RESEARCH ARTICLE | JULY 24 2023

# Space research related topics at high school physics class

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*AIP Conference Proceedings* 2843, 050006 (2023)
https://doi.org/10.1063/5.0150986

# Space Research Related Topics at High School Physics Class

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**Abstract.** This paper, present a school project which helps to combine theoretical knowledge and students' creativity as well as engineering skills in a STEM activity. The topic is applied in classroom through inquiry and project-based teaching method. The goal is to develop students' competencies in a way that is interesting and fascinating to them. The project involves building a controllable rover that can explore unknown areas (planets) and meet specific measurement requirements, then transmit the data to the control center. In addition to the design and construction of the robot, the students will undergo every phase of testing and data processing until a well-functioning tool is produced.

## INTRODUCTION

The topic of space research in a classroom condition can be a challenging one for teachers. It is up to the teacher to figure out how to incorporate astronomy and space exploration related topics into the mandatory lessons in a useful, efficient manner since it is not part of the curriculum. Despite their enthusiasm for the theme, students are unable to process space-related research due to their impatience with the systematic study of the theoretical background and their inadequate knowledge of mathematics, physics, or computer science. A teacher who initiates a lesson focused on this should be able to make up for these shortcomings. In this case, the relevant European Space Agency (ESA) or NASA educational projects and their application within the given school context could be useful. The projects (recommended by ESA) require the building of different controllable devices, such as robots, that can explore unknown areas (planets) and perform measurements there, then transmit the data to the control centre. Among the main phases of the project are: to design of the rover, to write the motion control programs, to plan and theoretical foundation of the measurement task (design of the electrical circuits), to build the rover/equipment, and to coordinate the operation of each individual module, followed by the test.

It is essential to incorporate these elements into classroom work (physics or computer science classes), harmonize them with subject-related knowledge, and provide students with more opportunities for practical application, which they can learn about their usefulness and effectiveness. Whenever a project-based or research-based learning approach is used, students are active participants, and the teacher acts as a facilitator and leader. The teacher's primary role is to bring a challenging problem into focus. Once the problem is raised and discussed, the teacher will have to organize working groups so that each group can work independently, seeking answers to specific questions in different ways. This is the phase of inquiry that draws on interaction, brainstorming, and debate. The traditional elements of "school work" at this stage of the learning process can undermine inquiry and natural curiosity. The role of the teacher is to offer resources, direct curiosity in the relevant direction, and provide cognitive mentoring. In the second phase of learning, the teacher must clarify the information and misconceptions, as well as the data and knowledge gathered, selecting relevant elements, and then fitting them to the topic. At this point project ideas, scientific challenges, and implementation possibilities should be presented. In the meantime, working groups are established, which can be followed by the research and investigation phase. The research and investigation phase involves substantial, individual and group work, which is a very active and intensive stage of learning process. It is expected that the students will find answers to these questions, verify or disprove the hypothesis, experiment, and develop innovative and creative solutions. At this point of the learning process, the teacher works with the students, supervises their progress and

*Proceedings of the TIM20-21 Physics Conference*
AIP Conf. Proc. 2843, 050006-1–050006-10; https://doi.org/10.1063/5.0150986
Published by AIP Publishing. 978-0-7354-4594-9/$30.00

intervenes only if the subject goes completely off topic or if the time limit has not been met. The final, concluding stage of the project requires students to present their work, review it with the rest of the class, then clarify any questions or misinformation with experts and their teacher.

## THE TEKI - "MARS ROVER"

Teaching Approach, Learning Activities

The challenge from a pedagogical perspective was to incorporate a complex competition task (prescribed by the competition rules) into the learning process so that all students of the class could be involved in some way with this project. The purpose of the contest was to build a remote-controllable rover, a machine that can explore an unknown area (like a planet), perform precise measurements there, collect some samples of the examined area, transmit the data, images and information to a control centre and then analyse, interpret them (data). As part of the classroom's awareness-raising and introduction, we presented pictures, videos, news articles about new results related to Mars exploration and exoplanets. The question is what students know about this, how interesting it is to them, how well informed they are.

