.**

3. **What is the soil pH of your sample? What does that mean for organisms living in and on it?**

4. **Observe the soil sample under the microscope and draw the different inorganic particles that make up your soil sample. Try to identify whether they are sand, silt or clay.**

5. **Is there any dead organic matter? If so, draw it and try to identify it.**

6. **Are there any living organisms in your sample? If so, draw them and try to identify them.**

3.2.2.4 EXPERIMENT: DIY LABORATORY WATER ANALYSIS

YOU WILL NEED

- Water samples
- Small dishes or containers
- Dropper or pipette
- Microscope
- Microscope slides and coverslips
- Water pH test strips (optional)

PART 1: TESTING PH LEVEL WITH CABBAGE JUICE

STEP 1: COLLECT WATER SAMPLES

It would be best to test several water samples in parallel. Try to compare outdoor water samples (from a lake, the sea, a pond, a bird feeder, etc.) with tap water.

Gather water samples from different sources in separate containers, and mark them (so as not to mix them up).

STEP 2: APPLY THE CABBAGE JUICE INDICATOR

Using a dropper or pipette, add a few drops of cabbage juice indicator to each water sample. Observe any change in colour. Pink to red indicates acidity, purple is neutral, while blue and green to yellow indicates alkalinity. For comparison, you can also use pH test strips (from pet stores for testing aquarium water) to verify the results.

PART 2: MICROSCOPIC OBSERVATION OF WATER SAMPLES

STEP 1: PREPARE THE MICROSCOPE SLIDE

Using a dropper, place a small drop of water from the sample onto a clean microscope slide.

STEP 2: COVER AND OBSERVE

Gently place a coverslip over the water drop, ensuring there are no air bubbles. Carefully place the slide on the microscope stage and focus on the water sample. Use the microscope to explore the microscopic organisms present in the water sample. Note their shapes, movements and any observable features.

STEP 3: RECORD YOUR FINDINGS

Make sketches or take pictures to document your observations.

1. **What are the pH levels in your samples? How does that affect the organisms living in the water?**

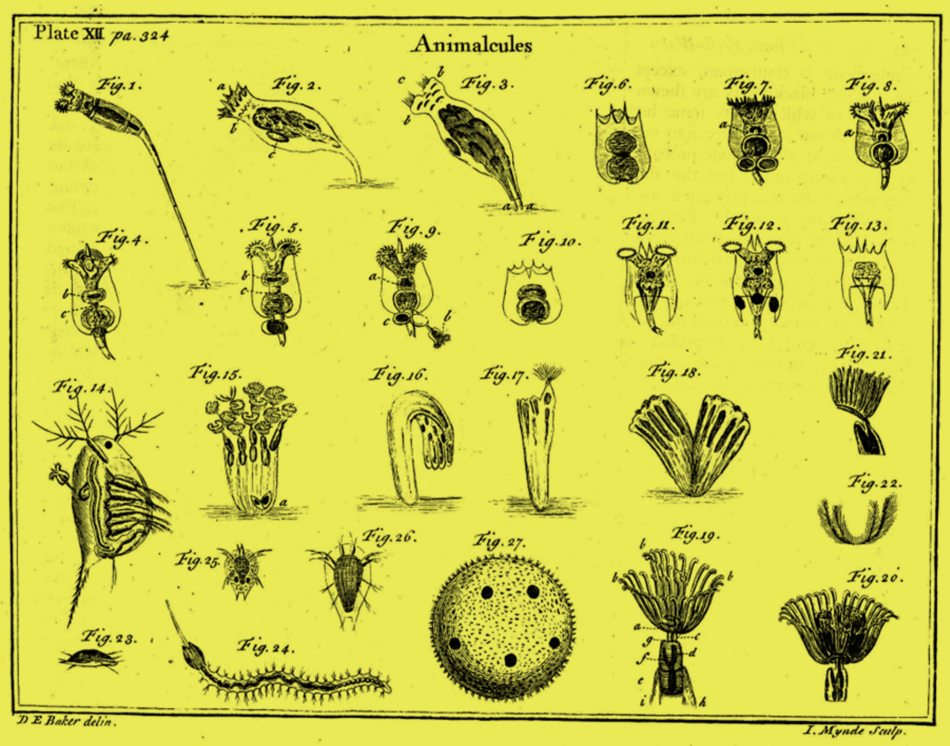
2. **Try to take multiple samples from different water sources (pond, river, sea, sink, etc.) and determine their pH. Is there a difference in pH between water sources? Try to determine what is causing these differences.**

