Building a Raspberry Pi based air quality measuring device for chemistry education

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Abstract: This article outlines the building and use of a Raspberry Pi based measuring device capable of detecting air quality. The device can be used in chemistry teaching as a tool to demonstrate air composition or used in air chemistry laboratory experiments. The project is supported by theories of project-based learning, laboratory work and implementation of technology into chemistry. This article also provides a lesson plan using the device.

Keywords: gas detection, chemistry teaching, Raspberry Pi, air quality, laboratory work, project-based learning

1 Introduction

Chemistry is an exceedingly difficult subject to learn because of its nature (Cardellini, 2012). Phenomena and concepts in chemistry are abstract and understanding them requires strong visual and spatial thinking skills. In addition, chemists use three levels of explanations for each phenomena: macroscopic, submicroscopic and symbolic levels (Cardellini, 2012). Teachers move from one level to another with ease, but students often struggle. Establishing relations between the levels is crucial and can take years (Sarıtaş ym., 2021). What can help students in learning chemistry is the use of different teaching methods such as laboratory work, using electronics and project-based teaching. In this project, all three teaching methods were used to create a lesson plan investigating the composition of air in different situations and what affects the quality of air. This article also outlines the building and testing of a Raspberry Pi based air quality measuring device used in the lesson plan.

2 Theoretical framework

One method of teaching chemistry in a meaningful way and enhancing students' chemistry knowledge is laboratory work. School laboratory activities can facilitate learning, provide an experience of doing science and teach a student observation, thinking and problem-solving skills (Hofstein, 2004). What makes chemistry, and especially laboratory work, so difficult for students is the relationship between

observations and theory (Sarıtaş ym., 2021) . This coupled with the knowledge that all chemistry can't be seen with your eyes, provides a real challenge to students only beginning their chemistry education. This is especially true when talking about gasses and air composition.

The traditional way of scientifically gathering data in a laboratory experiment consists of setting up the experiment, establishing a hypothesis, making observations during the experiment and drawing conclusions based on the data (Sarıtaş ym., 2021). Laboratory work can promote cognitive and metacognitive skills and influence students' attitudes and interests towards chemistry. In addition, laboratory work can provide a much-needed break from the more traditional teaching methods, thus enhancing students' motivation. Laboratory work, if done with planning and thought, has the potential to be an important tool for teaching either by introducing a new concept or procedure, or as a proof of a concept. (Hofstein, 2004)

A second tool for teaching chemistry effectively is project-based learning. It allows students to learn while they are doing. The idea in project-based learning is to take part in solving a real, meaningful problem that is relevant to the students and their life. The goal is that a student forms a deep understanding of a given subject based on their experiences and interactions. (Krajcik & Blumenfeld, 2005) In chemistry, project-based learning can look like a laboratory experiment or a research project. For project-based learning to succeed, it needs to be student-centered and students are required to take an active role in the learning process. Students need to solve problems, ask questions, design experiments, and investigate, gather, analyze and interpret data as well as draw conclusions and report their work. (Kokotsaki ym., 2016)

Chemistry teaching can also benefit from open-source electronic hardware as well as the associated software. Devices made by teachers or students form relatively cheap parts and coded with the help of open-source sites, can be used to experiment, demonstrate and enrich chemistry education. (Urban, 2014) Possibilities for these devices are endless and building them can develop students' programming and building skills. Using electronics as a part of chemistry teaching links modern chemistry, electronics and computer science to create a rounded, meaningful, creative learning experience. (Urban, 2014)

For this project-based lesson plan, air quality was chosen to be the theme of the project. Understanding the composition of air is a central component in environmental chemistry and therefore an important issue for students since they are the decision

makers of the future and their actions, along with ours, will shape the future of the planet (de Berg, 2014).

Air quality has many heath, ecosystem and climate effects along with societal effects. Air pollution is defined as gasses and aerosols (small particles) emitted by humans that cause direct or indirect damage to life forms, ecosystems and structures. Effects include but are not limited to respiratory illnesses, cancer and allergies, loss of biodiversity and crop yields and changes in regional climate. Air pollution can be measured as air quality by measuring the concentrations of gaseous pollutants such as COx, aerosols, mold, dust or ammonia by size or number of particulars. (Monks ym., 2009) For these reasons, air quality was selected as a theme for the project. It allows students to investigate, perform laboratory work, ask questions and apply not only chemistry knowledge but also physics and math.

3 Methods

The initial idea for an educationally relevant cheap measuring device, was to build a small, portable Raspberry Pi 3B+ based system that could detect common gasses in air. For the device to be usable in a classroom, data from the measurements needed to be shown on screen and saved in a format that could then be plotted by students or a teacher. Also, the cost and level of difficulty to assemble the system needed to be low. For this project, Raspberry Pi 3B+ kit was selected for its availability and price.