Through a short introductory survey, we examined how comfortable are the students with the following terms, acronyms and objects. Can they name which term each one relates to? Each student was only required to answer the questions they knew the answers to in full confidence.

1. ESA, ESO, NASA, CSA
2. planet, exoplanet, star, moon
3. satellite, moon, planet
4. binoculars, space telescope, ground telescope;
5. spectra, infrared, ultraviolet, visible light;
6. spacecraft, space shuttle, rocket, airplane;
7. astronaut, space rover, International Space Station

In addition to subject knowledge, the survey revealed who was interested in space research, one of today's fastest growing sectors. When young people tried to answer these "simple" questions, it was also revealed that they mostly had only superficial knowledge. Based on the results, it was important to form mixed groups where well-informed and motivated students could cooperate with their less interested but very creative peers. Taking into consideration the prior knowledge and working methods that youngsters have at different grades, the topics that we have studied were implemented with different groups of students. Learning topics for the class were the followings:

1. The electromagnetic spectrum and its relation to space exploration.
2. How do bodies move on the planet Mars? Investigation of straight, curved and angular motion.
3. Is there an atmosphere on another planet? Atmospheric characteristics (pressure, temperature, relative humidity, gas components, etc.) and their measurement.

As a subject students meet with optics in 9th and 11th grade class (in Romanian physics curriculum) as they learn about mirrors, lenses, and electromagnetic waves. However, it is hard for them to comprehend that this knowledge can be used for astronomical research. To become familiar with the concept of spectrum and understand that solar radiation is very complex, they must perform simple measurements and experiments. Using the Kahoot app, we start the lessons with short, attention-grabbing questions. If any questions that are not answered correctly, they must be rechecked after the measurement. Here, simple sensors measuring devices are used, which are easy to perform, lead to results immediately and can also be implemented in school yard or classroom.

Light measurement with semiconductor sensors: The aim of the measurements is to determine the radiated light components (visible, IR and UV index) using a simple measuring device. The dependence of the detected UV light on different parameters of the set up should be investigated by the measurement. The devices used for the measurement are: Arduino or Redboard (equivalent board) microcontroller, LCD display or laptop monitor, different light sensors (SI1145, TSL2561 and VEML6075), connecting wires, breadboard, UV and LED lamp as light source, power supply 5 V or 3 V (Fig. 1).


**FIGURE 1**. The breadboard, Si1145 sensor, Arduino and Redboard, UV lamp and wires for light and UV measurements

Setup instructions for the circuit (Fig. 2):
a). Connect the sensor Vin pin to the power supply, 5 V on the Arduino board.
b). Connect the GND pin to common power-ground pin on the Arduino;
c). Connect the SCL pin to the I2C clock SCL pin on your Arduino UNO analog A5 pin.
d). Connect the SDA pin to the I2C data SDA pin on your Arduino UNO analog A4 pin.
e). Connect the Arduino microcontroller to the laptop.
d). Check the circuit again, then load the appropriate program for the sensor from the library Arduino.

