Implementing a Raspberry Pi Based Digital Measurement System to Foster STEM Education

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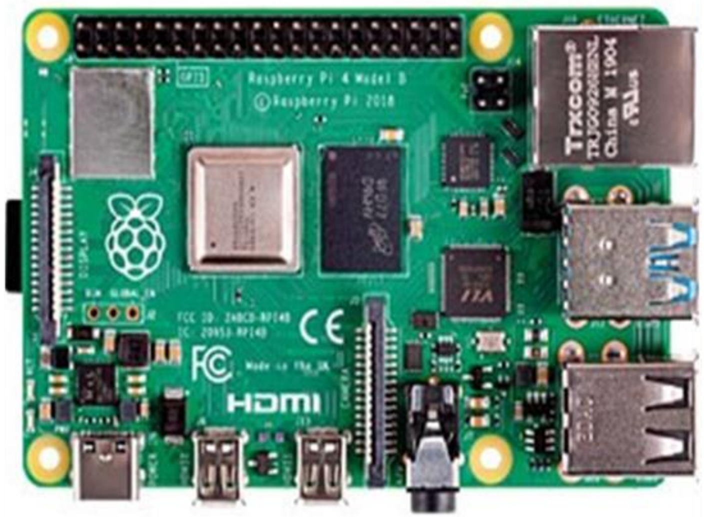
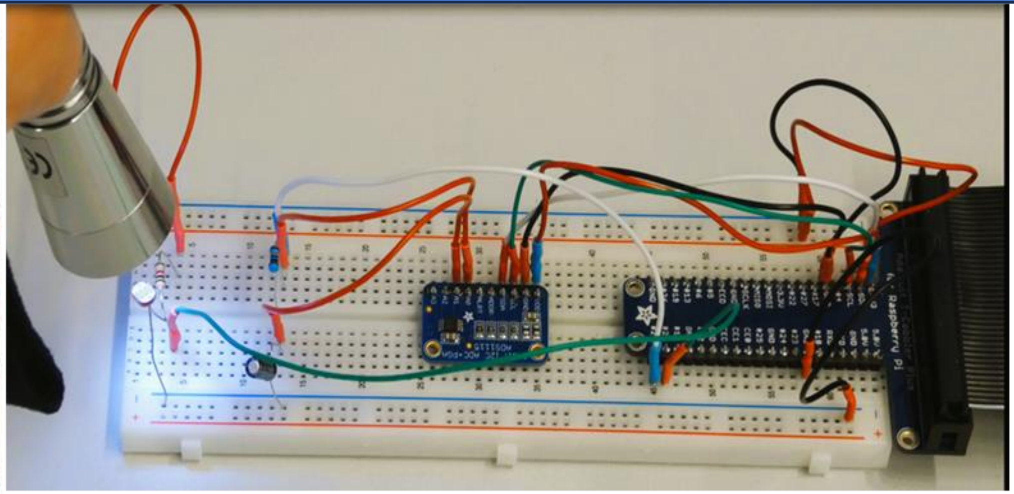
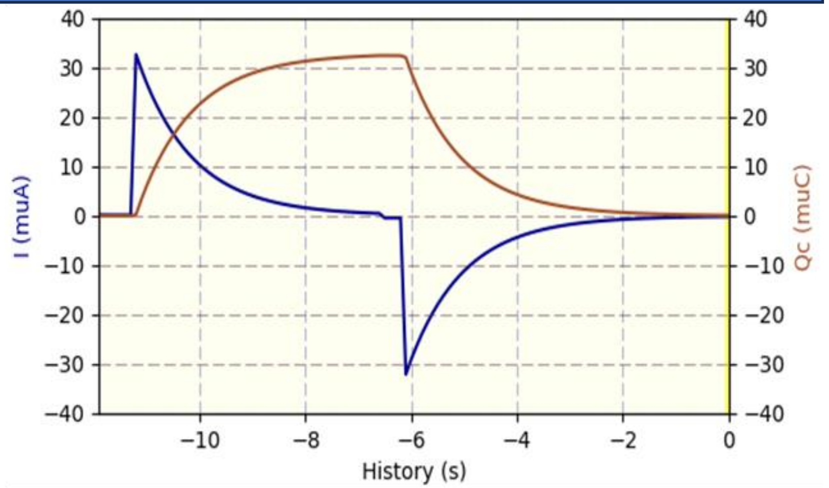


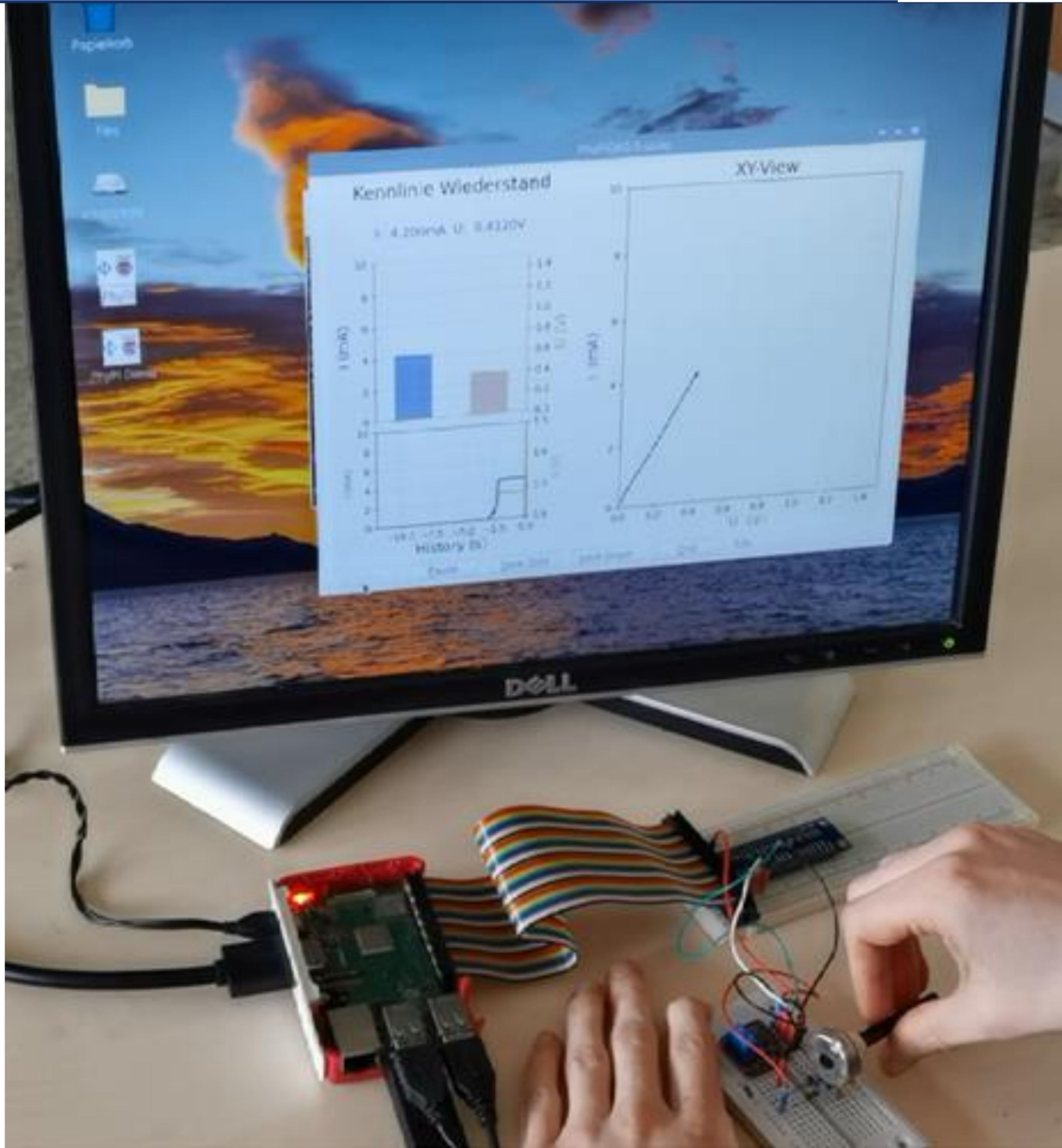




Objectives

- Contribution of the DMSRP as technological tool and rich learning environment in STEM education.

- Investigating on both hardware and software capabilities of the DMSRP to enable the integration of STEM disciplines through active learning approaches in authentic learning environments so as to meet the requirements of key characteristics of integrated STEM.