3. **Are there organisms actively swimming around? If so, sketch them and try to identify them.**

4. **Are there any sedimentary (immobile) organisms? Sketch them and try to identify them.**

5. **Can you determine what photosynthetic and heterotrophic organisms are? (The former eat other organisms and the latter feed on organic particulates.) Are all photosynthetic organisms in your sample sedimentary (like plants) or do some of them move? Are all the organisms that you see protozoa and algae, or are there other types of living organism present?**

6. **Have you noticed any difference between water sources in terms of the number of species and organisms you have found?**



Animalcules by Henry Baker, 1754 (from Wellcome images, Wellcome Trust, UK charity organisation CC BY 4.0)

3.2.3 INTERACTION

Ecological interactions play a pivotal role in shaping ecosystems and maintaining the delicate balance of life on Earth. These interactions encompass a wide array of relationships between organisms and their environment, resulting in a complex web of dependencies that sustain life as we know it. They can be classified as "intraspecific" and "interspecific" interactions.

Intraspecific interactions involve interactions between individuals of the same species. These interactions are critical for activities like mating, cooperation, competition for resources within a population and establishing social hierarchies, all of which influence the population dynamics and behaviours of a particular species in its environment.

Interspecific interactions refer to relationships and interactions between different species in an ecosystem. These interactions can take various forms, such as predation, mutualism, competition or commensalism, and they play a vital role in shaping the structure and function of ecosystems.

Intraspecific interactions involve interactions between individuals of the same species.

Interspecific interactions refer to relationships and interactions between different species in an ecosystem.

The most important types of interaction to understand are:

- **PREDATION** is a fundamental ecological interaction where one organism, known as the predator, hunts, kills and consumes another organism (the prey) for sustenance. This interaction plays a crucial role in regulating populations, driving evolutionary adaptations and maintaining the ecological balance within ecosystems.
- **PARASITISM** is a symbiotic relationship in which one organism (the parasite) benefits at the expense of another organism (the host) by deriving nutrients, shelter or other resources. These interactions can range from microscopic parasites like bacteria to large organisms like ticks and tapeworms. They often have significant impacts on the health and behaviour of both parasite and host.
- **MUTUALISM** is a fascinating ecological interaction that involves two or more species in a mutually advantageous relationship that boosts their odds of survival and reproduction. Examples include pollination performed by animals such as bees, hummingbirds and bats, which benefit from nectar while facilitating plant reproduction, and the vital role animals play in seed dispersal, either through ingestion and excretion or the attachment of seeds to fur or feathers. These interactions showcase the remarkable ways in which organisms cooperate in nature to achieve shared goals.
- **COMMENSALISM** is an ecological interaction in which one species benefits while the other remains unaffected. An example is the relationship between remora fish and sharks: the remora attaches itself to the shark to hitch a ride, obtaining protection and access to nutrients without harming or benefiting the shark in any discernible way.
- **COMPETITION** for resources is another key ecological interaction. When two or more species vie for the same limited resources (e.g. food, water or shelter), they engage in a struggle for survival. This competition can lead to the evolution of specialised traits or behaviours that enable species to coexist by occupying slightly different niches within an ecosystem. Competition also occurs between individuals of the same species.

3.2.3.1. GENERAL OBSERVATIONAL QUESTIONNAIRE

Use this questionnaire to record observations of your chosen object from Chapter 3.2.1.

Observe your chosen object through different times of the day/on more than one day/through different seasons.

1. **How much sunlight falls on your observed object? Is there an equal amount of sunlight everywhere on your object?**
2. **Observe plant life on and in your chosen object. Where do they grow? Do they prefer sunny or shady places? Try to identify them.**
3. **Observe different animals on and inside your object. Do they live on or in the object, or do they only spend some of their time there? What do they do there (feed, find shelter, etc.)? Try to identify them.**
4. **Are there parts of the object that some organisms prefer and some that they actively avoid? If so, which ones and why?**
5. **List all the living beings you noticed during your observations.**
6. **Are there parts of the day or season when some organisms are more active and some when they are less? Does the weather affect them?**
7. **Try to write anything else that you might have noticed during your observations.**