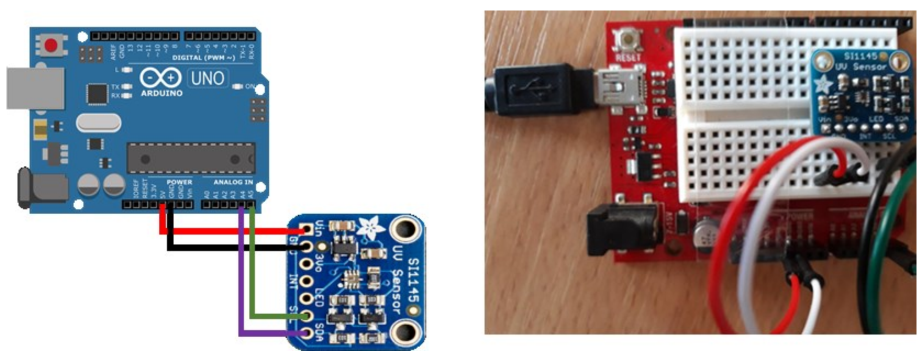


**FIGURE 2.** The experiment set up for light and UV index measurement with the SI1145 sensor

In accordance with the description of SiLabs, this SI1145 sensor does not contain a separate element for UV measurement, but its UV index value is calculated based on the visible and infrared light intensity of the solar radiation. There are also individual visible and IR sensing elements, which can measure their intensity directly. The sensor is calibrated (this can be verified by the students by comparing the data measured by the sensor with those measured by the official meteorological centre for a few days) and it is suitable for school measurements.

The other two sensors (TSL2561, VEML6075) require similar assembly, loading the appropriate software package from the Arduino library, and then experimenting. These sensors have been used because they have a complete and free software package in the Arduino library, are calibrated, and provide reliable data. Students do not have to program the measuring device; they can concentrate on the observed phenomenon and processes during the measurement. Each of the three workgroups (each group works with a different sensor in a similar environment) presents their results and discusses them at the end of the measurement (Fig. 3).

Measuring tasks:

After the circuit is assembled, measure the sensor's readout to see if it shows 0 in absolute darkness. Turn the sensor towards a window in direct sunlight and note the maximum reading: $\boldsymbol{I_{max}}$ ($I_{max}$ -is the maximum of measured intensity of light).

Put the sensors on the desk and measure the value without switching the light on in the classroom ***I,*** (I- is the measured intensity of light).

Place an UV-lamp 1 m (***d=1 m***) above the UV sensor (SI1145, TSL2561, VEML 6075) and observe on the laptop or display the appeared data.

Reduce the distance (***d***) first by 20 cm than by 10 cm finally by 5 cm between the sensor and the lamp, and collect your measurement data in a table. Plot an ***I-d*** diagram using the measurement data. The measurement can be performed for other distances as well; it is important to have more measurement data from which a graph can be plot.

Effect of different filters: Set coloured transparent foils or glass plates in front of the lamp and observe how the measured intensity (***I***) values will change.

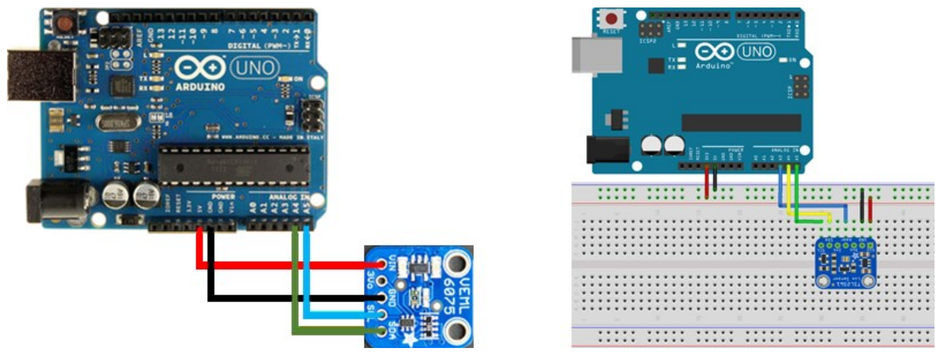


**FIGURE 3**. The experiment set up for VEML6075 and TSL2561 sensor

Questions to be answered:

A. How does the measured light intensity and the UV index change as a function of the distance between light source and the sensor? Describe the measured light intensity-distance (***I-d***) diagram. Explain how the intensity changes with distance! (Fig. 4)

B. How does the measured intensity and UV index change if different coloured glass plates are placed in front of the lamp to illuminate the sensor? Explain: how the measured light intensity and UV index are changing, if through different coloured discs or foils is the sensor lighted up?

C. What is the difference between filters of different thickness and colour?

D. Which one filters the UV radiation of the lamp more efficiently? What is the practical significance of this? Name some differences between these light filters. Which one is the most efficient for UV radiation? Describe the possible application of this filter!

Please describe your feelings and observations about the experiment. What did you learn from the measurement?