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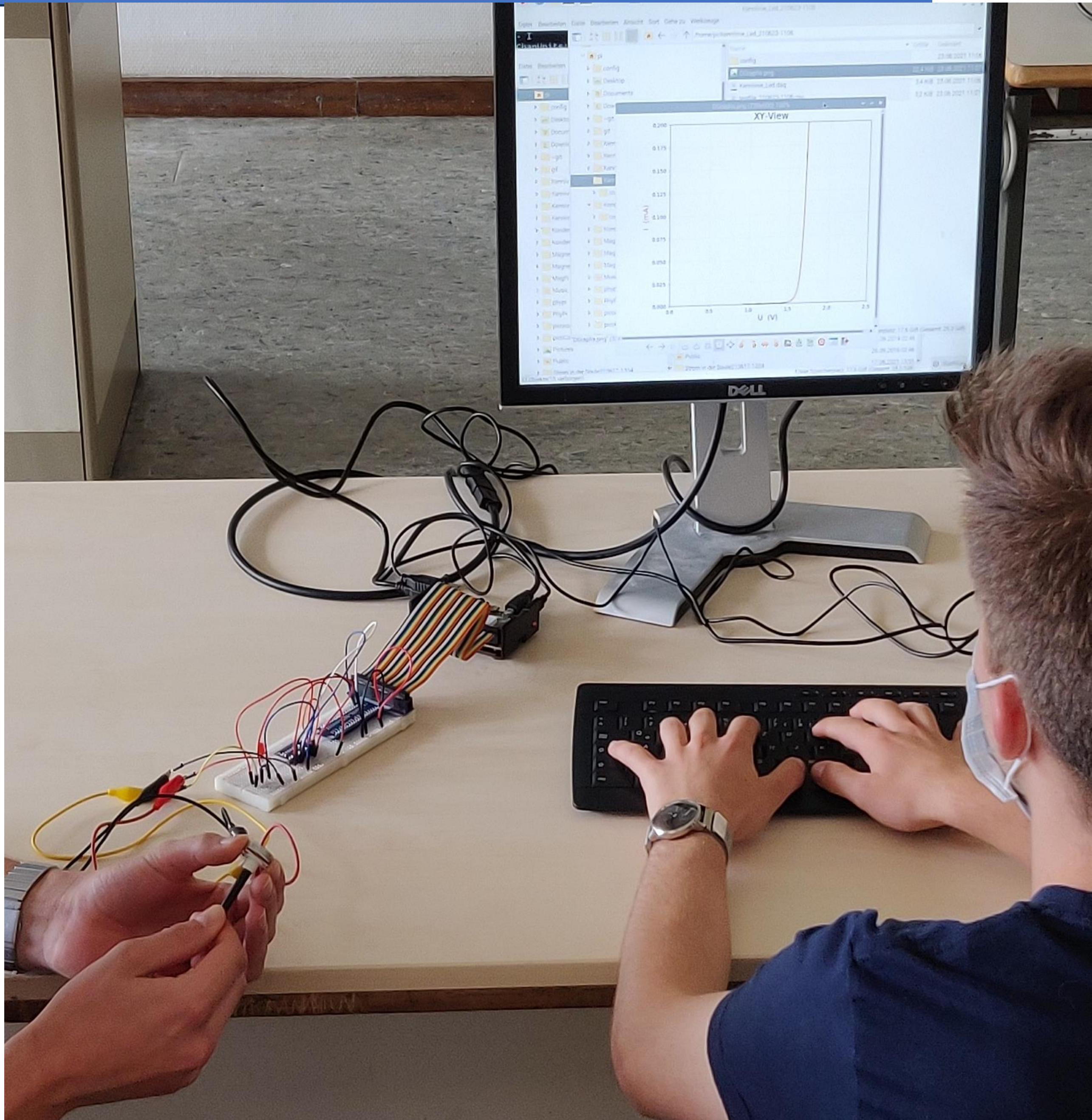
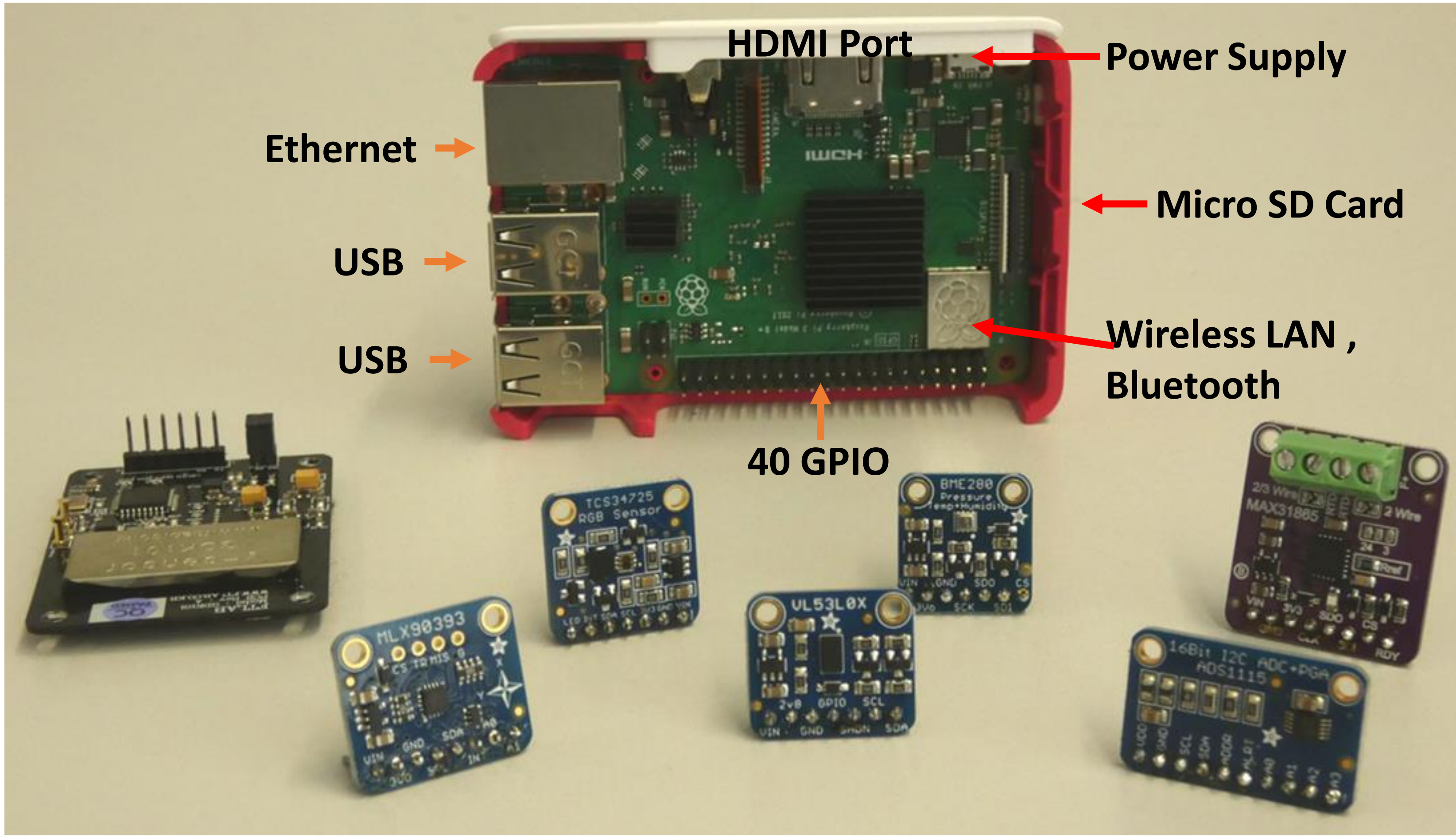


- **DMSRP is a low-cost, accurate measurement system for sciences and engineering projects.**
- **DMSRP allows acquisition, display, and storage of data from a wide range of inexpensive sensors connected to the Raspberry Pi .**

Advantages of the Raspberry Pi:

- **Low-cost single-board computer**
- **Own operating system: Raspberry Pi OS; microSD cards for data storage**
- **Internet connectivity: Ethernet, Bluetooth and WiFi**
- **Powerful computation capability**
- **40 GPIO to interact with sensors and actuators**

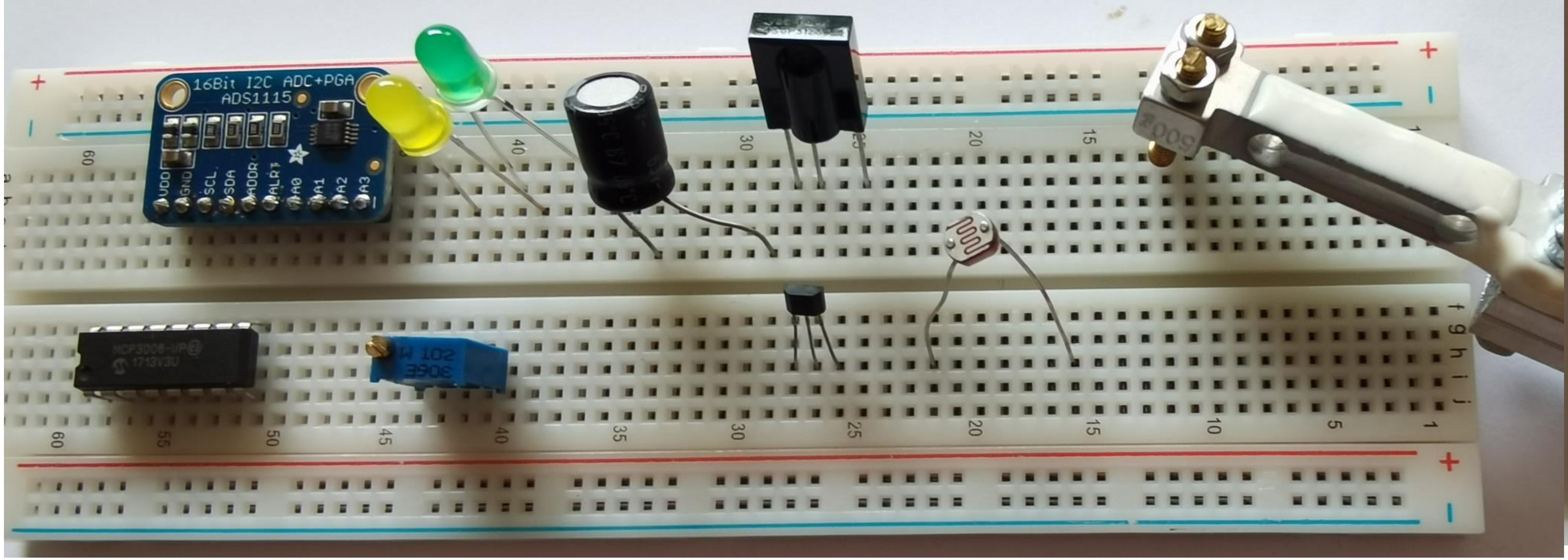
Technological Tool and Educational Resource

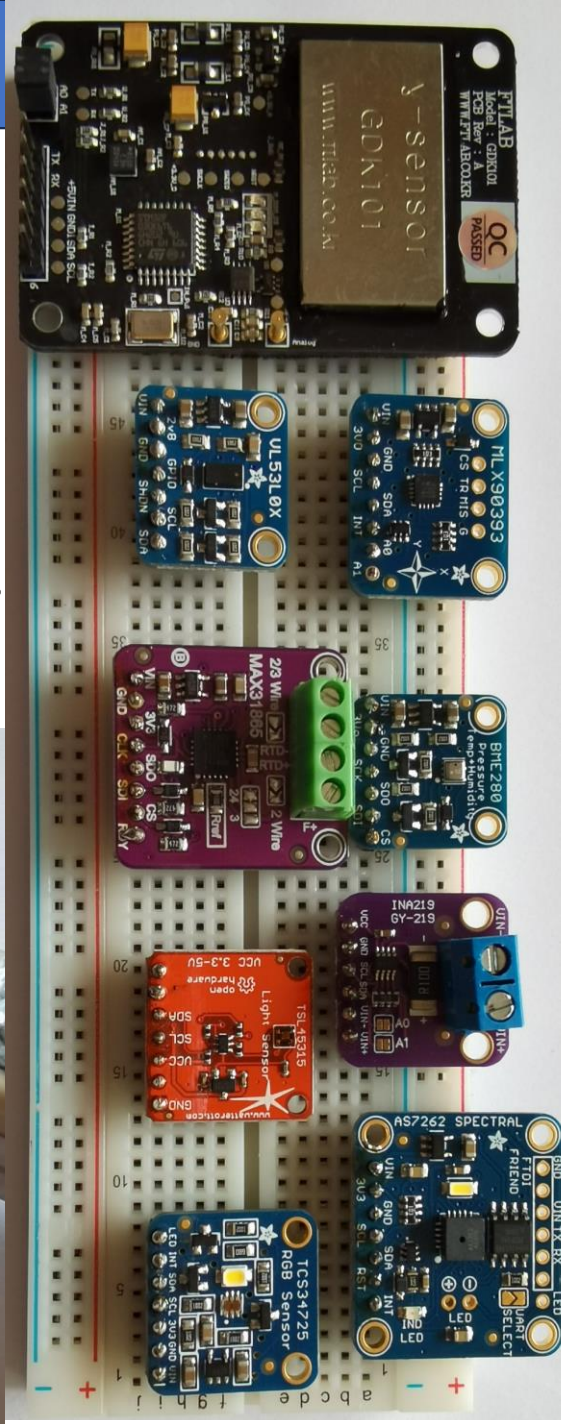


1. Understanding DMSRP and its Benefits for STEM

Sensors and Actuators

- High-accuracy yet inexpensive, digital and analogue sensors
- Current and power sensor, temperature, magnet field, distance, environmental sensor, gamma-radiation, spectral sensor
- I^2C-compatible interface allowing sensors to transmit measured data to the Raspberry Pi
- Analog sensors interfaced with the Raspberry Pi via analogue-to-digital convertor ADS1115
- Additional: operational amplifier, electrometer-amplifier, level shifter





1. Understanding DMSRP and its Benefits for STEM

Open-Source Software Package PhyPiDAQ: **Prof. Quast,** *Karlsruhe Institute of Technology (Germany);* phypidaq.github.io

