Research and inspirations

Flowcharts:

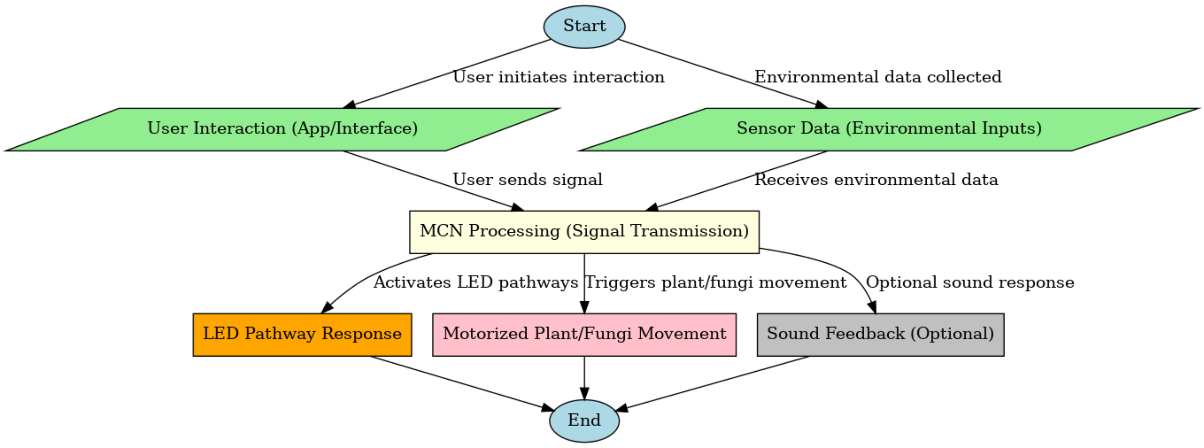


Diagram 1: Full Process Flow (Start to End)
This flowchart represents the complete life cycle of a user or environmental interaction within the system:

- Start: Marks the initiation points of interaction—either manually by a user or automatically through environmental changes.
- User Interaction (App/Interface) & Sensor Data (Environmental Inputs): Inputs can be sourced from digital or physical interfaces, aligning with the project's aim to support modular and multi-source signal inputs.
- MCN Processing (Signal Transmission): This node mimics the centralized signal processing hub, inspired by the mycelium communication network. It interprets both user signals and sensor data.
- Output Responses:
  - LED Pathway Response: Represents visual output, illuminating the flow of information like synaptic or fungal pathways.
  - Motorized Plant Movement: Provides a physical, bio-inspired response, simulating organic behaviour.
  - Sound Feedback (Optional): Enhances the multisensory aspect of the system, enriching the immersive experience.
- End: Denotes the completion of one cycle of communication and prepares the system for the next interaction.

This diagram encapsulates the system’s biomimetic feedback loop, showcasing how technological elements are structured to reflect natural processes.

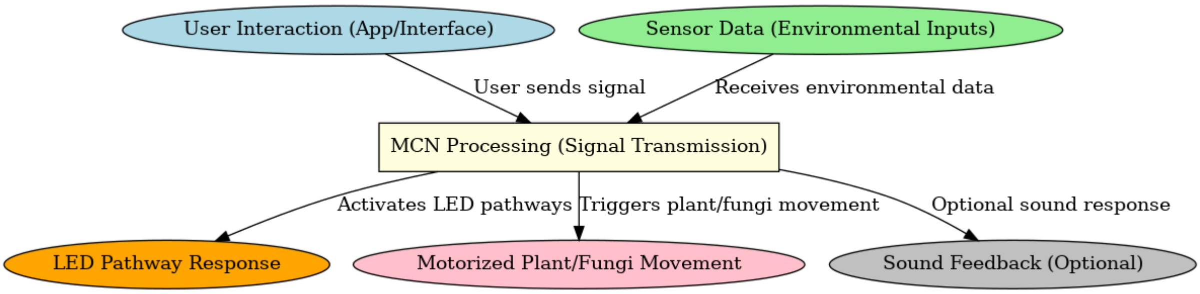


Diagram 2: Core Signal Network (Nonlinear Representation)

This second diagram strips away the linear start-to-end logic to showcase the modular, decentralized nature of the system:

- MCN Processing remains at the core, receiving simultaneous input from both User Interaction and Sensor Data.
- The simultaneous branching of outputs (LEDs, movement, sound) reflects how the system can react in a fluid, organism-like manner—parallel processing akin to fungal networks.
- The elliptical node shapes and radial layout reinforce the idea of organic, non-hierarchical data flow, inspired by decentralized computing models and biological information systems.

These flow charts in turn streamline the project purpose through:
Biomimicry: Structure and function are modelled after mycelium networks and are aligned to be distributed, adaptive, and responsive.