E. How could these filters be used in space exploration? What is the role of light filters, how can the knowledge of the light spectrum be utilized in astronomical observations and space research?

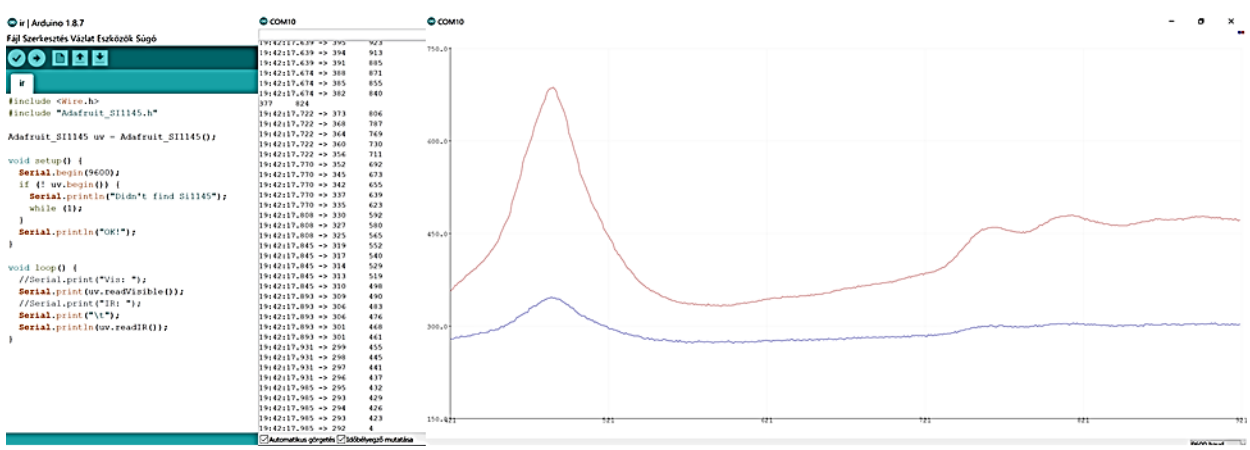

**FIGURE 4**. Arduino program for light measurements, raw data for visible and IR light intensity diagram

The whole class can perform these simple experiments, using sensory measurements and analogue measuring instruments, preferably in parallel. A comparison of the two measuring results allows discussion of the accuracy of the instruments, the concept of measurement tolerance, and the selection of the most appropriate measurement method. In addition, this method can also be used in introducing students to the possibilities offered by the Arduino board, enabling them to perform similar measurements on their own, even with sensors built into their smartphones. As students are carrying out the measurements, they should explore the practical applications and usefulness of the measurements, so that they can make the connection between the theory and practical application in the real world.

## The TEKI Rover-project

The planet Mars is a potential future target for human space exploration. Before astronauts are sent there, key technologies need to be explored and tested with the help of robot missions. An important step in this plan will be a mission in which humanoid robots could land, move on the surface, and then collect samples from the soil and rocks, and perform there some experiments. There were similar challenges in the exo-Rover project. The purpose of the contest was to conduct a space experiment based on scientific principles.

Essentially, the rover was designed to gather information about the environment, atmosphere and soil characteristics of a place that has yet to be discovered. Therefore, images and soil samples were collected from the surface. In order to achieve this, we measured the indexes of the electromagnetic spectrum: ultraviolet, visible, and infrared radiation, as well, took air quality measurements and defined the relative humidity. The inertial sensor systems included gyroscopes, accelerometers, and magnetometers in order to gather data on the motion of the unit.

Three major parts of the project were identified: planning and preparation, testing and correction, and the final product implementation. A discussion style-debate will begin the preparation phase of the project, during which participants will learn about the structure, launch, and research of the new Mars rover Perseverance. In this preparatory phase, the students acquired the necessary tools and equipment (space-related knowledge, videos, images, and technical information about Mars missions). A group of students was formed for each phase of the rover project based on their individual motivation and abilities. Following the introduction and questioning phase of the learning process, working tasks were defined with the deadlines within which they must be completed (Fig. 5).