3.2.3.2 EXPERIMENT: DIY HONEY TRAP (FOR INSECTS) AND OBSERVATIONAL QUESTIONNAIRE

Insects are incredibly diverse and abundant members of the animal kingdom, and their contributions to ecology are both extensive and vital. They play key roles in various ecological processes:

- In the realm of pollination, insects like bees, butterflies and beetles are essential for the reproduction of many plant species. They facilitate the production of fruits, vegetables and nuts, which not only sustain numerous species but also provide essential sources of food for human beings.
- In the process of decomposition, insects such as ants, beetles and flies act as nature's recyclers, breaking down dead organic matter. Their efforts accelerate the decomposition process, returning nutrients to the soil and enhancing soil fertility.
- In addition to their role in decomposition, insects also function as both predators and prey in various food chains. They help regulate populations of herbivorous insects and small arthropods, contributing to the overall balance of ecosystems.

Insect trap

- Insects serve as important indicators of environmental health. Changes in their populations or behaviours can signal environmental disturbances and pollution, which helps researchers assess the well-being of ecosystems.
- Insects are a significant dietary source for many animals, including birds, bats and amphibians, making them a critical energy source for higher trophic levels in food webs.
- Some insects, such as termites and ants, are considered ecosystem engineers due to their construction of complex underground tunnels and mound structures. These structures alter soil composition and water flow, which impacts local habitats.
- Certain insects, such as ants and beetles, contribute to seed dispersal by transporting seeds to new locations, thereby promoting plant diversity and helping plants colonise new areas.
- Insects can influence nutrient cycles, particularly nitrogen. Some species can fix atmospheric nitrogen into forms that plants can utilise, thereby contributing to soil fertility.

In summary, insects play foundational roles in the ecological processes of pollination, decomposition and nutrient cycling, among others. Their multifaceted contributions highlight their significance in maintaining biodiversity and ecological balance, emphasising the importance of their conservation for both ecosystems and human well-being.

In this experiment, we will make a simple DIY honey trap to help us observe the insect species in our environment.

YOU WILL NEED

- Plastic bottle
- Honey
- Scissors
- String or twine
- Small sticks or twigs (optional)

STEP 1: PREPARE THE BOTTLE
Begin by ensuring the plastic bottle is clean and dry. Remove any labels or residue.

STEP 2: MAKE THE TRAP
Use scissors to carefully cut the bottle in half horizontally, creating two distinct pieces. You'll be using the upper half for the trap. Turn the upper half of the bottle upside down so that the open end is facing downwards. This will serve as a funnel to guide the insects into the trap.

STEP 3: CREATE A HANGING LOOP (OPTIONAL)
If you plan to hang your trap, use the scissors to make two small holes near the top of the bottle. Thread a piece of string or twine through these holes and tie a knot to create a loop.

STEP 4: APPLY THE HONEY
Generously coat the bottom of the bottle with honey. This will serve as the bait for the insects.

STEP 5: ASSEMBLE THE TRAP
Place the honey-coated top back onto the bottom half of the bottle. Ensure the edges are aligned properly.

STEP 6: OPTIONAL PERCH (FOR BEES)
If you're specifically targeting bees, you can insert small sticks or twigs horizontally through the bottle. This will provide a perch for the bees to land on.

STEP 7: HANG THE TRAP (OPTIONAL)
If you've created a hanging loop, find a suitable spot to hang your trap. Make sure you choose an area of insect activity.

Find a suitable place to place your trap. Position it somewhere where you have noticed a large amount of insect activity, such as flower patches or tree trunks.

If possible, place it somewhere on your chosen object. Observe the insects caught in the trap over a couple of days.

1. **What types of insect do you think will be attracted to honey?**

2. **What insects are you observing and what behavioural patterns do you notice?**

3. **Once you have caught an insect in a trap, close the opening to observe it better. Sketch the insect. Try to identify it.**

4. **Set up traps in two different locations, e.g. one near a field and one in a flower garden. Note down all the different species that have been caught in your traps.**

Species from Location 1	Species from Location 2

5. **Is there a difference in biodiversity (number of species) between the two locations? Is there a difference in the number of insects caught? Why?**

3.2.3.3 EXPERIMENT: DIY BIRD FEEDER

Birdwatching is a fascinating and peaceful hobby that enables people of all ages to enjoy nature. It's a great way to learn about different birds and help protect them. Creating a simple bird feeder in your backyard or balcony provides a convenient spot for birds to find food, particularly when natural resources are scarce (as in the winter months). This also allows you to observe the fascinating behaviours of different bird species from the comfort of your back garden or balcony.