How to install the PhyPiDAQ

Install Raspberry PI OS on microSD card

↓

configure the Raspberry Pi

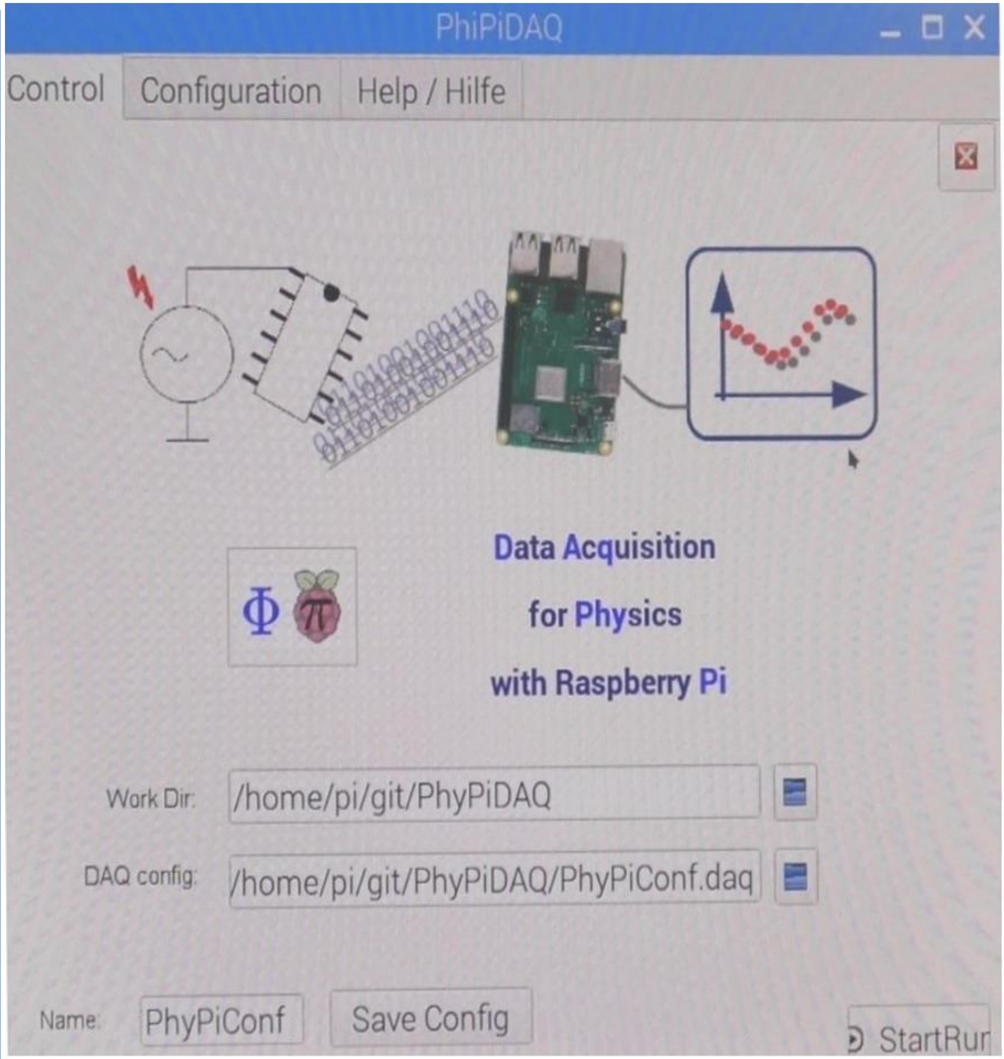
↓

install the PhyPiDAQ-Software

Students

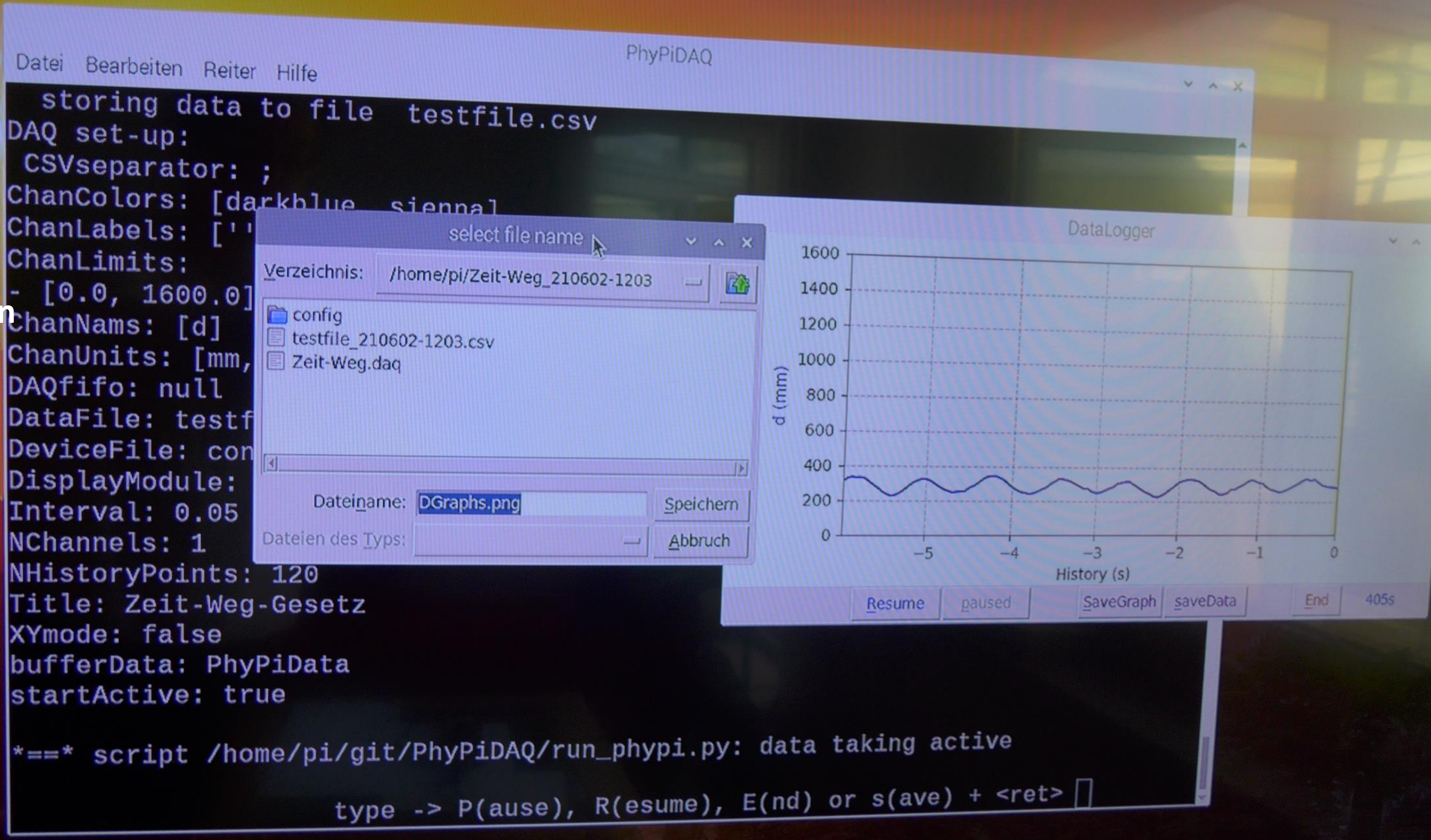
- **choose and edit specific configurations for devices and sensors: measuring ranges, number and type of channels…**
- **configure the graphical display of the measurements: display modes, measurement name and units, proper graphical ranges, formulae for displaying desired quantities, calibration of analogue sensors, save the measured data in .csv**

Graphical User Interface phypi.py



1. Understanding DMSRP and its Benefits for STEM

Real-time elongation of a spring-mass oscillator visualized in the measuring window of the DMSRP;



1. Understanding DMSRP and its Benefits for STEM

- *DMSRP enables the integration of STEM disciplines through active learning approaches in authentic learning environments*

- *DMSRP provides a rich learning environment including a variety of scientific and engineering practices.*

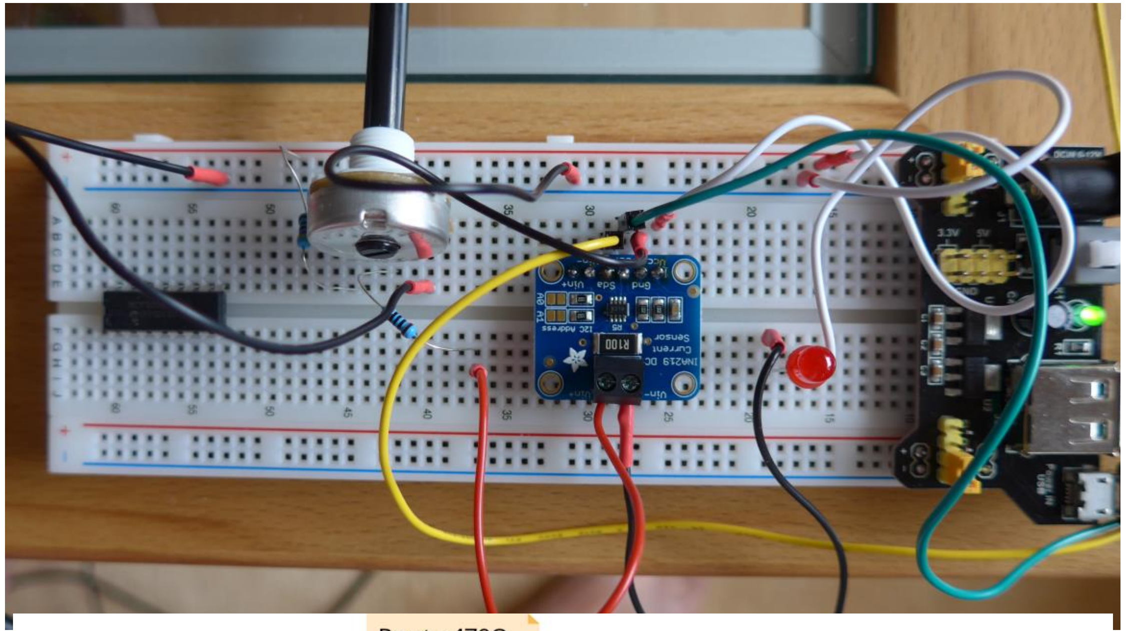
- *DMSRP promotes content and context STEM integration*
  multiple representations
  modelling approaches

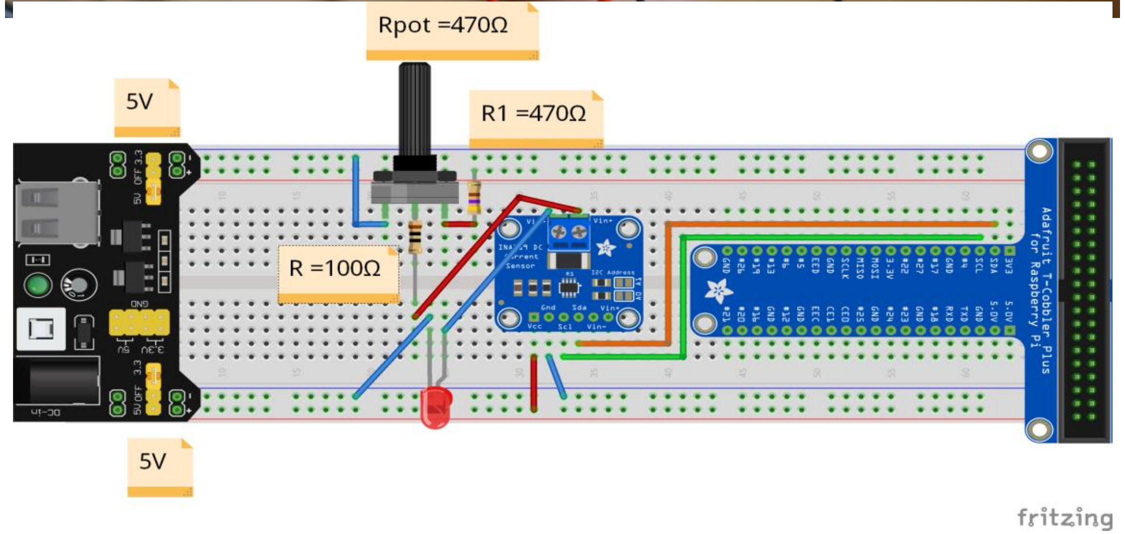
- *DMSRP encourages skilled communication, creativity and collaborative learning*