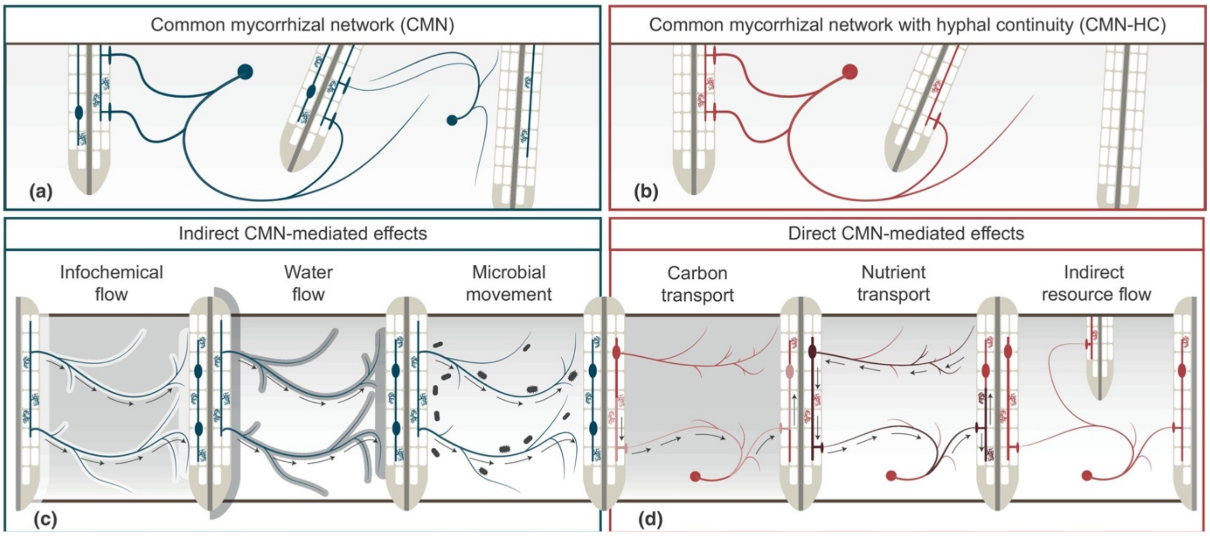
Modular Technology: Each component (input, processing, output) is separable yet interconnected.

Human-Computer-Bio Interaction: Merges digital input with biological-style output, paving the way for biohybrid interaction.

Multisensory Immersion: Visual (LED), kinetic (movement), and auditory (sound) channels enhance user experience.

Educational and Artistic Engagement: By revealing the “invisible” processes of root and fungal systems, the diagrams support the installation's goal to make ecological intelligence tangible and participatory.

Sensor Research:



'FUNCTIONAL DIFFERENCES BETWEEN HYPHAL CYTOPLASMIC CONTINUITY AND NON-CONTINUITY— DIRECT AND INDIRECT CMN-MEDIATED EFFECTS'[1]

As seen in the diagram above, there are six types of activity occurring through the common mycorrhizal network. However, we cannot represent all of these in an interactive installation, for example, there currently aren't Info chemical sensors on the market that are compatible with an Arduino. Therefore, we will be considering other factors which affect the behaviour of the plants, which we can represent through robotic movements to create visual interest. Therefore, we will also be considering other aspects that affect the appearance of the plants to create visual interest in our installation. Another factor that we need to take into consideration is how the resources interact with each other. They aren't independent, for example, when air flow increases, the water levels decrease. This makes it necessary to research each resource and all the impact it has on the environment around it, whether that resource has been depleted or is in excess.

Resource	Sound
Sensor	Microphone Sound Sensor Module
How does it relate to the Common Mycorrhizal Networks	Unfortunately, there is no direct correlation between sound and CMN. The only relation is that the benefits of the sound on the plant will increase the effectiveness of the CMN. There is a symbiotic relationship occurring between the CMN and the plants, for example the fungi's 'feed off carbohydrates photosynthesised by

[1] Rillig, M.C. et al. (2024) "Clarifying the definition of common mycorrhizal networks," Functional ecology [Preprint]. Available at: https://doi.org/10.1111/1365-2435.14545.

	their partners'[2] whilst aiding in the absorption of resources for the plant. Such as water and nutrients.[3]	
How does this resource impact the plant and its local environment.	Scientific studies have confirmed that 'Sound stimuli can influence germination rates and increase plant growth and development', 'improve plant immunity against pathogens and can also increase their tolerance to drought', and 'increases the absorption efficiency of the light energy'.[4] Therefore the plants growth rate will be increased, and other problems such as pests, diseases and Mold have reduced from 'greenhouse conditions with sound treatment'.[5] Allowing the plant to focus its energy on growing rather than dealing with rather than fighting with It promotes growth	
Visible observations	Lack of Sound	Excess Sound
		- Death - Damadged Plant Tissue

Resource	Air Flow
Sensor	Metal Pitot Tube, Acrylic 2.5mm ID Tubing, XGMP3v3 Differential Pressure Sensor[6]
How does it relate to the Common Mycorrhizal Networks	Whist the Air Flow doesn't directly impact the CMN, it stills influences the soil, which is where the processes occurring in the MCN are based. Where there is more air in the soil, it benefits the soil structure, soil biology and soil chemistry. This makes it easier for the plants to absorb the nutrients, water and oxygen.[7] It allows

[2] (No date e) Kew.org. Available at: https://www.kew.org/sites/default/files/2023-10/State%20of%20the%20World%27s%20Plants%20and%20Fungi%202023.pdf#:~:text=Without%20such%20knowledge%2C%20limited%20conservation%20resources%20may,low%20priority%20populations%20of%20a%20widespread%20species.&text=Mutualistic%20fungi%20improve%20the%20uptake%20of%20essential,mineral%20nutrients%2C%20such%20as%20nitrogen%20and%20phosphorus). (Accessed: May 8, 2025).