There are lots of different bird feeders. Some are like little wooden houses and others are just flat trays on tree branches filled with different kinds of seed. It doesn't matter how big or what kind your feeder is. The most important thing is that it contains food and is in a good spot where birds can easily get to them.

Here are some easy DIY ideas for bird feeders.

YOU WILL NEED

- Apple, orange or pinecone
- Bird seeds
- Honey
- String or twine
- Scissors
- Small stick or twig (optional)

STEP 1: PREPARE THE FRUIT OR PINECONE
Cut an apple or an orange in half horizontally. Scoop out any pulp or seeds from the fruit to create a hollow space for the seeds and honey mixture. If using a pinecone, it's ready to use as is.

STEP 2: CREATE THE SEED MIXTURE
In a bowl, mix the bird seeds with honey. The honey acts as a natural adhesive, helping the seeds stick together and stay in place.

STEP 3: FILL THE FRUIT OR PINECONE
Using a spoon or your fingers, carefully fill the hollowed-out fruit or the spaces between the pinecone scales with the seed mixture. Press gently to ensure the seeds stick.

STEP 4: ADD A HANGING LOOP (OPTIONAL)
If you want, create a hanging loop using string or twine. Push the ends through the top of the fruit or pinecone and tie them securely in a knot.

STEP 5: OPTIONAL PERCH (FOR APPLE OR ORANGE FEEDERS)
If you have a small stick or twig, you can insert it horizontally through the fruit to provide a perch for visiting birds.

STEP 6: HANG YOUR BIRD FEEDER
Find a suitable spot to hang your feeder. It should be a place where birds can easily access it, like a tree branch or a hook in your garden.

Bird feeder

Bird feeder

Hang your newly crafted bird feeder in a safe and easily visible spot, preferably near a window. If possible, place it somewhere on your chosen object. Use your questionnaire to record your observations.

1. **How many different bird species did you see? Can you identify the species?**

2. **What were they doing? (eating, flying, resting, etc.)**

3. **Did you notice any interesting behaviours?**

4. **Were there any other animals around (squirrels, insects, etc.)? If so, list them.**

5. **Prepare two different feeders, one with larger seeds and the other one with smaller seeds. What do you observe? Which species preferred the feeder with smaller seeds and which preferred the feeder with larger seeds?**