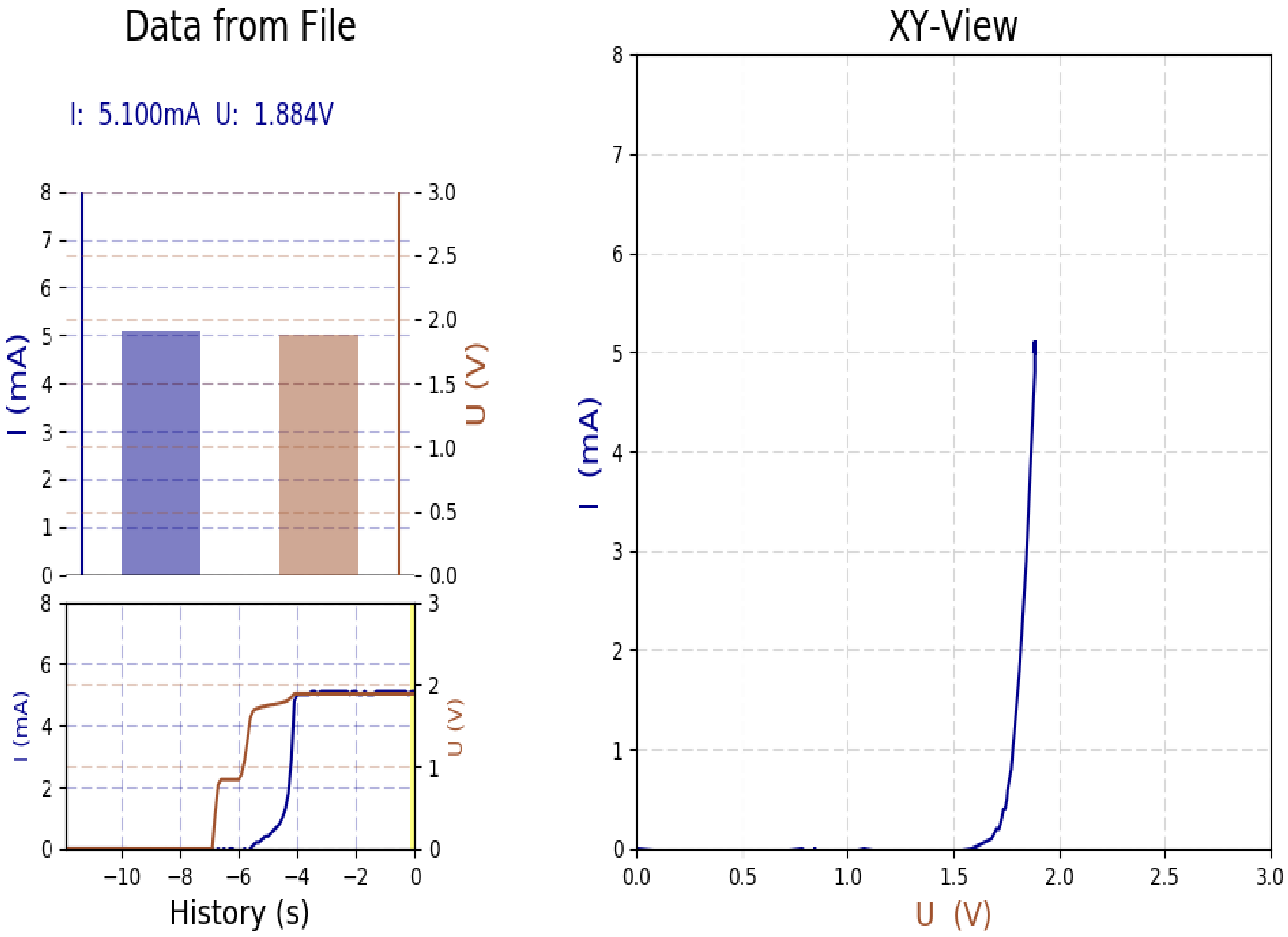
1. Understanding DMSRP and its Benefits for STEM

Multiple Representations with the DMSRP

https://mint.hw-schule.de/index.php/mint-projekte/phypidaq-international?view=article&id=48





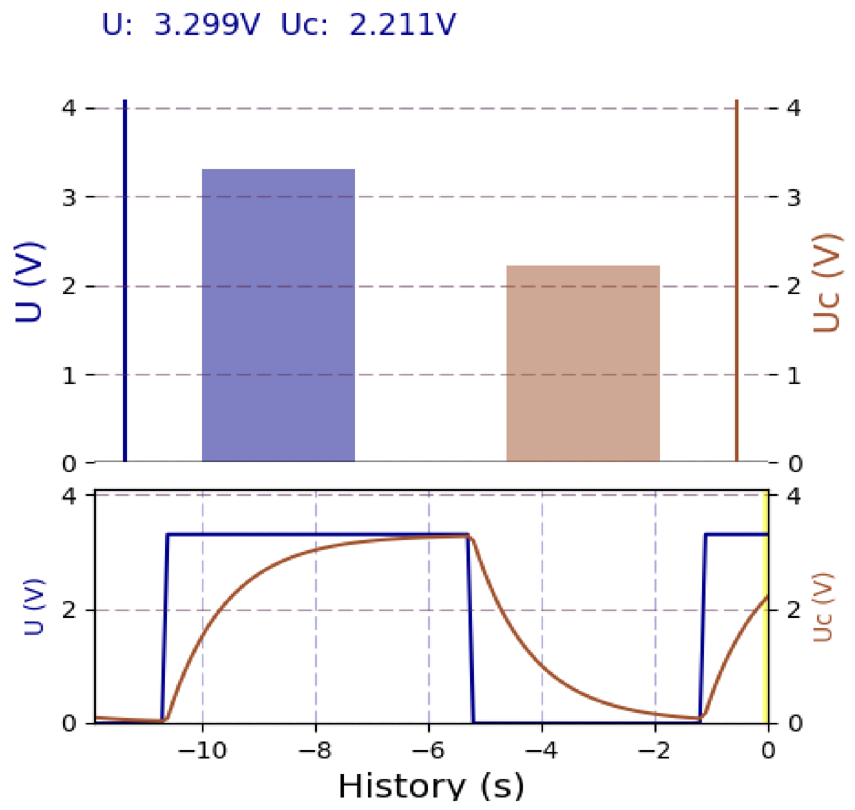


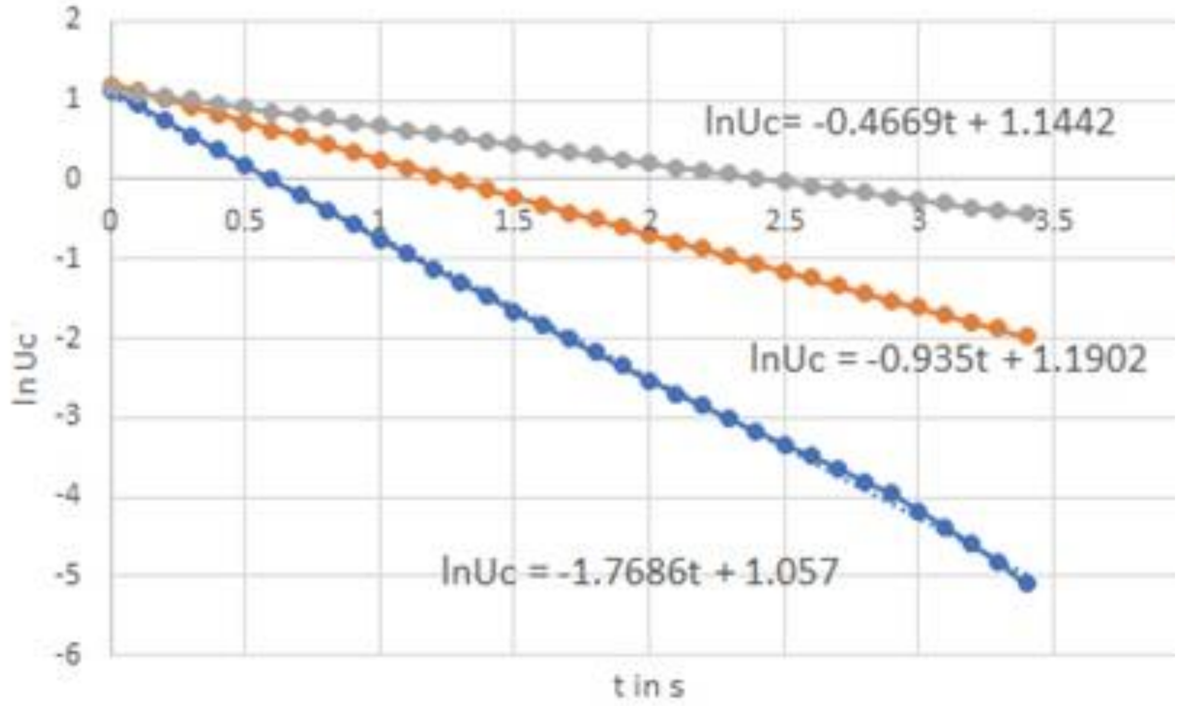
Example: Current-Voltage Characteristics of a LED recorded with the INA219 Sensor

Modelling Practices with the DMSRP

https://www.youtube.com/watch?v=jRX7j9fn1oQ

10muF-Kondensator, 100KOhm-Widerstand



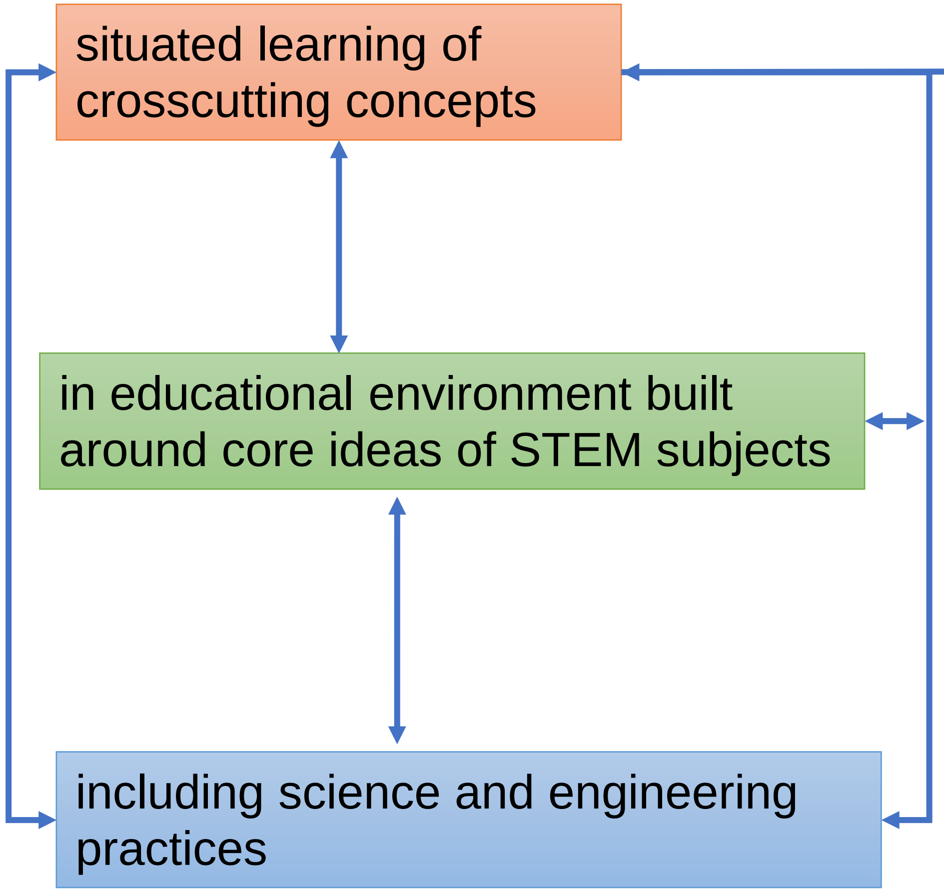


Charging and discharging characteristic of a capacitor U_C (t) controlled by the square waveform voltage U(t)

Plotted values of the natural logarithm of the voltage across the capacitor at each moment t; $\ln(U_C) = \ln(U) - t/\tau$; $\tau = RC$ is the time constant