[3] Symbiosis (2014) Trees for Life. Available at: https://treesforlife.org.uk/into-the-forest/habitats-and-ecology/ecology/symbiosis/ (Accessed: May 8, 2025).

[4] Frongia, F., Forti, L. and Arru, L. (2020) "Sound perception and its effects in plants and algae," Plant signaling & behavior, 15(12), p. 1828674. Available at: https://doi.org/10.1080/15592324.2020.1828674 (Accessed: May 9, 2025)

[5] Hassanien, R.H.E. et al. (2014) "Advances in effects of sound waves on plants," Journal of integrative agriculture, 13(2), pp. 335–348. Available at: https://doi.org/10.1016/s2095-3119(13)60492-x (Accessed: May 8, 2025).

[6] Pitot tube airspeed sensor for arduino and raspberry pi — (no date) Maker Portal. Available at: https://makersportal.com/shop/pitot-tube-airspeed-sensor-for-arduino-and-raspberry-pi (Accessed: May 8, 2025).

[7] Why you should aerate (no date) AerWorx. Available at: https://www.aerworx.co.uk/why-you-should-aerate (Accessed: May 9, 2025).

	the transports of sugars from the plants to the MCN[8] to occur more effectively, improving their growth and ability to perform the necessary processes.	
How does this resource impact the plant and its local environment.	When there are high amounts of air movement, it has a drying effect on the plants.[9] Therefore they require more water at shorter intervals. Without any air movement occurring the leaves become 'saturated with water vapour'[10]. This increases the risk of pathogen attacks as a warm and moist environment is the perfect place for bacteria to grow.[11] Overall this weakens the plant and can make it more susceptible to catching diseases which increases the likelihood of it spreading to the neighbouring plants[12].	
Visible observations	Lack of Air Flow[13]	Excess Air Flow
	- Mildew and mould growth. - Leaves curling in. - Discolouration or yellowing of the leaves. - Limited growth.	- Dried out, becoming shrivelled and brittle. - Change in colour, going from vibrant to dull.[14]

Resource	Moisture
Sensor	**DHT11** or **DHT22** humidity sensor
How does it relate to the Common Mycorrhizal Networks	Water flows through the MCN, therefore if the amount of water in a plant has decreased, it will then increase the amount it takes from the flow, reducing the amount that the other plants will be able to receive.

[8] (No date f) Sciencedirect.com. Available at: https://www.sciencedirect.com/science/article/pii/S0065229616300878 (Accessed: May 9, 2025).
[9] Air movement - American orchid society (no date) Aos.org. Available at: https://www.aos.org/orchid-care/air-movement (Accessed: May 8, 2025).
[10] CANNA Research (no date) How air temperature affects plants, Canna-uk.com. Available at: https://www.canna-uk.com/articles/how-air-temperature-affects-plants (Accessed: May 5, 2025).
[11] Florida Department of Agriculture and Consumer Services (no date) Florida Department of Agriculture & consumer services, Fdacs.gov. Available at: https://www.fdacs.gov/Consumer-Resources/Health-and-Safety/Food-Safety-FAQ/What-conditions-encourage-bacteria-to-grow (Accessed: May 8, 2025).
[12] Ampt, E.A. et al. (2022) "Plant neighbours can make or break the disease transmission chain of a fungal root pathogen," The new phytologist, 233(3), pp. 1303–1316. Available at: https://doi.org/10.1111/nph.17866. (Accessed: May 8, 2025).
[13] Santos, D. (2023) "Does my plant have enough air circulation?," Growace, 8 December. Available at: https://growace.com/blogs/learning-center/does-my-plant-have-enough-air-circulation?srsltid=AfmBOoqGLgXTW7PB9hcZyNbFn6JW44IOW0JjepFvoEYoUV_IOSaRfTvG (Accessed: May 8, 2025).
[14] Frank, R.B. (2024) Understanding the colour shifts of dried floral creations, Bouquet & Frame. Available at: https://bouquetandframe.com/blog/understanding-the-colour-shifts-of-dried-floral-creations (Accessed: May 8, 2025).

How does this resource impact the plant and its local environment.	Water makes up 80-95% of plants weight[15] and is necessary for transporting nutrients and maintaining turgor pressure[16], this is what helps the plant stand up without drooping. With reduced amounts of water, the processes of respiration, transpiration and photosynthesis are decreased.[17] Water aids in maintaining the temperature of plants and acts as a buffer.[18]	
Visible Observations	Lack of Water[19]	Excess Water[20]
	- Wilting - Yellow Leaves - Brown & Crispy leaves - Leaf Drop	- Roots become brittle and damaged - Root rot - Leaf Mold

Resource	Light
Sensor	Grove Light Sensor
How does it relate to the Common Mycorrhizal Networks	Depending on the type of light, different activity was promoted. For example, with Red Green LEDs, 'mycorrhizal development and nitrogen metabolism' increased improving the connections between the MCN and the plants. Whereas white increased the soil enzyme activities[21] which is very beneficial for nutrient cycling; the process where organic matter is converted into nutrients the plants can process. [22]
How does this resource impact the plant and its	Light is used to regulate many of the physiological processes within plants. It is the main source of energy which is gained through the process of photosynthesis.[23] Therefore when the light decreases, so does photosynthesis. It is also a factor in 'germination, leaf

[15] Water is Essential for Food Production (2025) Student Materials. Available at: https://serc.carleton.edu/integrate/teaching_materials/food_supply/student_materials/1090 (Accessed: May 5, 2025).