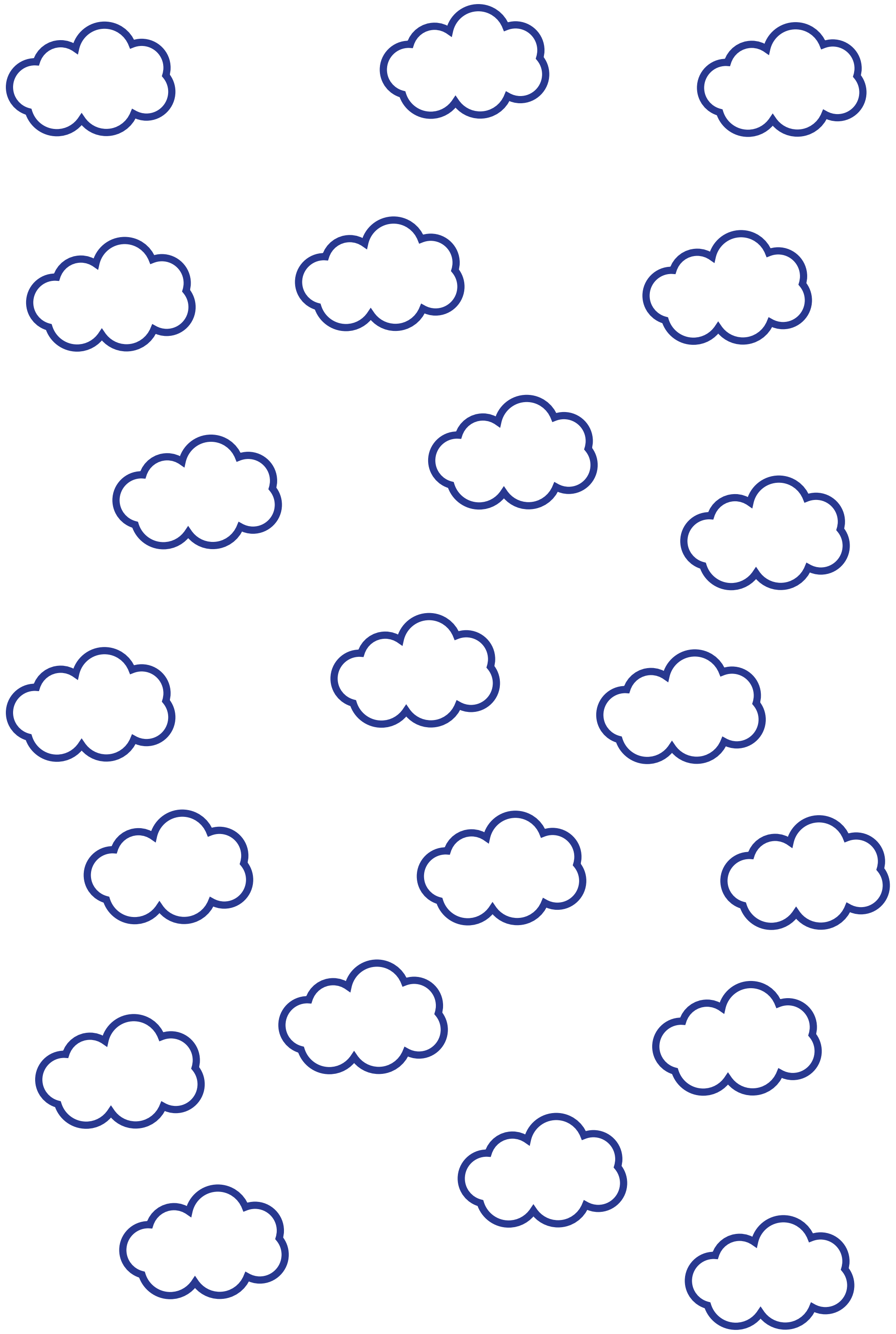
3.2.3.4. QUEST: FOOD WEB MAPPING

Use all the data and observations documented in this chapter to create a visual representation of biological interactions in the form of a mind map.

Place the names of the observed species (plants, animals, algae, protozoa, etc.) within the clouds.

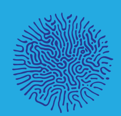
Then draw connecting lines between species that have exhibited interactions, specifying the type of interaction (e.g. predation, mutualism, etc.) along these lines.

This approach will enable you to visually comprehend the diverse range of interactions within the ecosystem.



4

Engineer (Design and Create)



4.1

Closed Systems, Systems Thinking and Design

Imagine being inside a bubble, where everything stays in and nothing comes out – that's a closed system. Closed systems are like little worlds of their own, where all the action happens inside, without any interaction with the outside environment. Within the context of systems thinking and design, closed systems refer to environments in which interactions occur solely within the system's boundaries, without exchanges with the outside. In closed systems, inputs, outputs and processes are contained within the defined system, fostering a self-contained dynamic.

In these systems we need to think about how all the different parts work together, just like the pieces of a puzzle. Systems thinking emphasises an understanding of the interconnectedness and interdependencies within closed systems. Changing one piece can affect everything else, for example – like how adding too much food to a fish tank can make the water murky. So when we design closed systems, we must keep everything steady –maintaining equilibrium while also being ready to adapt when things change – and also maintain system stability (homeostasis). It's like finding the perfect harmony between stability and flexibility so that our little world can keep running smoothly.

Designing closed systems involves careful consideration of feedback loops, emergent behaviours and maintaining equilibrium. Effective design requires balancing stability and adaptability to ensure that the system can function efficiently and evolve over time within its closed environment.

4.2

DIY microcosmos

The easiest way to learn about systems thinking and design is to start small. You can make a fish aquarium your case study example (of a semi-closed system), or you can even go smaller into the world of microbes. Here we give you some interesting and fun examples to play with: a Winogradsky column and microbial fuel cells.