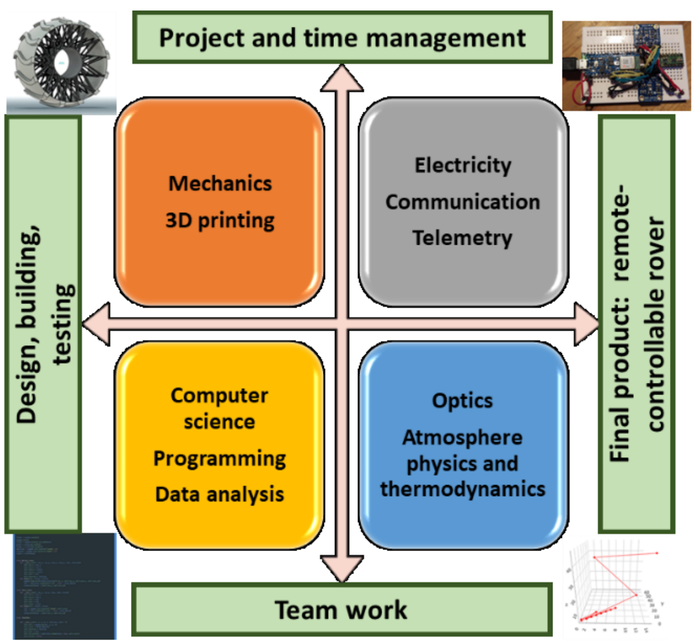


**FIGURE 5**. The Teki project work diagram

The rover has four-wheel drive, which made easier to control when entering curves. The tires were similar to Michelin Uptis (Unique Puncture-Proof Tire System), the airless mobility solution for passenger cars, which reduces the risk of punctured tires as well as other defects caused by road hazards. This idea was proposed by one of the students who has been studied this type of tire (Fig. 6). Finally, treads were added to the tires to increase efficiency, an idea that came from studying the wheels of a Perseverance rover.

**FIGURE 6**. The Michelin Uptis airless tires vs our printed 3D tires designed by Cs. Cs.

To simulate the assembly process, the final product, and determine how certain elements should be installed for space-efficiency, the design team compiled some virtual visual plans of what the rover would look like (using Fusion 360 free software in 3D). A 3D printed shape was used to construct the main chassis for the rover, as we considered it would be possible to design a structure of the right size and strength to meet the contest requirements, as well as protect the built-in measuring devices. In order to examine the physical properties of the finished structure: flexibility, fragility, etc, a test piece was printed for every component: tires, axles, robot arm, chassis, and cover. This was accomplished by testing different types of print fibres - for example, all eight wheels and axles were printed from different kinds of fibres (PLA, ABS, PET-G, and fishing fibre) to find out which would lend the rover better mechanical properties. Load and fracture experiments conducted in the classroom revealed that ABS and PLA fibre wheels and axles crack under high stress. The PET-G fibre-made axles and wheels withstood loads and temperature changes better, though they were damaged by moving on a high-friction surface. The grass-mowing fibre, on the other hand, was flexible enough but difficult to print and quickly wore down its surface during friction. The experiments and test measurements have led to the conclusion that PET-G fibre will be suitable for the rover's chassis and axles. The most flexible material was the Python flex (high-performance flexible thermoplastic polyurethane (TPU) filament), while Fiberflex should be used for the wheels.

To design the circuits, the appropriate sensors, microcontrollers, and communication elements had to be selected first. Designers of electrical circuits were challenged to determine not only which was the most cost-effective circuit component for rover control, movement, and measurements, but also how to make it work. Due to this, the different circuit modules have been designed with several aspects in mind. As part of the design, the biggest challenge was how to control the rover remotely. What communication units (transmitter, receiver, GSM, etc) have to be built in to control the robot, the robot arm, the camera, and the measurement modules hundreds of kilometres from the classroom.