[16] Water Deficiency in plants (no date) Myplantin.com. Available at: https://myplantin.com/diseases/water-deficiency-in-plants (Accessed: May 5, 2025).

[17] Effect of water scarcity on plants (2020) Airowater.com. Atmospheric water Generator. Available at: https://www.airowater.com/blog/effect-of-water-scarcity-on-plants/ (Accessed: May 5, 2025).

[18] (No date i) Researchgate.net. Available at: https://www.researchgate.net/profile/Amit-Kumar-509/publication/339715902_The_Importance_of_Water_in_Relation_to_Plant_Growth/links/63823cb6c2cb154d292d1e2c/The-Importance-of-Water-in-Relation-to-Plant-Growth.pdf (Accessed: May 5, 2025).

[19] Bce, A.R.N. (2024) Reading the leaves: Signs of overwatering and underwatering & how to know the difference, Rockledge Gardens. Available at: https://rockledgegardens.com/reading-the-leaves-signs-of-overwatering-and-underwatering-how-to-know-the-difference/ (Accessed: May 5, 2025).

[20] "Plants and water—A brief look at how water affects plant growth" (2022) Swan Hose, 24 March. Available at: https://swanhose.com/blogs/general-watering/how-does-water-its-amount-its-quality-affect-plant-growth (Accessed: May 5, 2025).

[21] Hristozkova, M. et al. (2017) "Led spectral composition effects on mycorrhizal symbiosis formation with tomato plants," Applied soil ecology: a section of Agriculture, Ecosystems & Environment, 120, pp. 189–196. Available at: https://doi.org/10.1016/j.apsoil.2017.08.010. (Accessed: 6th May 2025)

[22] Daunoras, J., Kačergius, A. and Gudiukaitė, R. (2024) "Role of soil Microbiota enzymes in soil health and activity changes depending on climate change and the type of soil ecosystem," Biology, 13(2), p. 85. Available at: https://doi.org/10.3390/biology13020085. (Accessed: 9th May 2025)

[23] Wu, W. et al. (2024) "The role of light in regulating plant growth, development and sugar metabolism: a review," Frontiers in plant science, 15, p. 1507628. Available at: https://doi.org/10.3389/fpls.2024.1507628. (Accessed: 6th May 2025)

local environment.	proliferation and expansion', so without it the growth is slowed and stunted.	
Visible Observations	Lack of Light[24]	Excess Light
	- Dropped Leaves - Longer & thinner stems. - Turn from green to yellow to white. - Fail to produce flower buds.	- Scorched & Bleached leaves - Brittle[25]

Resource	Nutrients	
Sensor	ZE08CH20 Electrochemical Sensor	
How does it relate to the Common Mycorrhizal Networks	In Common Mycorrhizal Networks (CMNs), nutrients such as nitrogen, phosphorus, and potassium are exchanged between plant roots via fungal hyphae. This symbiosis enables nutrient sharing, especially when one plant is in deficiency and another has excess.[26] The ZE08-CH2O sensor, while designed for formaldehyde detection, can be adapted in this context to simulate changes in chemical stress or environmental imbalance—representing a form of nutrient deficiency. In our project, this triggers an artificial signal across the network, redistributing "resources" to mimic nutrient flow through a mycorrhizal system.[27]	
How does this resource impact the plant and its local environment.	Nutrients play essential roles in plant function: Nitrogen supports chlorophyll production and vegetative growth.[28] Phosphorus aids in energy transfer (ATP) and root development. Potassium contributes to enzyme activation and water regulation. Deficiencies reduce photosynthesis, delay growth, and increase disease susceptibility. CMNs can help buffer these effects by reallocating nutrients across connected plants, promoting ecosystem stability.[29]	
Visible observations	Nutrient Deficiency	Nutrient Excess (Toxicity)[30]
	- Chlorosis (yellowing of leaves) – typically from nitrogen or iron deficiency - Stunted growth or small leaves	- Leaf tip burn or necrosis - White crust or salt buildup on soil - Leaf deformation or cupping

24 Lighting for indoor plants and starting seeds (no date) Umn.edu. Available at: https://extension.umn.edu/planting-and-growing-guides/lighting-indoor-plants (Accessed: May 5, 2025).
25 Excess light on indoor plants (no date) Umd.edu. Available at: https://extension.umd.edu/resource/excess-light-indoor-plants/ (Accessed: May 5, 2025).
26 Simard, S. W., Perry, D. A., Jones, M. D., Myrold, D. D., Durall, D. M., & Molina, R. (1997). Net transfer of carbon between tree species with shared ectomycorrhizal fungi. Nature, 388(6642), 579–582.
27 Karst, J., Jones, M. D., & Hoeksema, J. D. (2023). Positive citation bias and overinterpreted results lead to misinformation on common mycorrhizal networks in forests. Nature Ecology & Evolution, 7, 1–10.
28 Marschner, P. (2012). Marschner's Mineral Nutrition of Higher Plants (3rd ed.). Academic Press.
29 van der Heijden, M. G. A., Martin, F. M., Selosse, M. A., & Sanders, I. R. (2015). Mycorrhizal ecology and evolution: the past, the present, and the future. New Phytologist, 205(4), 1406–1423.
30 Marschner, P. (2012). Marschner's Mineral Nutrition of Higher Plants (3rd ed.). Academic Press.