Sensor selection was the most important part of getting the project going. For this project, temperature, moisture and CO_x sensor were desired to measure the quality of air. Everything else was considered desired as shown on the specification table 1.

Table 1. Target specifications for the project.

Function	Required	Desired
Temperature measuring	Separate sensor	Both temperature and moisture combined
Moisture measuring	Separate sensor	Both temperature and moisture combined
Gas measuring	CO_2 and CO	NH_4, H_2 and VOC (volatile organic compound)
Particle sensor	not required	desired
Screen	Computer screen with HDMI cable	Touchscreen or pixel screen
Size	Portable	Small

Sensors range from a few to hundreds of euros and since the project needed to have a low cost, expensive and analytical grade sensors were out of the question. Also, the amount of individual sensors needed to be kept low, to ensure that novice teachers could replicate this project. Finally, the availability of sensors and their compatibility with Raspberry Pi needed to be considered. A morphological matrix (table 2) was used to determine which available sensors and other parts were compatible and desired.

Table 2. Morphological matrix for parts.

Need	Option A	Option B	Option C
Temperature + humidity sensor	DHT22, digital 4-pin temperature and humidity sensor	MIKROE-2818, add-on board temperature and humidity sensor	T9602-3-D, humidity and temperature sensor probe
Hydrogen sensor	SGAS701, trace hydrogen gas sensor		
Other gas sensors	CO_2 sensor: T6713, CO_2 sensor module	Ammonia, Carbon Monoxide, Ethanol, Hydrogen, Methane, Nitrogen Dioxide sensor: MICS-4514, MOS (metal-oxide semiconductor) sensor, OR MICS-5524, air quality sensor	CO_2 sensor: PASCO2V01AUMA2, air quality sensor (Has recently been discontinued and replaced by a newer model PASCO2V01).
Particle sensor	HPMA115S0, particulate matter sensor		
Usable all-inclusive kits	ENVIRO+ PIM458, evaluation board pHAT for Raspberry Pi		
Screen	Standard computer screen and HDMI (high-definition multimedia interface) cable	MDOB128064VV-YM, 38mm x 28.5 mm yellow on black display	MD256128A6W-FPTLW, white on black LCD (liquid crystal display)
Storage	SD (secure digital) card (from kit)	USB (universal serial bus) stick	
Power supply	from kit		

Based on price and desired gas detectors Enviro+ PIM458 (45,32 €) and HPMA115S0 (37,75€) were selected for the total price of 83,07€. Enviro+ works directly with Raspberry Pi and the HPMA115S0 particle detector was determined to work with the Enviro+ board, with some adjustments to the connecting cable. Next, some important facts about the chosen parts.

3.1 Enviro+ PIM458

Enviro+, manufactured by Pimroni, is designed to work directly with a Raspberry Pi to detect and monitor air quality. It has a BME280 temperature, pressure and humidity sensor, TR-559 light and proximity sensor, MICS6814 analog gas sensor, ADS1015 analog to digital converter (ADC), MEMS microphone and a 0.96" color LCD screen. It comes fully assembled, is compatible with all 40-pin header Raspberry Pi models and has an instruction manual available online. Enviro+ can be used with or without a particle sensor that is sold separately. (*Enviro for Raspberry Pi - Monitor Your World! - Pimoroni*, 2022) For a project aimed at novice electronics builders and teachers, this was by far the most user friendly way to incorporate many sensors to this project without making the assembly difficult. Since everything is preprogrammed and tested, one can use Enviro+ without any knowledge of coding.

On Enviro+, temperature data is shown in celsius with a choice to either compensate for the heating of the Raspberry Pi board or to not do so. Compensation and temperature acquisition are preprogrammed as are pressure and humidity. Pressure data is given in Pascals (hPa) and humidity in percentage (%).

The analog gas sensor, MICS6814, can detect carbon monoxide (shown as reducing gas), nitrogen dioxide (shown as oxidizing gas) and ammonia (NH3), but it is also sensitive to other gasses such as hydrogen, ethanol, and hydrocarbons. The data is shown in Ohms (Ω). The gasses can not be individually identified, since they are grouped as reducing and oxidizing gasses, but the overall composition of air can be deduced from the data. Also, changes in that composition can be read. The data will show reducing and NH_3 resistance readings dropping when the gas concentration increases and the oxidizing sensor reading will increase with increasing levels of nitrogen dioxide. (*Getting Started with Enviro+*, 2022) Data from the gas sensor will print on the terminal as shown in figure 1.