4.2.1 GUIDED TUTORIAL: MAKING A WINOGRADSKY COLUMN

A Winogradsky column is a fascinating and miniature ecosystem encapsulated in a simple glass or plastic cylinder. Named after the Russian microbiologist Sergei Winogradsky, these columns serve as remarkable models of microbial diversity and ecological interaction. By harnessing the power of mud, water and sunlight, Winogradsky columns allow scientists and enthusiasts to observe the intricate relationships between various microorganisms, such as bacteria and algae, as they thrive in different environmental niches within the column. This unique and self-sustaining microcosm offers valuable insights into biogeochemical cycles, nutrient cycling and the intricate web of life at a microscopic level. Winogradsky columns are not only educational tools, but also windows into the complex world of microbial ecology.

Winogradsky columns are versatile tools with several key applications:

- **MICROBIAL ECOLOGY AND DIVERSITY**
  They are used to study how microorganisms interact and thrive in simulated environments, providing insights into microbial ecology and diversity.
- **BIOGEOCHEMICAL RESEARCH**
  They help researchers understand how microorganisms influence biogeochemical cycles, shedding light on nutrient cycling and environmental processes.
- **ENVIRONMENTAL MONITORING**
  They can be used as bioindicators to assess ecosystem health, detect disturbances, and monitor pollution or nutrient imbalances.
- **EDUCATIONAL TOOLS**
  They serve as engaging educational tools, and allow students to observe ecological processes and better grasp microbiology and ecosystem dynamics.
- **BIOREMEDIATION RESEARCH**
  These columns aid in researching bioremediation strategies by studying how specific microorganisms break down contaminants.
- **ARTISTIC AND OUTREACH**
  Their colourful, dynamic ecosystems make Winogradsky columns engaging for artistic displays and public outreach. This raises awareness of the importance of microbial life to the environment.

This experiment will teach you how to make a Winogradsky column at home.

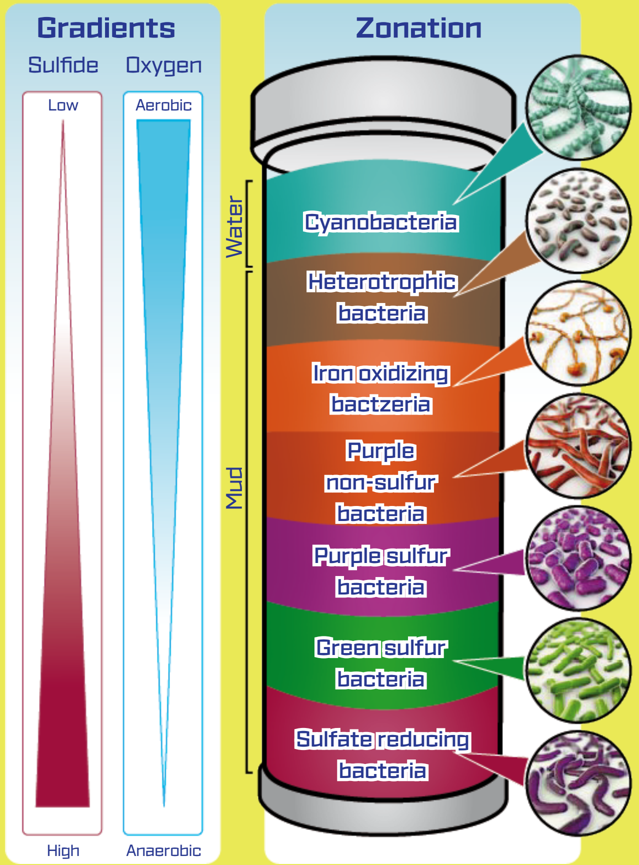


Illustration of a Winogradsky column by HHMI BioInteractive

YOU WILL NEED

- Bucket
- Small shovel
- Soil samples
- Pond water or boiled tap water
- Mud from pond or dirt from garden
- Plastic bottle
- Scissors
- Dried leaves or paper
- Eggs
- Bowl
- Plastic foil
- Scotch tape
- Aluminium foil (optional)

STEP 1

Begin by collecting soil samples from a nearby pond, stream or garden. If you don't have a pond or stream nearby, you can use tap water – but you will need to boil it first to remove chlorine, then let it cool.

STEP 2

Take a plastic bottle and, using scissors or a knife, carefully cut off its top section into three parts. Be careful of any sharp edges.

STEP 3

Separate egg yolks and whites. Crush the eggshells into a fine powder, and cut dried leaves or paper into smaller pieces. Mix half of the collected mud with the egg yolk, eggshells and dried leaves/paper.