	- Purple or reddish tint (common with phosphorus deficiency) - Leaf edge browning or curling (potassium deficiency) - Poor root development or reduced flowering	- Impaired water/nutrient uptake due to pH imbalance - General stress symptoms despite nutrient availability

Resource	Temperature	
Sensor	**DHT11** sensor	
How does it relate to the Common Mycorrhizal Networks	'Both mycorrhizal colonization levels and length of extraradical hyphae (ERH)'[31] increased as the temperatures got warmer. Additionally, every time the temperature drops by 10 degrees, the mycelium's ability to do chemical processes halves.[32] This affects how effective the communication between the plants is, it is necessary that the temperature remains optimum.	
How does this resource impact the plant and its local environment.	Whilst the temperature from day to night fluctuates, it is recommended that it only decrease by 10 to 15°C. Any extreme temperature change can lead to stress which can hinder the plants growth.[33] This increases their risk of disease. Warmer temperatures lead to more photosynthesis and respiration.[34] Additionally warmer soil temperature boosts the amount of water and nutrients absorbed.[35]	
Visible observations	Excessive Low Temperature[36]	Excessive High Temperature
	- Wilting - Red or purple discoloration - Plant turns mushy / black - Death of leaves, stems, or entire plants	- The leaves change angles and roll in on themselves.[37] - Wilting - Discolouration - Scorching

[31] Bunn, R., Lekberg, Y. and Zabinski, C. (2009) "Arbuscular mycorrhizal fungi ameliorate temperature stress in thermophilic plants," Ecology, 90(5), pp. 1378–1388. Available at: https://doi.org/10.1890/07-2080.1.
[32] "What mushrooms do in the winter" (2021) National Trust for Scotland, 16 December. Available at: https://www.nts.org.uk/stories/what-mushrooms-do-in-the-winter (Accessed: May 5, 2025).
[33] (No date g) Tamu.edu. Available at: https://aggie-horticulture.tamu.edu/ornamental/a-reference-guide-to-plant-care-handling-and-merchandising/light-temperature-and-humidity/#:~:text=Excessively%20low%20or%20high%20temperatures,plant%20growth%20than%20high%20temperatures. (Accessed: May 5, 2025).
[34] CANNA Research (no date) How air temperature affects plants, Canna-uk.com. Available at: https://www.canna-uk.com/articles/how-air-temperature-affects-plants (Accessed: May 5, 2025).
[35] Cherlinka, V. (2023) "Soil temperature for optimal crop growth and development," EOS Data Analytics, 30 January. Available at: https://eos.com/blog/soil-temperature/ (Accessed: May 5, 2025).
[36] (No date h) Jacksonandperkins.com. Available at: https://www.jacksonandperkins.com/signs-your-plant-is-too-cold/a/signs-your-plant-is-too-cold/ (Accessed: May 5, 2025).
[37] Weber, H. (2023) Plant responses to heat stress, CID Bio-Science. Available at: https://cid-inc.com/blog/plant-responses-to-heat-stress/ (Accessed: May 5, 2025).

		- Leaf and branch burn[38]

<table>
<tr><td>Resource</td><td colspan="3">Motion (Flower Space, Root Migration, and Pollen Migration)</td></tr>
<tr><td>Sensor</td><td colspan="3">Motion Sensors (e.g., infrared or ultrasonic sensors)</td></tr>
<tr><td>How does it relate to the Common Mycorrhizal Networks</td><td colspan="3">In the natural world, the movement of plant roots within the soil or the spread of pollen in the air can be viewed as part of an ecological communication network, much like the nutrient and water exchanges that occur in CMNs. The mycorrhizal network connects plants through their roots, allowing them to share nutrients and chemical signals, which could trigger physical movement or migration of roots toward areas of resource abundance.[39] Similarly, pollen migration, often influenced by wind, insects, or animal vectors, can also represent a form of ecological ‘networking’ by facilitating gene flow and maintaining plant biodiversity. In our installation, motion sensors will track the movement of robotic flowers or root systems to simulate migration patterns, reflecting real-life plant behaviour such as phototropism (movement towards light) or gravitropism (root movement due to gravity).</td></tr>
<tr><td>How does this resource impact the plant and its local environment.</td><td colspan="3">Motion in plants—whether through root migration or flower/pollen movement—plays a significant role in plant survival and reproduction. Root migration helps plants find resources (water, nutrients) and optimize their growth.[40] Similarly, flower movement and pollen dispersal are critical for pollination and genetic diversity. The migration of pollen increases a plant’s chances of reproducing successfully by reaching suitable mates. Motion-driven changes, like the expansion of root systems into new territories or flowers opening in response to light, can impact local ecosystems by shifting nutrient and pollen distribution across the environment. In our project, robotic flowers and roots simulate these real-world motions, allowing users to visualize plant communication and growth dynamics as the "network" shifts and adapts over time.</td></tr>
<tr><td rowspan="2">Visible observations</td><td>Root Migration</td><td>Flower and Pollen Migration</td><td>Potential Problems with Motion</td></tr>
<tr><td>Roots growing towards moist or nutrient-rich areas (hydrotropism and chemotropism)
Expansion of root network in search of resources</td><td>Flowers shifting toward light (phototropism)
Flowers opening/closing in response to time of day or light changes
Simulated pollen spreading or</td><td>Overcrowding of roots in confined space, limiting space for growth
Flower wilting if the environment is unsuitable for pollen transfer (e.g., lack of pollinators or</td></tr>
</table>

[38] What every gardener should know about heat stress (no date) envii. Available at: https://envii.co.uk/blogs/news/what-every-gardener-should-know-about-heat-stress (Accessed: May 5, 2025)

[39] Simard, S. W., Perry, D. A., Jones, M. D., Myrold, D. D., Durall, D. M., & Molina, R. (1997). Net transfer of carbon between tree species with shared ectomycorrhizal fungi. Nature, 388(6642), 579–582.