Figure 1. Terminal view of the data from the gas sensor.

3.2 HPMA115S0 particle sensor

The particle sensor choice was made to broaden the data given by each measurement. Due to manufacturing delays and electronics shortage, the sensor sold as a companion to the Enviro+ was not available, so another sensor was purchased. HPMA115S0 has the same output signal (UART, universal asynchronous receiver transmitter) as the compatible sensor, the same data acquisition ppms and the same number of pinouts (8), so an educated guess was made to assume they could be made compatible. (*HPM Series Particulate Matter Sensors | Honeywell*, 2022)

The HPMA particle sensor is a laser-based sensor which detects and counts particles, based on size, using light scattering. The detection concentration range is 0 µg/m3 to 1,000 µg/m3. The chosen particle sensor measures particle sizes PM 2.5 (particle size less than 2.5 µm) and PM10 (particle size less than 10 µm) which correspond to particles such as mold, dust, spores and bigger organic molecules.

(Honeywell International Inc, 2017) The only downside to this sensor is that it doesn't have the extra fine particle detection that the companion sensor does, so all acquisition of that data for that particle size will be shown as 0 or not available.

3.3 Prototype

Raspberry Pi setup was done following the instructions of the system once booted up. A regular mouse and computer screen were used in this project. At a later stage, a projector was used for classroom demonstrations along with a document camera Enviro+ setup (figure 2) was done by following the manual provided by the manufacturer (*Getting Started with Enviro+*, 2022).
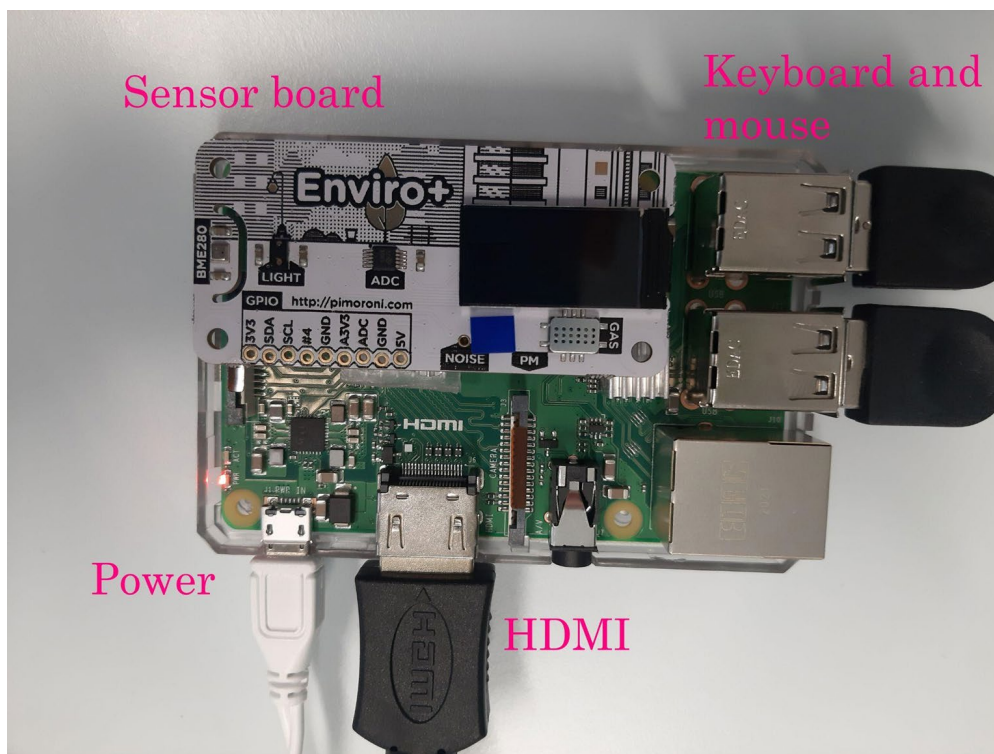

Figure 2. Raspberry Pi setup with Enviro+.

The particulate matter sensor was more difficult to get to work with the Enviro+. The software for the sensor was downloaded from GitHub (Faliszek, 2017/2021) onto the Raspberry Pi without attaching the Enviro+ at all to test the usability of the sensor. The particle sensor compatible with Enviro+ had the same coding bits as the HPMA sensor, only the pinouts were different (table 3) (Honeywell International Inc, 2017; Plantower, 2016). So, a new cable connecting the Enviro+ and HPMA particle sensor

was built with an 8-pin cable by not attaching cables 1, 3, 4 and 5 from the particle sensor onto the Enviro+ and attaching the remaining cables as shown in figure 3.