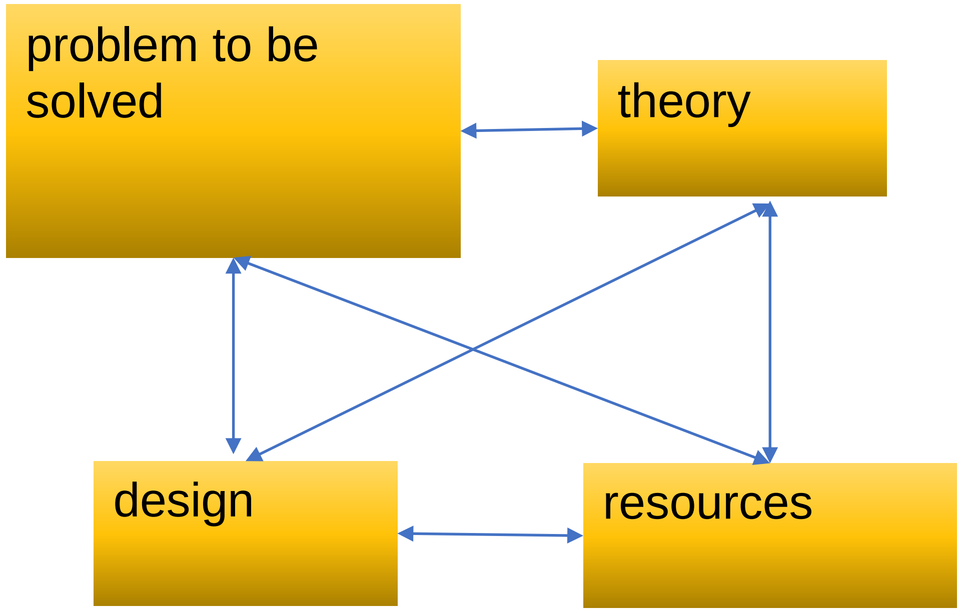
2. Emphasising the Potential of DMSRP as Integrator of STEM Subjects

The DMSRP is a powerful instructional tool that supports:



- Patterns
- Cause and effect
- Scale, proportion, and quantity
- Systems and system models
- Energy and matter
- Structure and function
- Stability and change

Next Generation Science Standards (NGSS, USA)



3. Exploring Interconnection of Science, Engineering and Technology

1.Plan the experiment, choose the appropriate sensors, devices and electrical components

2.Research the data sheet and the physical principles of the sensor(s)

3.Connections and communication with the Raspberry Pi

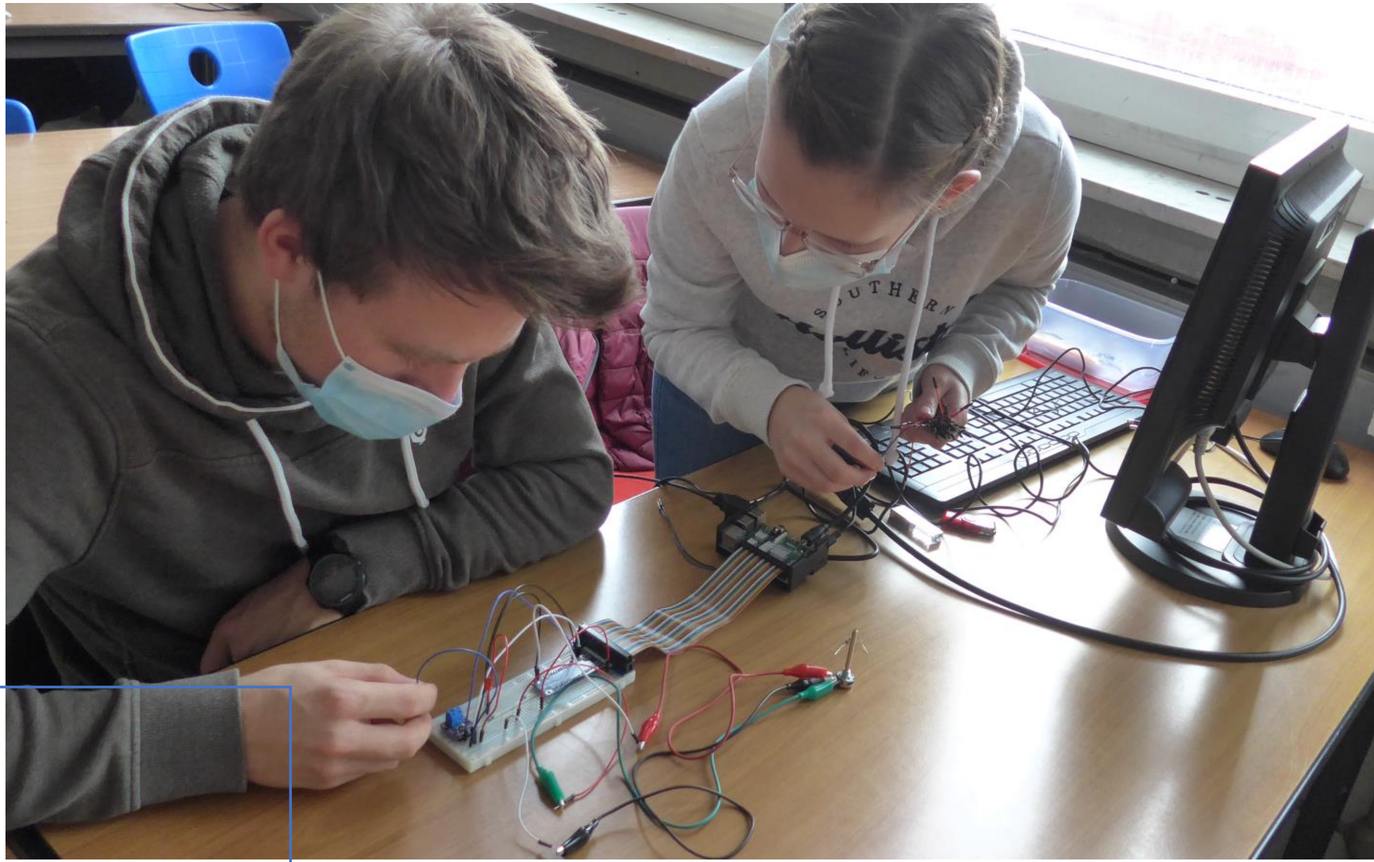
4.Design the electric circuit and setup on the breadboard

5.PhyPiDAQ-Software→ select the sensors' configurations→ select and edit commands for data acquisition, display and storage

6.Carry out the experiment

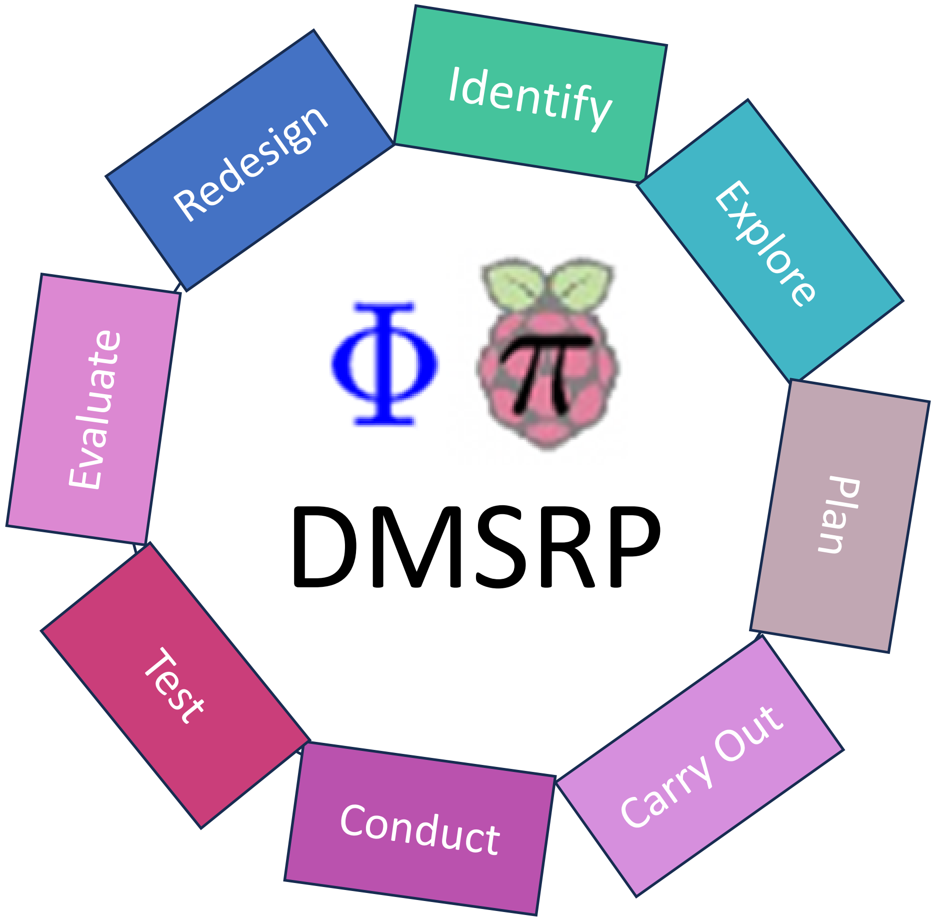
7.Measurements displayed in real-time, →analysing and interpreting data

8.Measurements stored in .csv files → Mathematical practices for processing big data amount



3. Exploring Interconnection of Science, Engineering and Technology

Chain of structured and iterative engineering design processes:



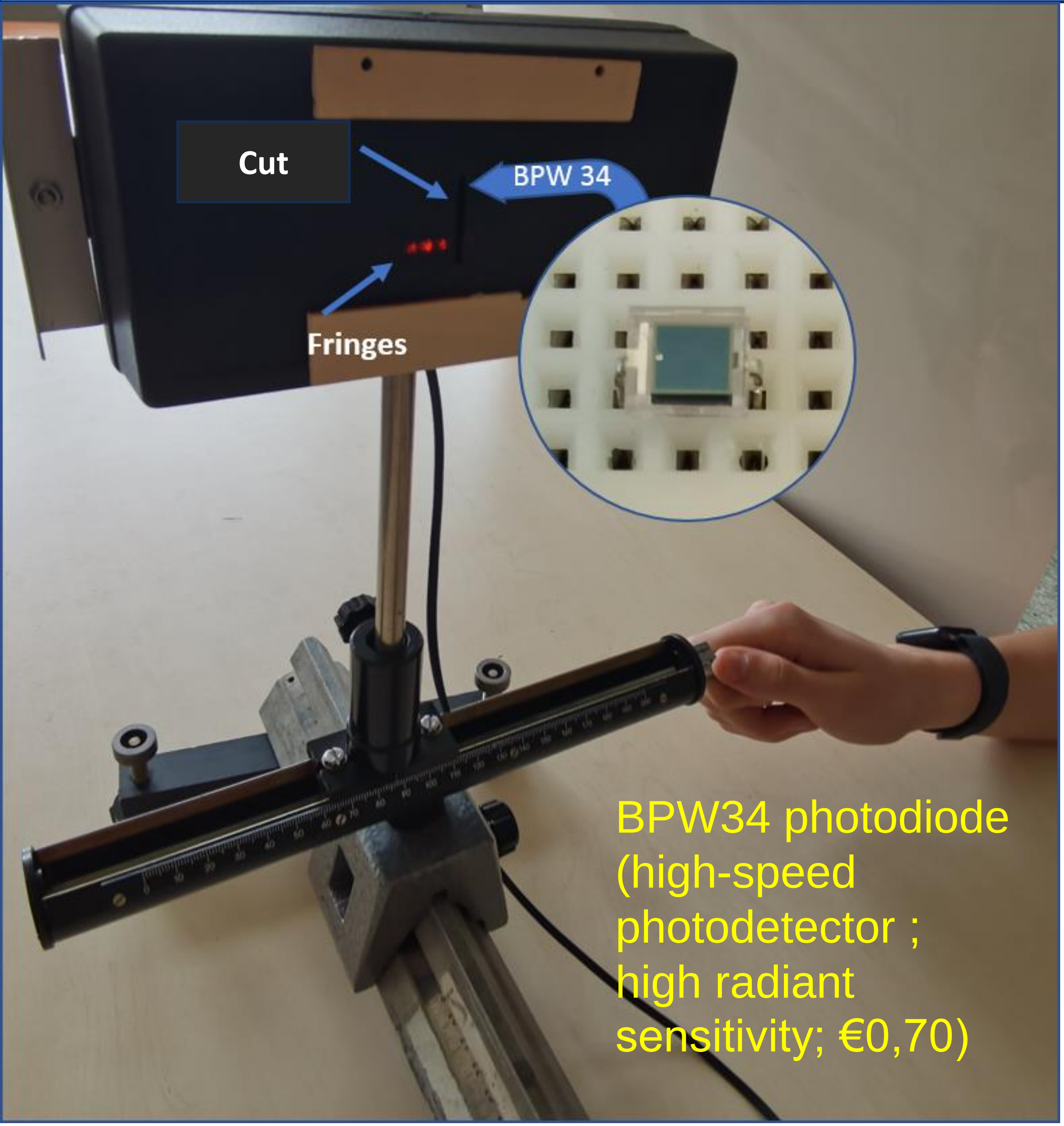
Identify and Explore Real-World Problem: multiple perspective; wide range of technological resources; constructivist approaches

Planning and Carrying out Investigations: design of the electric circuit; wiring diagram on the breadboard; multi-stage exploration (trial and error); configure the PhyPiDAQ software; cooperation across the learners

Conducting Measurements and Testing Results: optimize the visualisation of measurements (graphical ranges, sampling rate, formulae; different visualisation modes); large number of quality measurements; relationships sciences maths

Evaluating and Redesigning: explore and assess the functionality and effectiveness of the own experimental setting; feedback in real time; iterative process to repeatedly improve the performances

4. Case Study of Fraunhofer Diffraction: Low-Cost Diffraction Scanner based on DMSRP



Main goal: Design a low-cost Diffraction Scanner to measure the intensity of diffraction pattern

DMSRP operates the scanner by reading the signal from a light sensor interfaced with the Raspberry Pi via an analogue-to-digital converter.