[40] Marschner, P. (2012). Marschner’s Mineral Nutrition of Higher Plants (3rd ed.). Academic Press.

	Subtle physical movements of roots over time to new positions	"drifting" through sensors, visually representing cross-pollination and reproductive efforts	improper light conditions) Disrupted root or pollen movement due to environmental stressors (e.g., drought, extreme temperatures)

Light Sensor Experiment:

Components

- Raspberry Pi 4 Model B[41]
- 8 – Channel 12 bit ADC for raspberry Pi (STM32F030)
- Grove Base Shield
- Grove light sensor v1.3
- Grove 4-pin Cable
- USB 2.0 cable (USB Type-A to USB Type-B)
- HDMI Cable
- Monitor
- Keyboard
- Mouse
- USB-C Power Supply

Working Principle of the Grove Light Sensor

The Grove Light Sensor operates using a photoresistor (light-dependent resistor, or LDR), which changes its resistance based on the amount of light it receives. When the ambient light is strong, the resistance decreases; when the light is dim or absent, the resistance increases.

This variable resistance is part of a voltage divider circuit, allowing the sensor to output an analog voltage that corresponds to the light intensity. This analog voltage can then be read by a microcontroller (such as Arduino) using an analog-to-digital converter (ADC), and translated into a numerical value that represents the brightness of the environment. The higher the value, the brighter the light detected by the sensor (Seeed Studio, n.d.)[42].

Assembly Guide

1. Attach the 'Grove Base Shield' onto the Arduino Uno by aligning the pins together.

[41] The ultimate Raspberry Pi & maker store (no date) The Pi Hut. Available at: https://thepihut.com (Accessed: May 14, 2025).

[42] Grove - light sensor (no date) Seeedstudio.com. Available at: https://wiki.seeedstudio.com/Grove-Light_Sensor/ (Accessed: May 14, 2025)

2. Connect the 'Grove 4-pin Cable' to the 'Grove light sensor v1.3', then plug it into the A0 connector on the 'Grove Base Shield'.
3. Plug the Type B end of the USB cable into the Arduino and the Type A end into the Raspberry Pi.
4. Connect the USB-C Power supply to the Raspberry Pi.
5. Connect the HDMI cable to the Monitor and the Raspberry Pi.
6. Connect the Keyboard and mouse to the Raspberry Pi through the USB Ports.

Software

Operating System: Raspberry Pi OS
Libraries:

- Python3
- Pip3
- PySerial

Initial configuration:
Once in the Raspberry Pi Interface, open the terminal and type in the following commands sequentially.

1. sudo apt update
2. sudo apt install python3
3. sudo apt install python3-pip
4. pip3 install pyserial
5. python3 -m serial.tools.list_ports
6. Sudo raspi-config
    a. Select Interface
    b. Select Serial
    c. Disable login shell
    d. Enable hardware serial port
7. sudo reboot

Code Base

Final Code:

```
void setup(){
pinMode(A0, 0);
Serial.begin(9600);
}
void loop(){
Serial.println("Light value:");
Serial.println(analogRead(A0));
delay(1000);
}
```

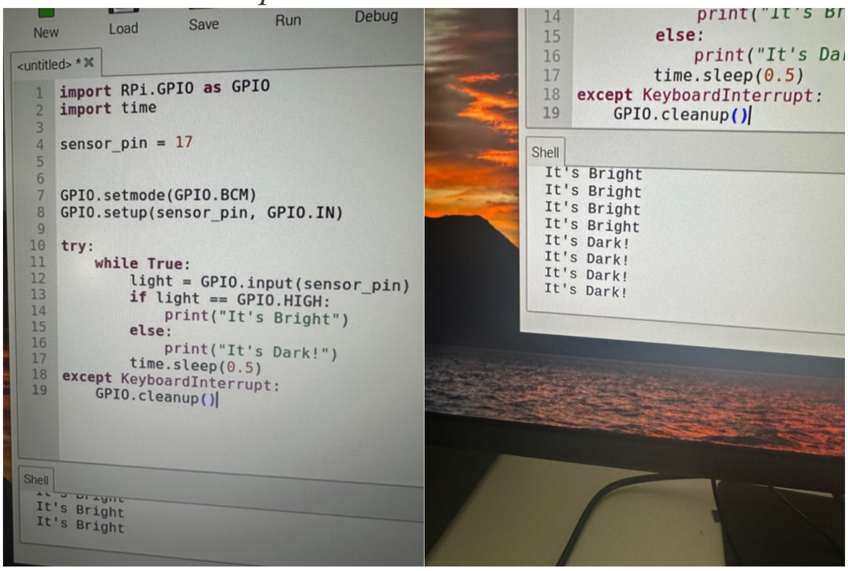
Data logging:

- Data can be stored in Jupyter Notebook[43], exportable as .TXT Files.