Table 3. Pinout for Enviro+ and HPMA particle sensor.

Pin	Enviro+	HPMA particle sensor
1	Power input	Power output
2	Ground	Power input
3	SET	NA
4	RX	NA
5	TX	NA
6	RESET	TX
7	NA	RX
8	NA	Ground

HPMA	Enviro+
1	Not connected
2	1
3	Not connected
4	Not connected
5	Not connected
6	5
7	4
8	2
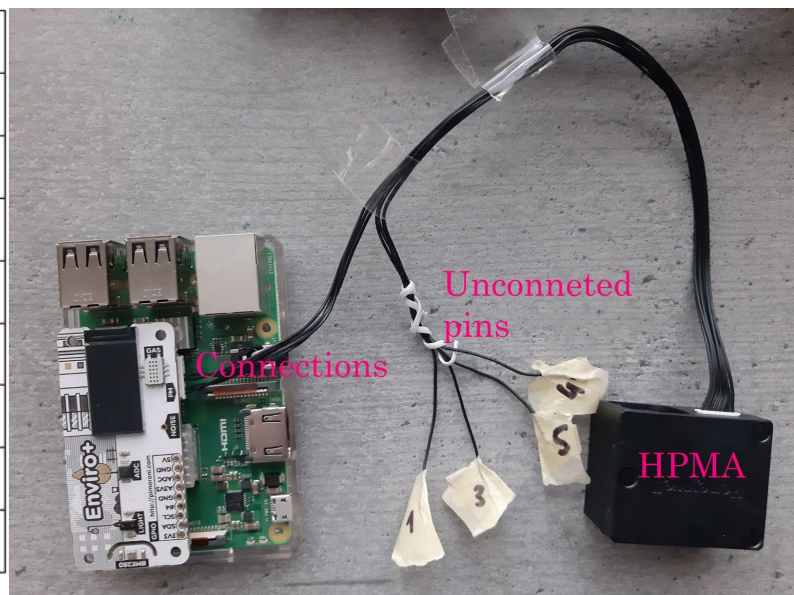
Figure 3. Particle sensor and Enviro+ attachment showing which cable form HPMA attaches to which pinout on Enviro+.

After this, Enviro+ and the particle sensor worked together with the premade code provided in the example files of Enviro+.
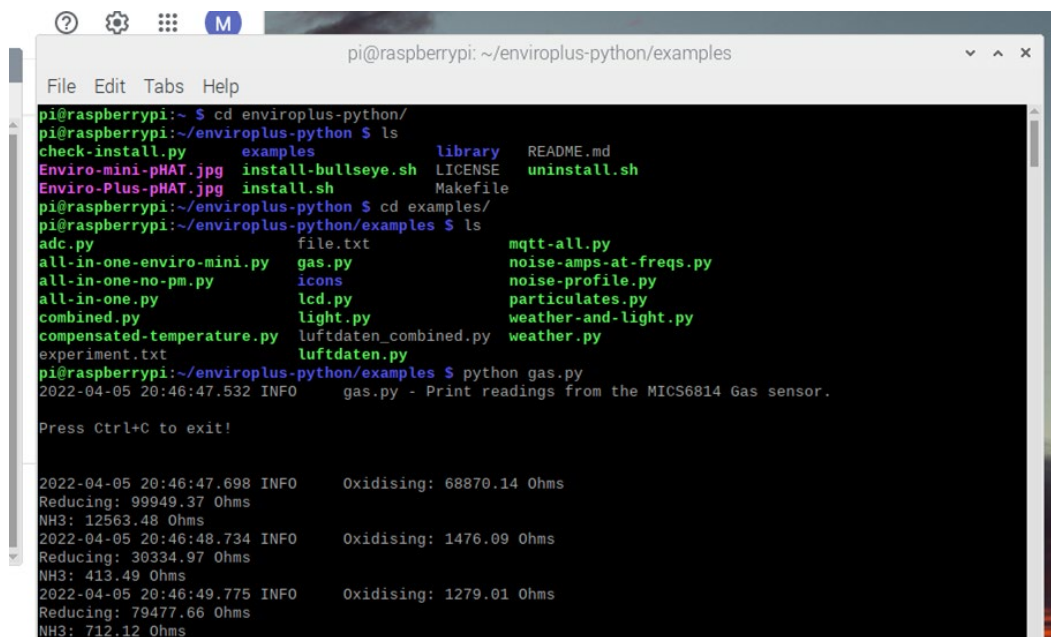
3.4 Testing

To find the different premade codes for measurements, in terminal write:

```
cd enviroplus-python
cd examples
ls
```

Here you will find a library of useful preprogrammed measuring sequences. To run one, write:

```
python nameofprogramm.py
```

An example terminal window of this process can be seen in figure 4.