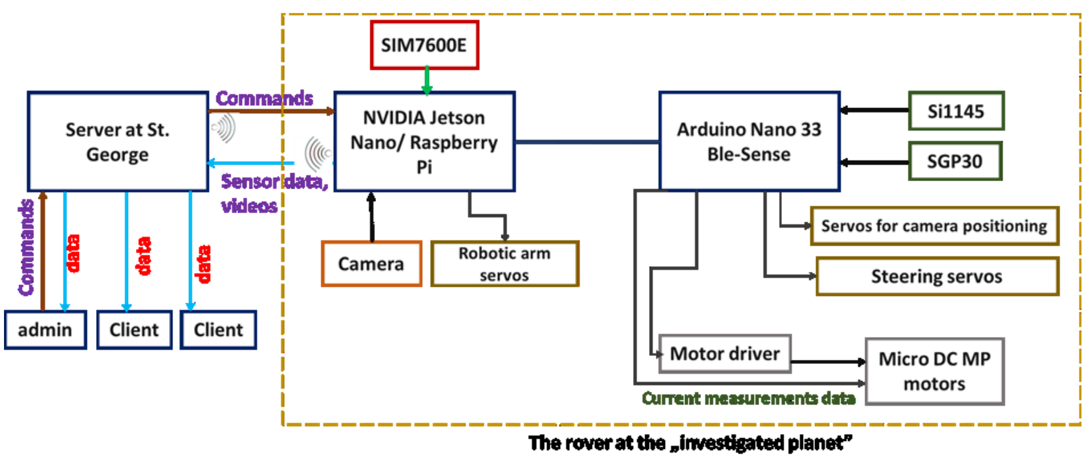


**FIGURE 7**. The flow diagram for Teki -rover and communication system

Our solution was to use an Arduino Nano 33BLE Sense microcontroller to drive the measuring module, since it has built-in sensors for temperature, pressure, humidity, light and color as well as a 9 axis Inertial Measurement Unit (IMU). It also has a low power consumption, powerful Cortex M4F processor and could be connect to additional sensors like: Si1145 for UV index and IR intensity, SGP30 to detect the air components. This microcontroller also allowed control of the servomotors (wheels, robot arm) and could be easily connected to the Raspberry Pi / Jetson Nano module (Fig. 7).

The IT team had to solve three main tasks: build the rover's remote-control program, collect and process camera and sensor data, and create a website that can track the robot's movement live and the graphs of measurement data. Different coding languages were used to achieve these tasks, like: Python, MySQL, Java, C++, which were learned partly at computer science classes and partly during the project to meet the contest challenges.

The Raspberry Pi microcontroller served as the "brain" of the rover. This microcontroller connected the server (which consisted of laptops), the radio communication unit, the internet protocol and the Arduino Nano controller module. Remote control tasks:

- Control and navigate the rover on the route via IP to reach a specific destination.
- Stable two-way communication;
- Command the rover through the server to correct the deviation from the course.
- Controlling the robotic arm that the camera continuously sends images of the area being examined.

For the IT group, the hardest part was broadcasting live camera images without losing contact with the rover. In order not to overwhelm the rover's internet connection, it was necessary to restream the live camera feed. Using this method, the traffic-intensive operations were offloaded to the server.

The rover was controlled with the help of a server-side application which ensures that in case are experienced any connectivity issues during the mission the server will store any unsent data until the connection is backed up (Fig. 8). All the data were encrypted and error checked using various methods in order to protect the project from any malicious attempts or data loss. The ground support equipment consisted of a server which handles the website, the live feed, and the communication between the rover and the control application. The graphical control interface run on the students' laptops.