Calibration procedures:

- Changed from only using Raspberry Pi to using both Arduino and Raspberry Pi to get the output from the sensor to change from written to numerical.

Prototype 1 – Written Output



In our initial attempt, we connected the Grove light sensor directly to the Raspberry Pi and conducted a basic test on the computer. However, we quickly realized that the light sensor provides analog output, which the Raspberry Pi cannot read directly since it lacks built-in analog input.

As a workaround during our first test, we treated the sensor's signal as a digital input. If the sensor detected any light, the program would print "It's Bright!", and if no light was detected, it would print "It's Dark!". This simple binary logic allowed us to test the interaction, even though it didn't provide accurate light intensity values.

To obtain more accurate data from the light sensor, we decided to use an analog-to-digital converter (ADC). Since the Raspberry Pi does not have native support for analog inputs, integrating an external ADC allowed us to convert the analog voltage output of the Grove light sensor into digital values that the Raspberry Pi could process. This approach enabled us to measure light intensity on a scale, rather than relying on a simple binary interpretation.

Code

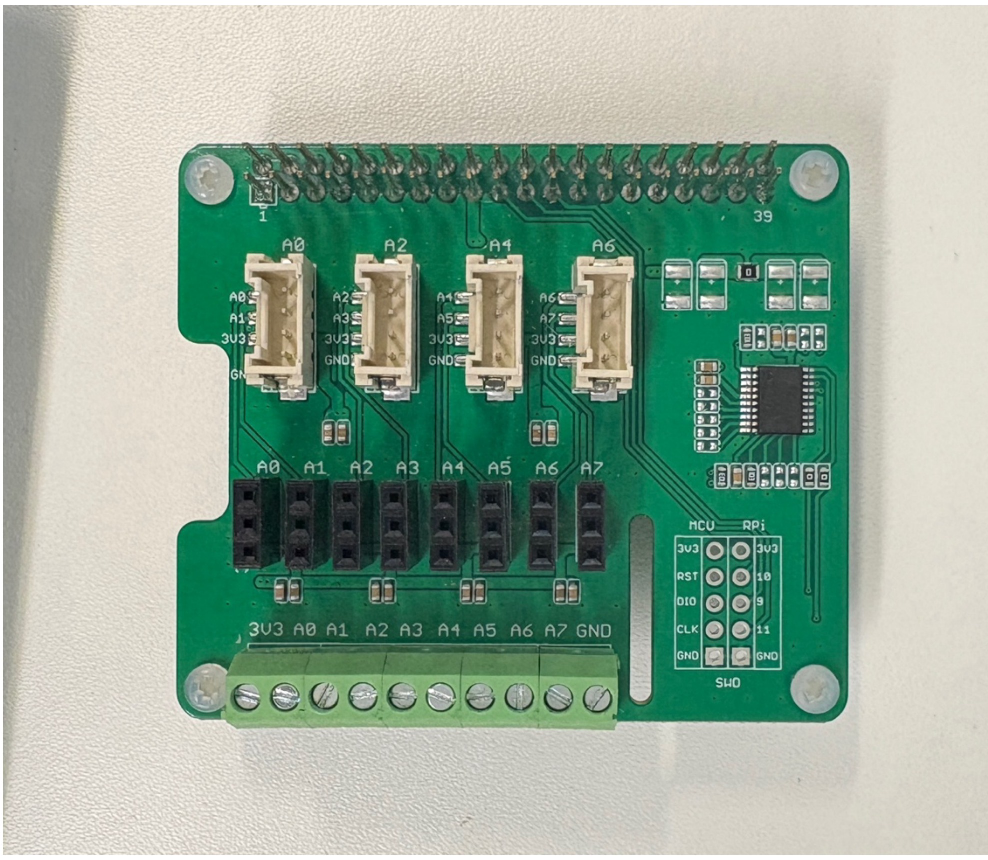
import RPi.GPIO as GPIO
import time
sensor_pin = 17
GPIO.setmode(GPIO.BCM)
GPIO.setup(sensor_pin, GPIO.IN)

[43] Project jupyter (no date) Jupyter.org. Available at: https://jupyter.org (Accessed: May 14, 2025).

```
try:
    while True:
        light = GPIO.input(sensor_pin)
        if light == GPIO.HIGH:
            print("It's bright")
        else:
            print("It's dark")
        time.sleep(0.5)
except KeyboardInterrupt:
    GPIO.cleanup()
```

Prototype 2 – Numerical Output

Since we needed to convert analog data into digital format, we initially used the 8-Channel 12-bit ADC for Raspberry Pi (STM32F030) to handle the conversion. However, as it was our first time working with this module, we encountered several issues. Despite having the correct wiring and Python code, we received no output when running our script.



We tested the serial connection using the terminal and confirmed that we were connected to the correct port, yet nothing was printed. After further research, we discovered that the module is not a plug-and-play ADC like the MCP3008. Instead, it is based on an STM32 microcontroller and must be pre-programmed with firmware in order to read analog input and send data over UART （Universal Asynchronous Receiver/Transmitter）[44].

Without flashing code to the STM32F030, the ADC module remains inactive and will not function as expected. This was a crucial insight that helped us better understand the module's architecture and limitations (STMicroelectronics, n.d.)[45].