STEP 4

In the first third of the bottle, place the mud mixture you have prepared. Add only mud to the second third and only pond/boiled tap water to the final third.

STEP 5

Securely seal the top part of the bottle with plastic foil to create an airtight environment. Place the column in a sunny location for a few months.

STEP 6 (OPTIONAL)

If you choose to take an additional step, create a second column and completely cover it with aluminium foil to block out all light. Position it alongside the first column, and let both columns sit for a couple of months. Remove the aluminium afterwards and notice the differences between the two columns.

After several months, examine the column. Notice the different layers and the colours in each layer.

1. How many different layers are there? What is the colour of the water on top? What colours can you see in each layer?

2. We placed egg yolk, eggshells and leaves in the bottom layer. Why? How do they affect the layers?

3. Why did we place them in the BOTTOM layer?

4. What are the concentrations of oxygen in each layer? How does that influence the microorganisms in each layer?

5. If you have performed Step 6, is there a difference between the two columns? Are all the layers present in both columns?

4.2.2 GUIDED TUTORIAL: MAKING A MICROBIAL FUEL CELL

Microbial fuel cells (MFCs) are an innovative and sustainable technology at the intersection of microbiology and energy generation. These devices harness the metabolic activities of microorganisms to directly convert organic matter into electrical energy. Essentially, MFCs function as living power sources, leveraging the ability of certain microorganisms to transfer electrons produced during organic substrate degradation to an electrode, and generating an electric current in the process. This fascinating blend of microbiology and energy science holds promising applications in wastewater treatment, bioenergy production and environmental remediation, positioning microbial fuel cells as a frontier technology in the quest for cleaner and more efficient energy solutions.

MFCs come in two types: one- and two-chamber. Two-chamber MFCs have a chamber with anaerobic conditions, an anode and bacteria and their food (mud with dry leaves, wastewater, etc.), a membrane that separates this from the other chamber, and a second chamber with a cathode and a lot of oxygen. A one-chamber MFC has everything in one chamber and just keeps anode and cathode as far away from each other as possible so that the anode can have anaerobic conditions and the cathode aerobic conditions.

In this chapter you will learn how to make a very simple DIY one-chamber MFC with the help of microbes found in mud – a so-called 'mud battery'. For electrodes, we will use graphite for anode and aluminium for cathode. Graphite is conductible material that isn't harmful to bacteria, so they can grow and feed on it; this produces electricity that the graphite captures. As a food source, we will add dry leaves or paper made from cellulose that the bacteria can degrade in anaerobic conditions and use to produce electricity. This is why the anode goes on the bottom where there is no oxygen. The cathode goes into the water, where it releases electrons onto oxygen.

YOU WILL NEED

- Bucket
- Small shovel
- Pond water or boiled tap water
- Mud from a pond or dirt from a garden
- Jar or a plastic urine container
- Copper wires
- Paper
- Scissors
- Dried leaves (optional)
- Pliers
- Hot glue gun
- Paper
- Graphite pencil
- Aluminium foil
- Multimeter
- Small LED light (optional)

STEP 1

Take the bucket and a small shovel and go to a nearby pond or a stream. Dig up some mud and take some of the water with you. If you don't have a pond or a stream nearby, you can use normal dirt from a garden or a park and add tap water. If you are using tap water, be sure to boil it first to remove any chlorine that might harm the microorganisms, then let it cool. While you are outside, try to collect some dry leaves if there are any. If not, you can use paper instead.

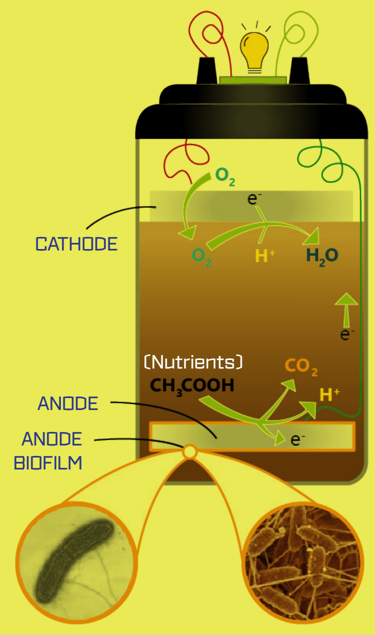


Diagram of soil based MFC (by MFCGuy2010 CC BY-SA 3.0) https://creativecommons.org/licenses/by-sa/3.0/

STEP 2
Prepare the wires by cutting them into shorter pieces. You need two per MFC. Strip them at both ends.