Figure 4. Terminal view of the setup for an experiment.

The data from acquisitions will appear in the terminal but also on the small LCD screen (figure 6) . This can be projected for students or the terminal can be shared.
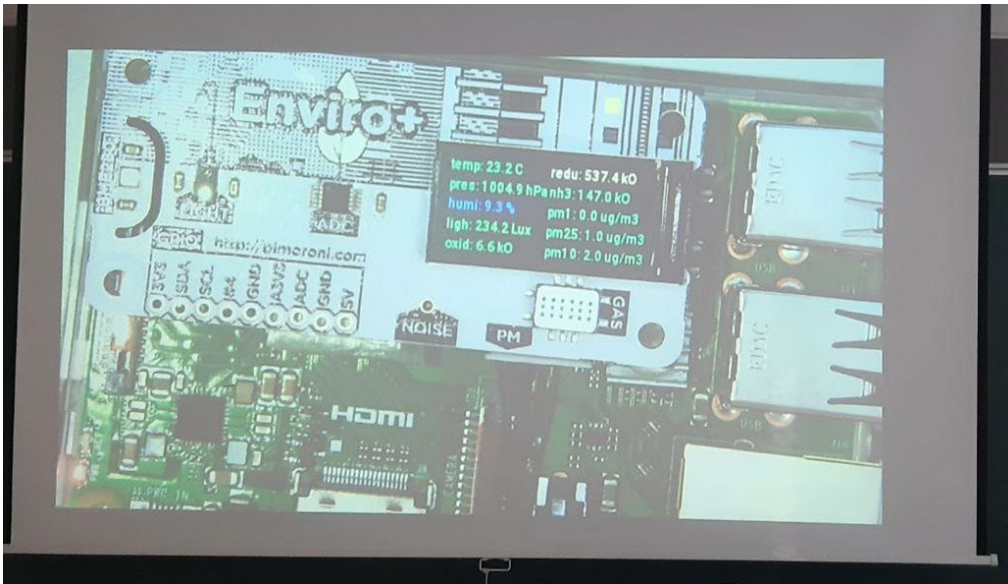
Figure 5. Student view of the LCD screen during *combined.py*
command in a classroom via document camera.

If one wishes to write a file of the data instead of showing it on the terminal, add "filename" property in the logger.config in the Python program:

```
logging.basicConfig(
format='%(asctime)s.%(msecs)03d %(levelname)-
8s %(message)s',
filename="outfile.txt",
level=logging.INFO,
datefmt='%Y-%m-%d %H:%M:%S')
```

The file written will be a text file and that can be manipulated in excel or some other data processing platform. From this data, graphs can be drawn.

4 Project-based lesson plan

OPS (perusopetuksen opetussuunnitelma) requires teachers to use laboratory experiments as a way to teach and evaluate students' progress. In OPS environmental issues also play a big role and teachers are required to teach about students' environment and its effect on their health and safety. (Opetushallitus, 2016). Thus, it can be reasoned that air quality should be taught at school.

With the increased availability of inexpensive electronics, a self-made air quality measuring device can be used to teach about what affects the quality of air. The students are given the topic, air quality, to research. They will need to determine what

affects the air quality, measure it and present their findings in graphs and figures. The teacher is there to facilitate learning and help the students if needed.

In this project students will need to:

- research what gasses and other particles make up the air we breathe
- define air quality
- make a plan for an experiment they can conduct with the device to see how they can positively or negative affect the air quality
- make a hypothesis for their experiment
- gather data from the experiment
- analyze the data and graph the relevant parts of it so it can easily be presented
- gather all their finding into a presentation

Assessment of the project will be based on the learning and is formative in nature. Grading should be supportive so students' motivation to take part in exercises such as this one will not diminish.

5 Conclusions

A Raspberry Pi based air quality measuring device can be built out of relatively inexpensive parts and assembled with little knowledge of coding and electronics. The system built does succeed in measuring air quality with the premade codes Enviro+ comes with. This device can be used in chemistry education as a demonstration tool or as part of a project-based learning lesson plan centered around laboratory experiments, aimed at figuring out what affects the quality of air.

Further testing of the system and its use in the classroom needs to be done to assure the durability and usability by students. The lesson plan needs to be tested on students and research into the lesson's effectiveness should be conducted. These steps should be done before implementing this teaching method into the classrooms at large. Also, there are many other lesson plans using this device that can be attempted such as showing air composition of a classroom in real time and measuring the gas composition of an exhale. The possibilities are endless.

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