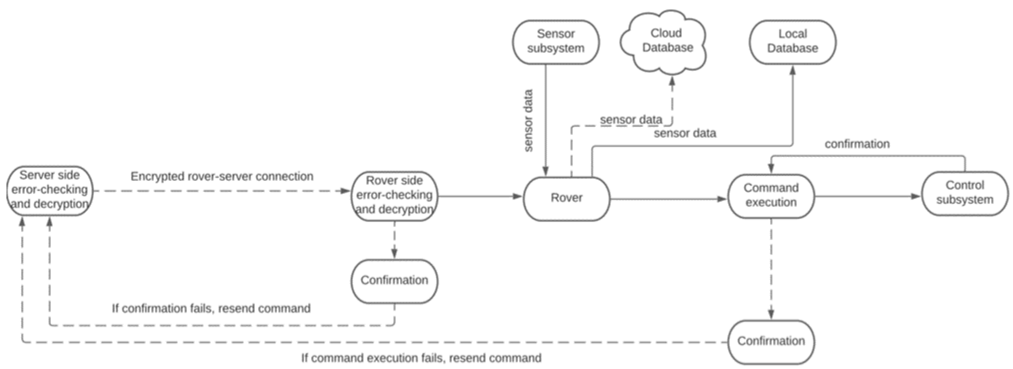


**FIGURE 8.** Flow- diagram of the command software (designed by G. Zs)

The global testing was carried out both indoors and outdoors. Indoor test provided a fast and reliable way to debug as well as replace specific components. During this phase each component separately had to be tested, aiming to check how accurate they measure (air quality sensors) and how long they resist under certain conditions (cold/hot, humid/dry, etc.).

**FIGURE 9.** Outdoor testing with the finished T3KI rover (photos by Teki team students)

The outdoor test was more challenging since it had to complete the entire route, overcome obstacles, take measurements, and test the remote control and video streaming. In this way, the camera was tested under various lighting conditions and the navigation system from distances of different lengths. As the youngster has to learn from errors when the device malfunctions, testing its movement with different obstacles was an essential step. So, the rover was driven to various locations on hillsides in order to measure both the wheel's efficiency and the vehicle's dynamics (Fig 9.) In order to determine whether the newly discovered "planet" was suitable for life, atmospheric measurements (pressure, temperature, relative humidity, atmospheric gas components, light and IR intensity, UV index) had to be performed and soil samples had to be collected. The gas components (CO2, TVOC gas concentration) were recorded by the SGP30 sensor, the light measurement was given by the SI1145 sensor and the thermodynamic characteristics of the air by the Arduino Nano 33 Ble sense built-in sensor, according to a properly written program for each. For data processing, the raw data collected by these sensors had to be sorted and compiled separately, and then graphs and analyses were created based on the processed data (Fig. 10). Creating a public website was essential to the success of this mission, as well as explaining the science behind the graphs with 2D and 3D diagrams. (http://exo.xdd.ro/ and https://www.facebook.com/mikoexoro/)

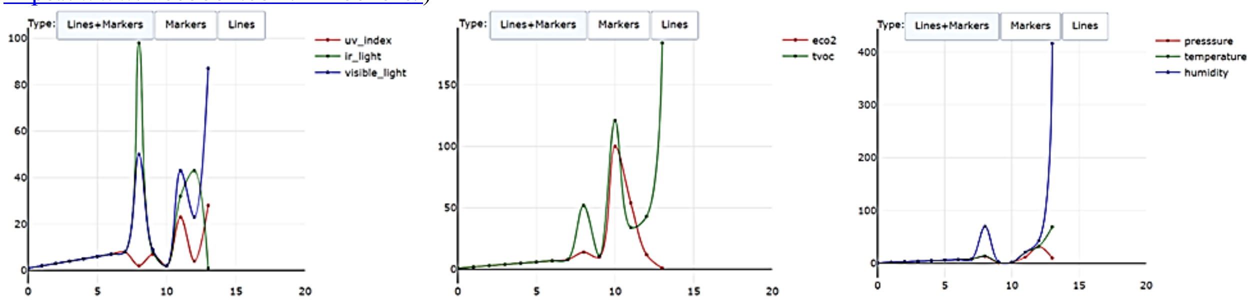


**FIGURE 10**. Data processing: light spectrum, air gas components, pressure, temperature and relative humidity

Following the light sensor data, it was seen that the rover was driving in completely dark, unlit and then in a strong sunny location on certain sections. The data of the morning measurements differed significantly from the data of the second, afternoon measurement, as the temperature of the atmosphere increased by more than 10 degrees during the day. These were indicated by our measurements, but were also checked on the data-basis of the official meteorological station.