STEP 3
Take the container you have chosen (we recommend glass jars or plastic urine containers as they are the easiest to get hold of and use) and puncture a hole in the lid big enough for the two wires to go through.

STEP 4
Draw a circle on paper with a graphite pencil the size of the bottom of your container. Fill in the circle with graphite pencil so that it is as dark as it can be. Cut out the circle. This will be the first electrode on which the bacteria will grow and produce electricity.

STEP 5
Glue one stripped end of the wire with a hot glue gun to the circle you have just filled in. Be careful not to burn yourself during the glueing process, and try to not get glue between the wire and paper (as this will isolate it, preventing electricity from being conducted).

STEP 6
Put the electrode on the bottom of the container and then place enough mud/dirt on the electrode to cover it. Then shred a bit of paper or add crushed dry leaves if you have any. Add more mud/dirt on top of that until you fill the container to half the volume. While you are adding the mud, try to compress it as much as you can so that no air becomes trapped.

STEP 7
Pour pond or boiled (and cooled) tap water into the container until it is completely full. Take the second wire and completely cover one stripped side with aluminium foil. Submerge it in the water and try to have it not touching the mud. This will be our second electrode.

STEP 8
Push both wires through the hole you made in the lid and close it. Let it sit for about ten minutes, then use the multimeter to check the voltage the MFC is producing. If you have a small LED light (5V), you can try to connect it and see if it produces any light.

1. **How much voltage is it producing? Was it enough to power an LED light?**

2. **Try to make several MFCs and connect them serially. Is there a difference in the voltage produced? How many would you need to make and connect to be able to charge your phone?**

3. **Try to think of a way to increase the production of electricity. Try changing the size of the electrodes, the soil composition and volume, the electrode material, etc. Write down what you have tried and learned.**

4. **Why did we use the aluminium foil for the second electrode if we know that it is harmful to bacteria?**

5. **Leave the MFC for some time and then measure the voltage. Is there a difference in the electricity produced? If so, when did it start to happen? Did the voltage increase or decrease?**

Innovate

Dear Reader, we have come to the last chapter of this open book. We hope it served at least a little of its intended purpose: to spark a desire in you to explore the amazing world around you and, driven by inspiration, to create new things.

To finish up, we invite you to design a future research/engineering project of your own.

We are sure many ideas came to your mind as you were exploring this book. We would like you to use the knowledge and experience you have gained, and to approach your future endeavours systematically.

We have created a short guided questionnaire to help you plan to make your idea come to life.

But most of all: **Have fun!**

5.1 Design your STEAM project

Guided questionnaire on developing personal ideas into TO DO project framework

PROJECT FORM

1. TYPE OF PROJECT (Mark and fill in.)

1.1.

⊕ **Scientific**
⊕ **Artistic-scientific**

1.2.

⊕ **Educational**
⊕ **Research**
⊕ **Development**
⊕ **Public event**

1.3. In connection with which scientific and/or artistic fields is the project associated?

2. PROJECT NAME

3. PROJECT GOAL

4. SUSTAINABILITY OF THE PROJECT (What doors does the project open?)

4.1. Does the project contribute to the development of science, art, and community?

4.2. Can the project be further developed? Upgraded? If yes, how?

4.3. What new projects could arise from it?

5. BRIEF DESCRIPTION OF THE PROJECT
(State all essential details. Minimum of 10 sentences.)

6. SPECIFIC GOALS

7. DELIVERABLES (What are the visible/tangible products of the project's developmental process?)

8. ACTIVITIES INCLUDED IN THE PROJECT (List and explain all activities the project encompasses.)

9. PROJECT EXECUTORS (List all executors of the project, their functions, and responsibilities.)

10. ESTIMATED DURATION OF PROJECT ACTIVITIES
(State the total duration of the project, approximate or exact start and end date, and each phase of the project.)

Total estimation:
1st phase: 2nd phase:
3rd phase: 4th phase:

11. DOCUMENTATION
(How will the project and its development be documented?)

12. REQUIRED RESOURCES
(For all materials and equipment, if rented, list the price.)

12.1. Equipment

12.2. Services (Such as printing, telecommunications, rentals, certifications, etc.)

12.3. Material

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