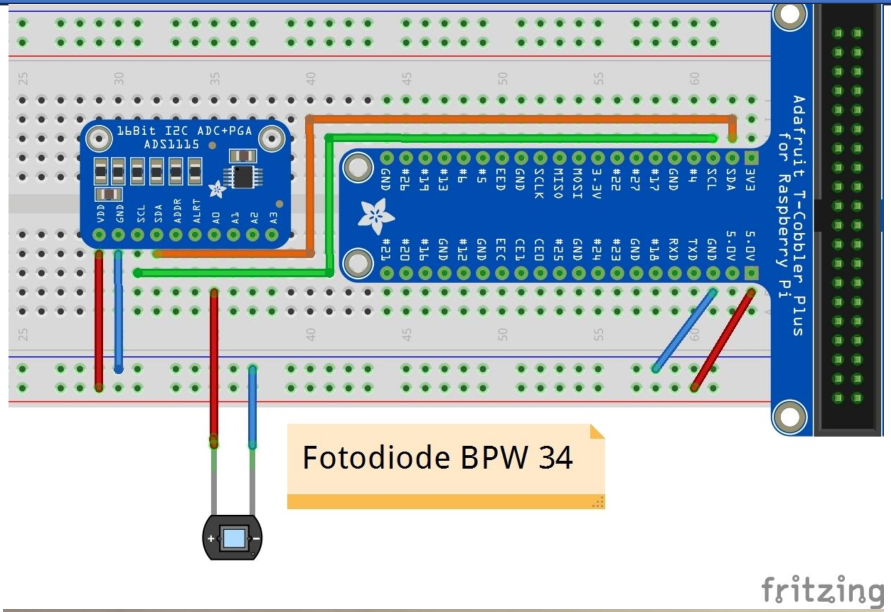
Project-Based-Learning strategy:

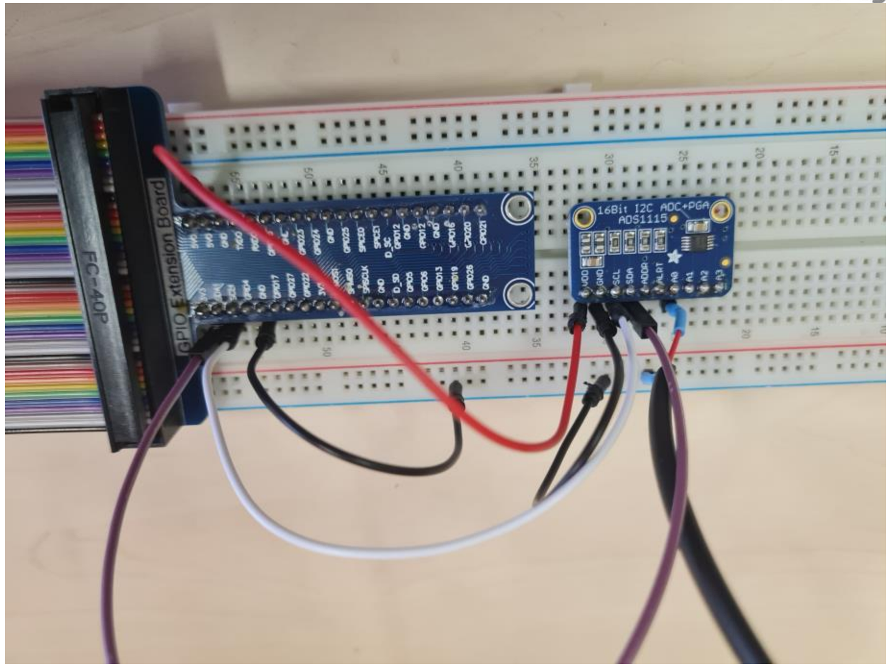
- open-ended authentic problem
- hands-on investigation
- collaborative learning
- technology-based exploration

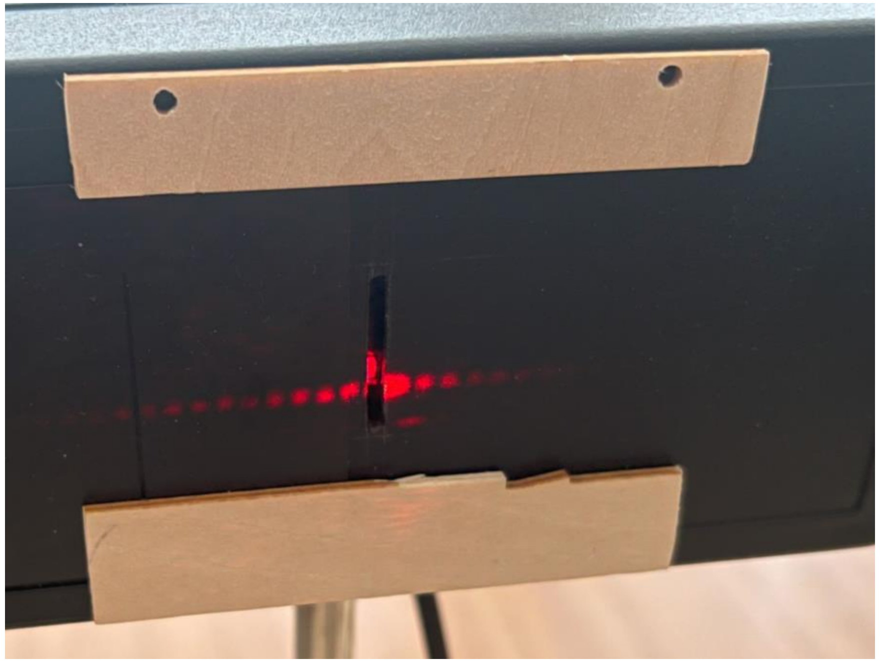
https://youtu.be/TDSzCIaUQVA

https://colab.research.google.com/drive/1alg1QaYBJECo-M2Th8BUxUzQmprFmL6V?usp=sharing

4. Case Study of Fraunhofer Diffraction: Low-Cost Diffraction Scanner based on DMSRP





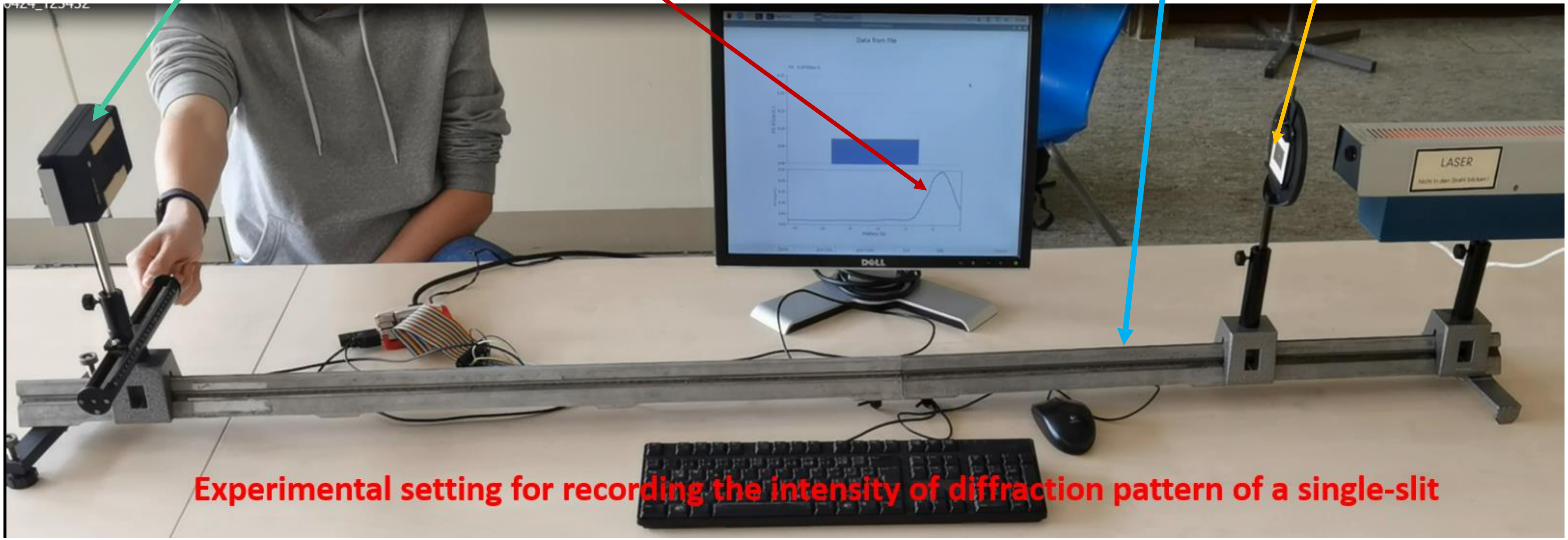


Iterative process:

- designing schematics
- realising wiring diagrams on the breadboard
- configure the PhyPiDAQ-Software
- measuring quantities and comparing outputs

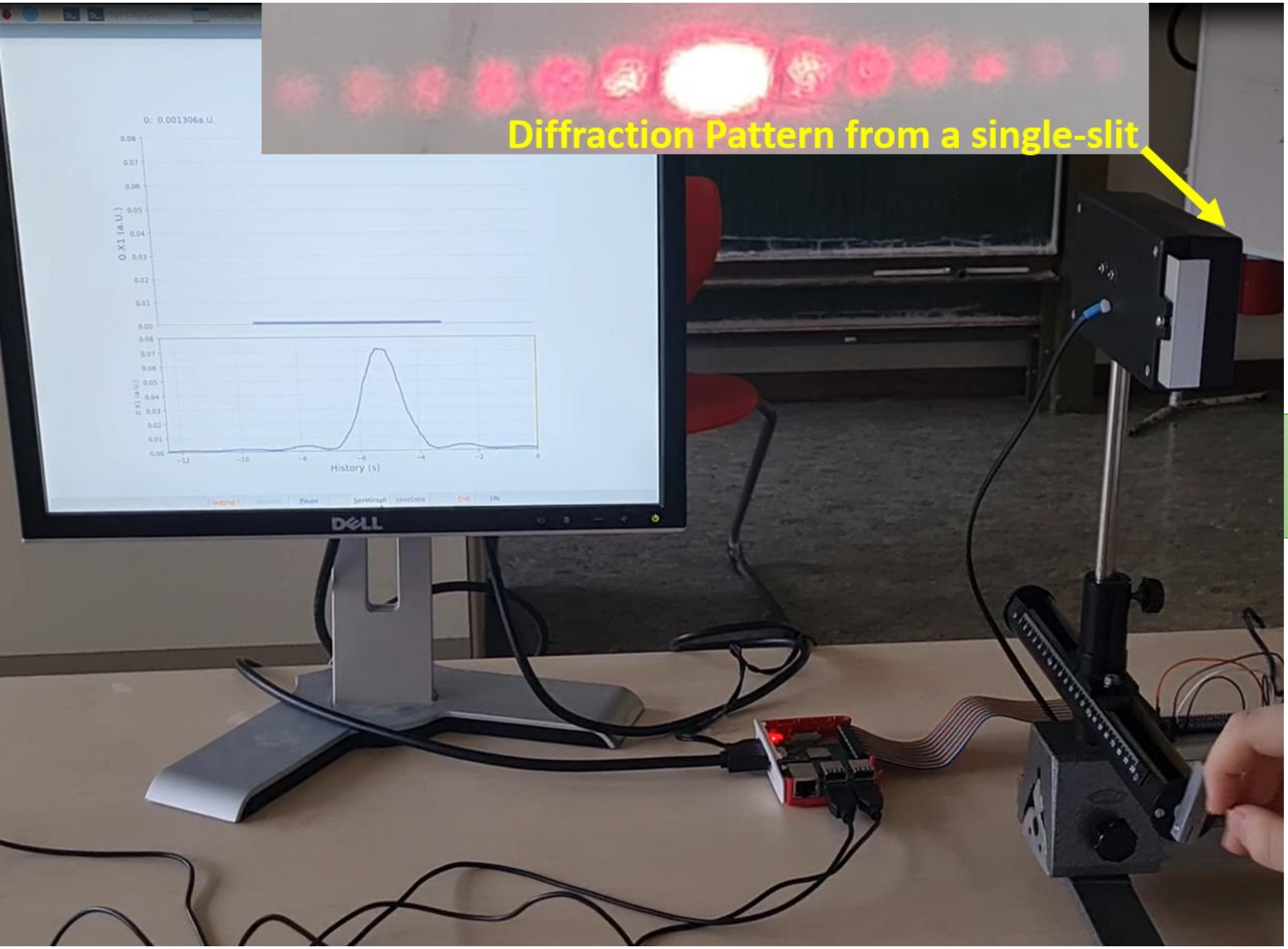
5. Learning the Physics of Waves With the DMSRP