**FIGURE 11**. From the 3D design prototype to the T3KI rover and team logo

By virtue of its name, this rover already embodies the essence of the whole project and learning process: T-talent, E-endurance, K-creativity, I-innovation. (Fig. 11) For all phases of the project, including design, construction, testing, data collection, and analysis, students' imagination and knowledge, as well as innovative ideas, were vital to solving the problems. In both the design and test phases, the knowledge gained during the mechanics lessons (force, speed, acceleration, curvilinear motion, deformation, flexibility or friction) were integrated. While electrical current, resistors and capacitors are vital for the design of circuits, it is equally important to learn new topics such as the principle of operation of semiconductor sensors and their physics. In order to implement remote control programs, long-distance communication successfully, the IT team needed to come up with creative ideas since that was an area they had never experienced before. Environmental data collection, atmospheric measurements and data processing used knowledge of ideal gases and thermodynamics. After that, the relationship between weather changes, air composition and thermal state characteristics had to be discovered and documented.

The project was a success due to the time that was spent preparing properly, studying the scientific background, and conducting it, as well as the constant encouragement and stimulation of students' creative work. A presentation of the results, mistakes, and failures was given to students who did not participate in the activities. These demonstrations are, in fact, the final step in clarifying knowledge, the stage of deepening a student's understanding. Teams were always able to find the best answer to a given question due to good team communication and meaningful debate throughout the whole project. During this interdisciplinary project, students have combined their knowledge from different science fields (physics, mathematics, chemistry, geology, geography, engineering, informatics, and applied computer science) that demonstrate their ability to complete such a complex task. In order to put all of their knowledge into a new perspective, they needed to develop scientific thinking to explain every-day and technological applications of science, evaluate their social, economic, and environmental impacts, and make decisions based on evidence and argument. Students' personalities and knowledge are developed through this learning process.

## CONCLUSION

As a result of the study, it was concluded that some factors need to be taken into consideration whenever we wish to attract students' attention to space activities. First, the topics should be presented as broadly as possible through simple activities. By showing the different aspects of space activities in our daily lives using simple communication, rather than lengthy classroom lectures, we need to make space activities more relevant. Pay attention to the small but significant results and discoveries that can even be presented with a short video and animation (as an attention-grabber) at the beginning of the lesson because they are significant for student understanding. To be effective, topics should not be forced every hour but rather be processed in short experiments or more extensive 2–3 months projects (like this TEKI-rover project).

Science will be more enjoyable, understandable, and eye-catching for students through this project. By participating actively, they can grasp the meaning behind the questions raised, to verify the hypotheses better than by learning in a traditional classroom. Thereby they acquire a better understanding of topics and concepts that are not directly related to their school work, but which can shape their worldview and attitude toward the space science. The teams made up of people with different background knowledge, skills, and interests worked well together. Students with mathematics and physics proficiency processed the scientific parts, while students with engineering ambitions constructed and assembled the structures. Youngsters with humanistic and artistic appreciation made the presentations, stickers, photos, and videos. The final survey and closing discussions, show that students who have been involved in the whole learning process already recognize the acronyms and terms used in space exploration, navigate in the world of space telescopes and research rovers safely.

Robots can be used in an educational environment to motivate and engage students in learning science, engineering, computer science, and math, as well as to expose them to new technologies and arts. The experience has shown that students who are involved in solving such tasks for at least one academic year, are more confident in their career choices, mostly in technical, IT-based undergraduate studies. These students have advanced critical thinking, are more open to technical innovations, easily engage in solving highly challenging problems, and are more creative.



## ACKNOWLEDGMENTS

The project was funded by Content Pedagogy Research Program of the Hungarian Academy of Sciences (MTA). I would like to express my appreciation and thank my students from the Székely Mikó Science Club for their dedication, hard and persistent work, for the excellent results over the last few years.

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