Code

```
import serial
 ser = serial.Serial('/dev/ttyS0', 9600, timeout=1)
 try:
  while True:
    line = ser.readline().decode('utf-8').strip()
    if line:
      print("Received:", line)
except KeyboardInterrupt:
  ser.close()
```

Prototype 3 - Connecting Arduino with Raspberry Pi

Due to the complexity of working directly with the STM32F030, which far exceeded our current technical knowledge, we then decided to pursue an alternative solution. We connected an Arduino board to the Raspberry Pi and used the Grove Base Shield (designed specifically for Arduino) to handle the analog-to-digital conversion.

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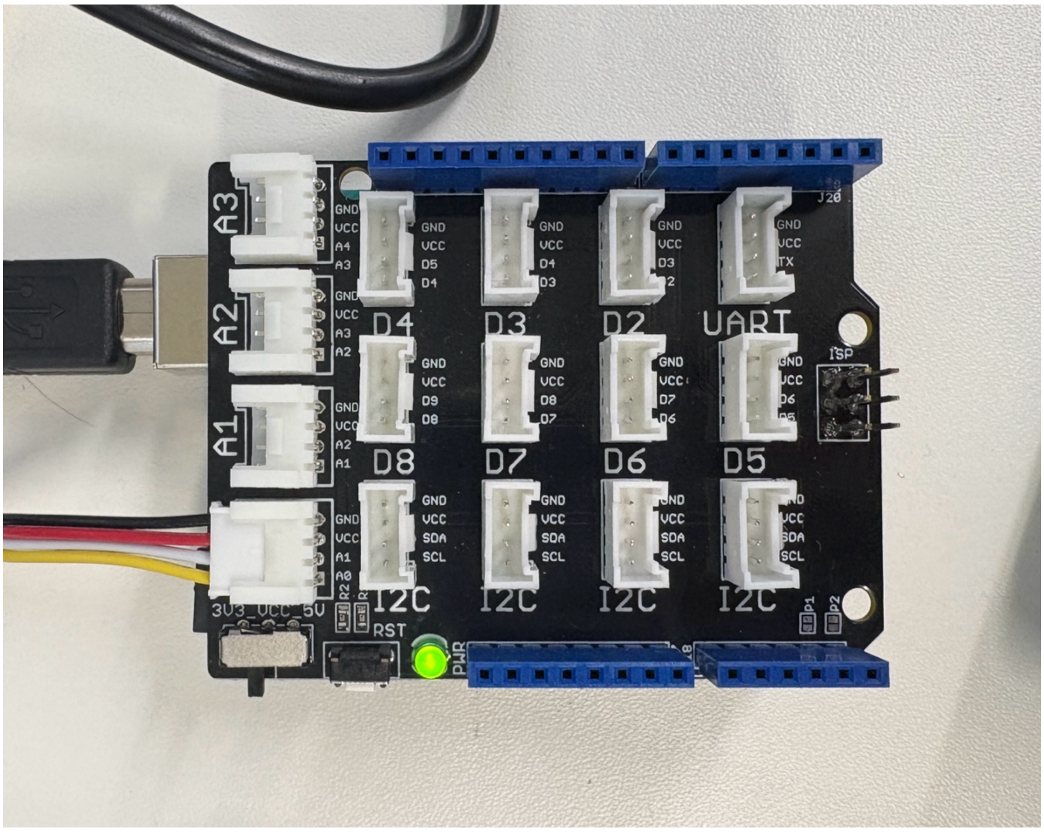
[44] Seeed Studio. (n.d.). *8-Channel 12-Bit ADC for Raspberry Pi (STM32F030)*. Available at: https://wiki.seeedstudio.com/8-Channel_12-Bit_ADC_for_Raspberry_Pi-STM32F030/ (Accessed: 14 May 2025)

[45] STMicroelectronics. (n.d.). *STM32F030F4 – Mainstream Arm Cortex-M0 Value line MCU with 16 Kbytes of Flash memory, 48 MHz CPU*. Available at: https://www.st.com/en/microcontrollers-microprocessors/stm32f030f4.html (Accessed: 14 May 2025)



To establish communication between the Arduino and the Raspberry Pi, we set up a serial connection[46]. We installed the Arduino IDE on the Raspberry Pi, identified the correct port, and connected the two devices using a USB cable. This allowed the Arduino to read the analog data and send it to the Pi, where it could be displayed in the terminal

The serial device used for communication was /dev/ttyACM0, which represented the USB connection between the Arduino and the Raspberry Pi. After setting everything up, we were able to successfully read and display the analog sensor values on the Pi.

Code

```
void setup(){

pinMode(A0, 0);

Serial.begin(9600);

}
```

[46] Raspberry Pi Arduino Serial communication - everything you need to know (2019) The Robotics Back-End. Robotics Back-End. Available at: https://roboticsbackend.com/raspberry-pi-arduino-serial-communication/ (Accessed: May 14, 2025).

```
void loop(){

Serial.println("Light value:");

Serial.println(analogRead(A0));

delay(1000);

}
```

Underwater Testing

We placed the Light Sensor inside a plastic container and submerged its base and sides. We then covered the sides with dark felt, and the light value decreased accordingly. We had to manually hold the container down to submerge it, as it kept floating to the top of the water. Therefore, we will need to add weights into the container to keep it underwater.