Students employ their self-created diffraction scanner into the common experimental setting available in the lab and visualize the intensity of diffraction peaks on the measuring window of the DMSRP for various slit widths



5. Learning the Physics of Waves With the DMSRP

Correlation of the diffraction pattern projected on the screen with the intensity distribution of the fringes:



DMSRP visualises and records at high accuracy the light intensity of the fringes in real-time as students manipulated the hand-crank of the sliding rider

DMSRP shows a bright central maximum followed by dimmer and thinner maxima on either side

Crosscutting Concepts to understand waves' behaviour at openings and obstacles

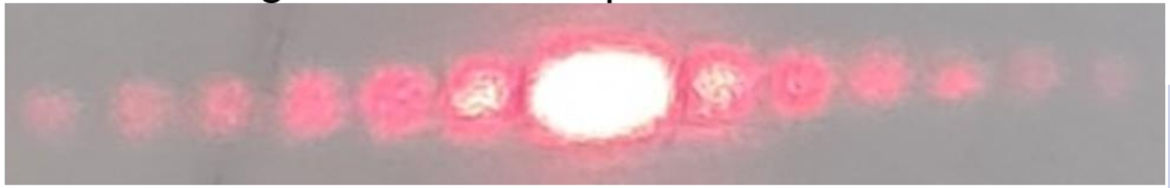
Ray model or wave model of light?

Similarities and differences in the single and double-slit patterns

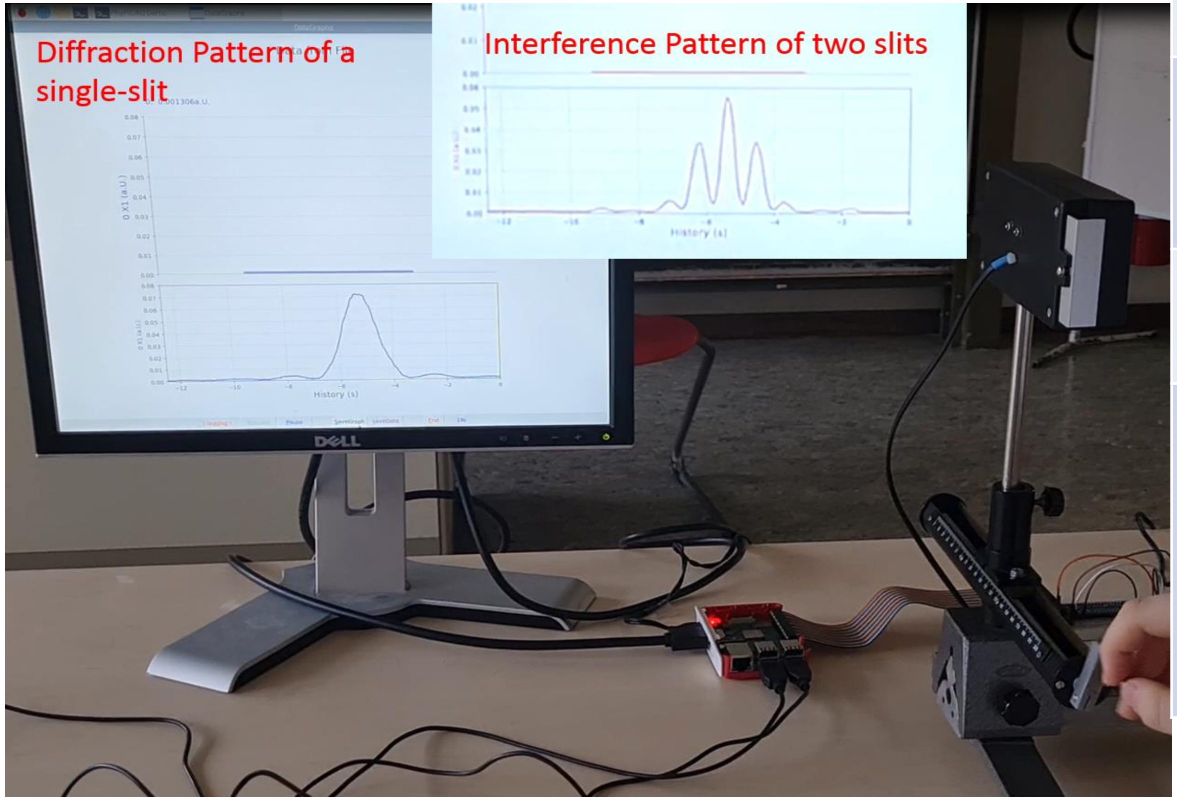
Integrated contents and concepts for different types of waves (Huygen' Principle; Superposition of waves, characteristic quantities)

5. Learning the Physics of Waves With the DMSRP

single-slit diffraction pattern on screen



interference pattern of double-slit on screen



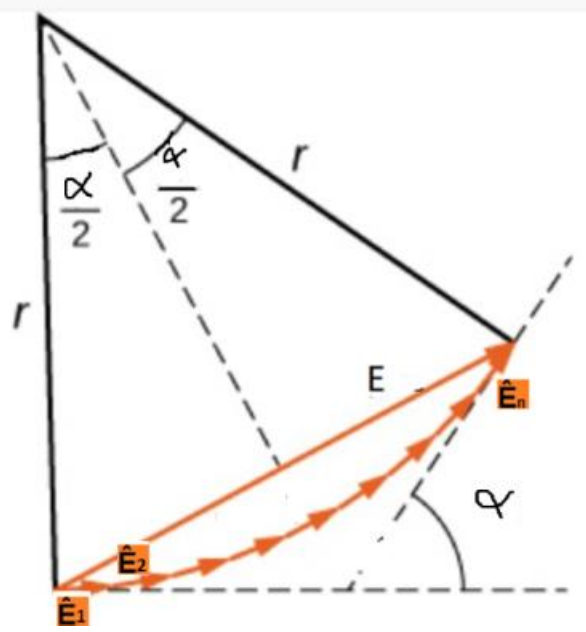
Young's Double-Slit Interference	Diffraction pattern of a single-slit
already explored; known	new; inquiry; contrastive learning
mathematical modelling: two slits: two narrow point sources	mathematical modelling: uniform distribution of point sources at the slit
Superposition of two secondary spherical wavelets	Superposition of many secondary spherical wavelets
diffraction effect in each slit is ignored	
constructive interference (maximum): $\delta = k \cdot \lambda$ destructive interference (minimum): $\delta = (2 \cdot k + 1) \cdot \frac{\lambda}{2}$	Textbook: destructive interference: $\delta = k \cdot \lambda$ constructive interference: $\delta = (2 \cdot k + 1) \cdot \frac{\lambda}{2}$???

https://youtu.be/GrCKBxUQPKk

Mathematics of Diffraction

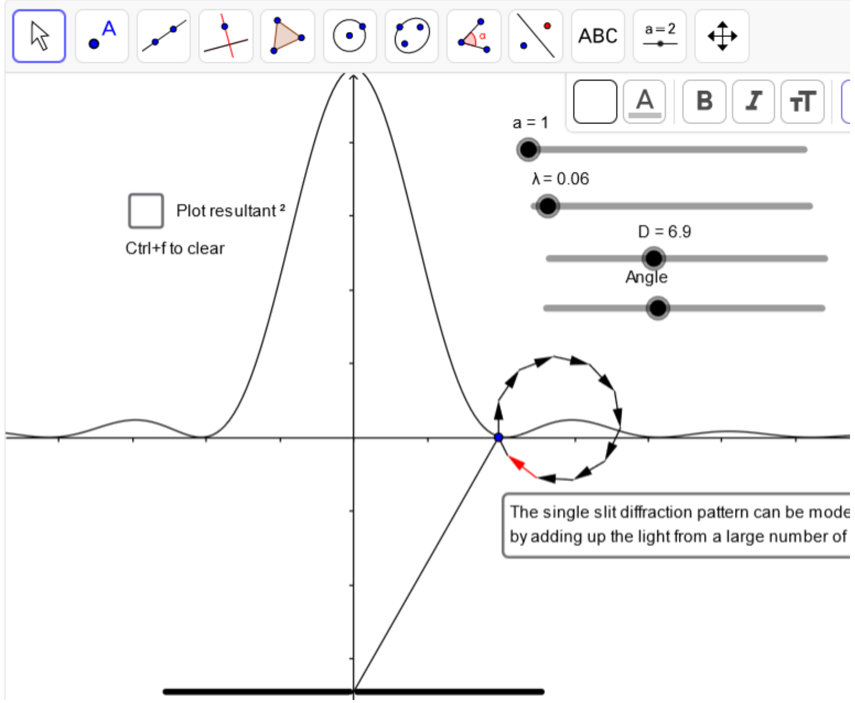
PBL: Calculate the light intensity relative to the central maximum as function of the diffraction angle

Model based on the phasor analysis known from alternating-current circuits



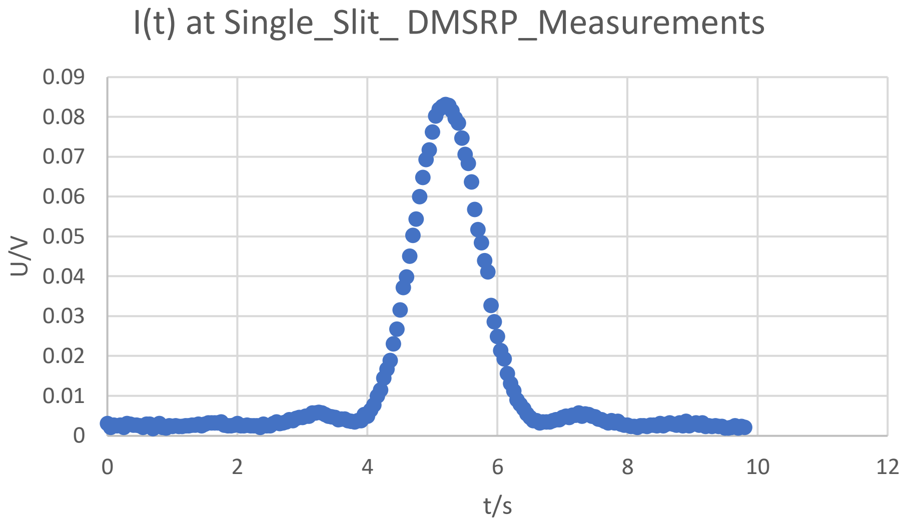
Source: https://pressbooks.online.ucf.edu/osuniversityphysics3/chapter/intensity-in-single-slit-diffraction/

Geometry of phasors for maxima and minima in the diffraction pattern (GeoGebra-Simulation)



https://www.geogebra.org/m/Jd2VfGCH

the DMSRP stored measurements in .csv file are analysed with spreadsheets

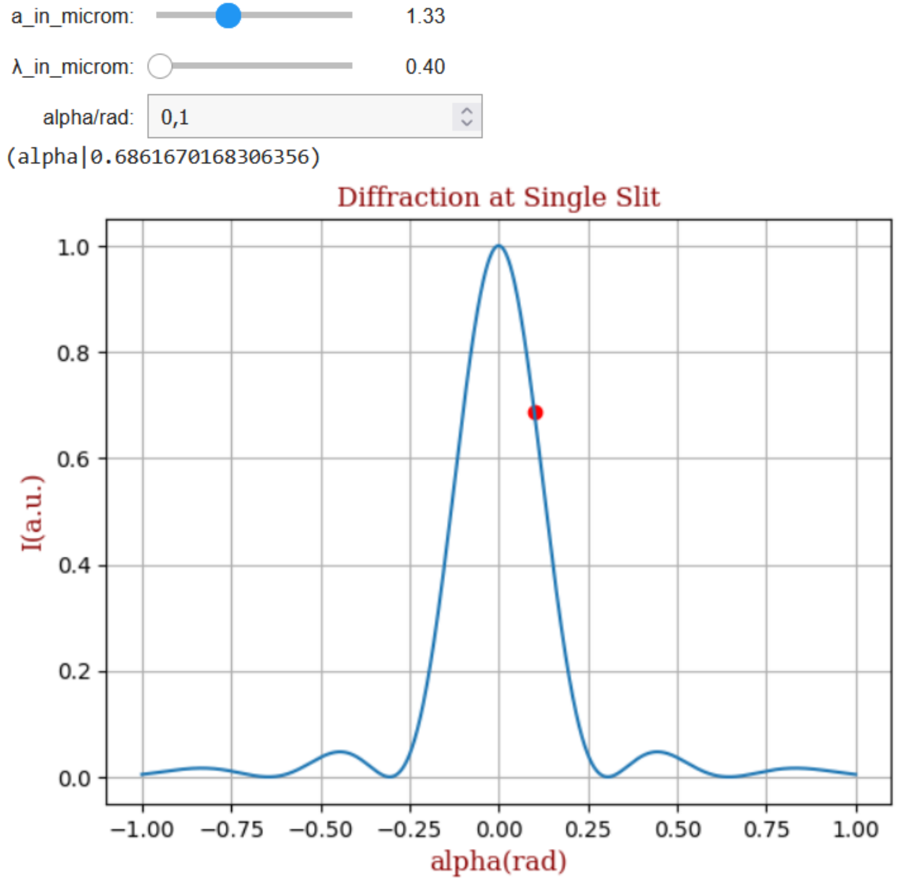


5. Learning the Physics of Waves With the DMSRP

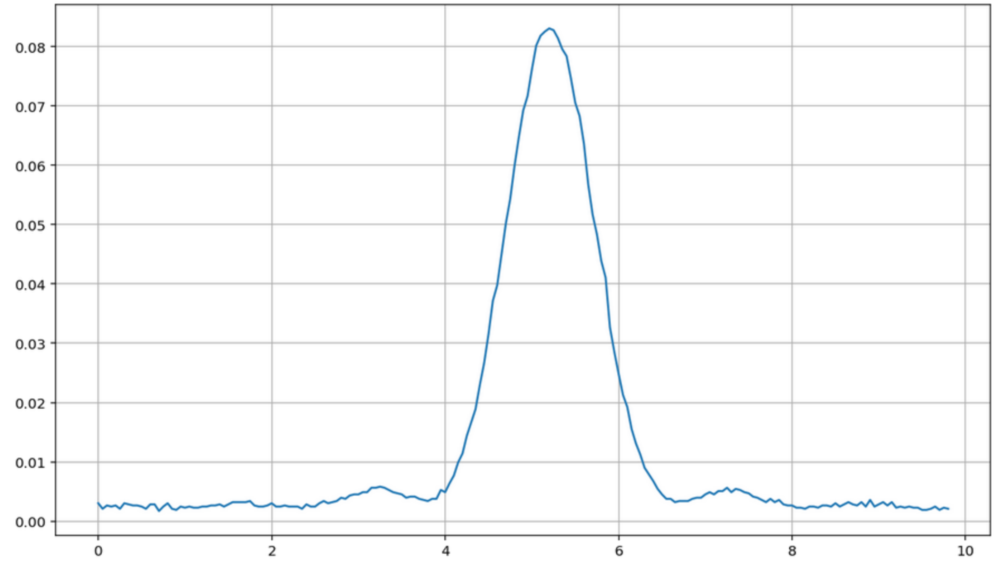
DMSRP can be integrated with web-based interactive notebooks such as JupyterLab

Students configure and arrange workflows including experimental description with images and videos, performing scientific processing of the collected measurements, scientific computing and interactive simulation of physical processes

$$I = I_0 \cdot \frac{sin^2\left(\pi \cdot \frac{a \cdot sin(\alpha)}{\lambda}\right)}{\left(\pi \cdot \frac{a \cdot sin(\alpha)}{\lambda}\right)^2}$$



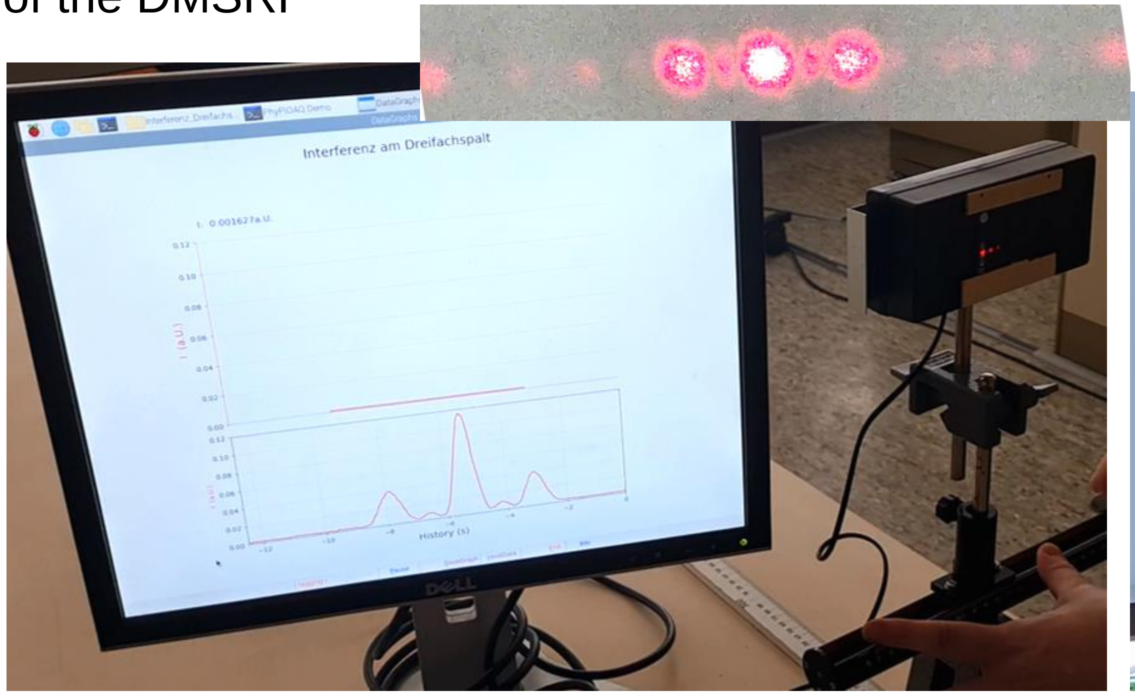

```
plt.plot(df["x"], df["y"])
plt.grid(True)
plt.show()
```

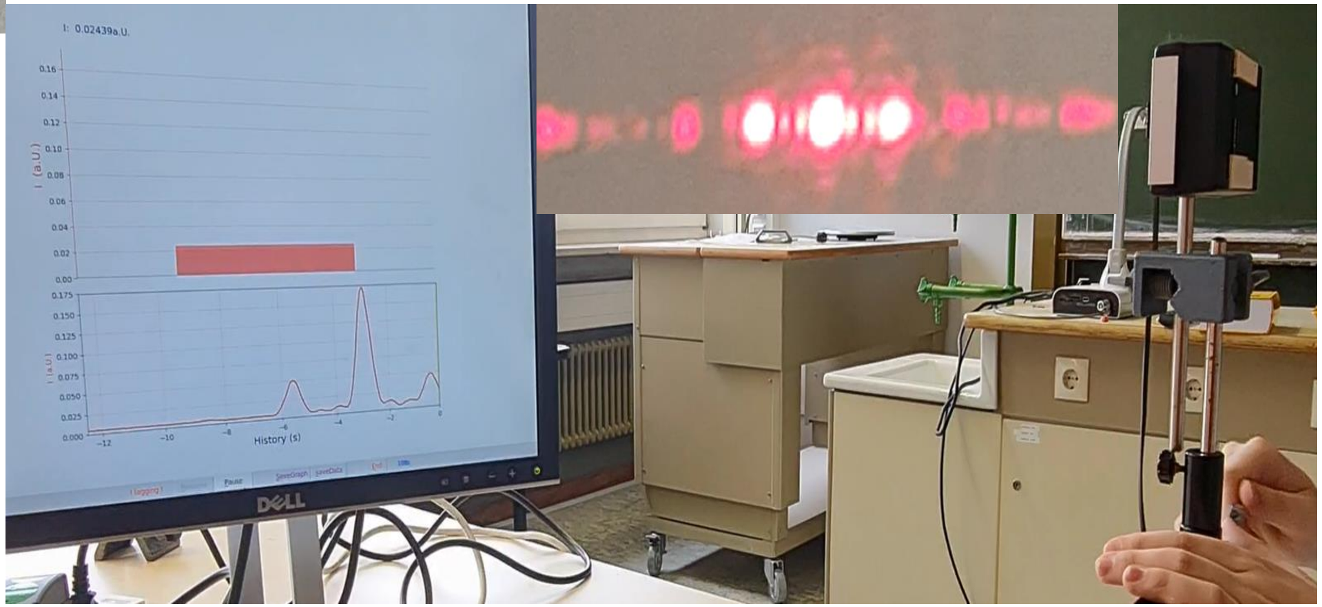


https://colab.research.google.com/drive/1Fe6fJzTRUWbWPmLVb-CxqTajVWvhCMwR?usp=sharing

DMSRP Supports Exploring of Interference in Two or More Actual Wide Slits Experiment

Intensity distribution at three- and four-slit experimental setting visualised in real-time in the DataGraph-Window of the DMSRP





https://youtu.be/I2H63bnTVHA https://youtu.be/k8rAGyqXAX4

Intensity distribution: Function as product of two factors describing the interference and diffraction at the same time. Interrelated to the simulated function https://www.geogebra.org/m/dvh6bg3a

Integrated with web-based interactive notebooks such as JupyterLab at:
https://colab.research.google.com/drive/1a1J9WNV0Bs0SotOvdB9TA-mna1RzkXQb?usp=sharing

6. Conclusions

DMSRP: powerful computation capability of the Raspberry; opensource PhyPiDAQ software; wide range of inexpensive sensors

Open-ended authentic problems

Constructivist approaches

DMSRP in various content and context integrated STEM environments; crosscutting concepts and core ideas such as in the case of wave

Engineering design as pedagogical approach; chain of purposeful hands-on investigation; technology-based exploration

Direct interaction of students with components of real-circuits that they can choose with respect to the characteristic of sensors or to the particularities of the built-in commands in the software

DMSRP supports mathematically modelling of complex science processes

Students become active contributors to their own learning in an environment which promotes self-confidence, endurance in learning complex concepts, excitement of solving authentic real-world problems and intrinsic motivation

The End