STExperiMents Toolkit: Inquiry-based Tasks for STE(A)M Classroom

Bahcesehir University (BAU) • Charles University (CUNI) • Johannes Kepler University (JKU) • University of Jyväskylä (JYU)

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The publication has not been stylistically revised. Authors of the articles are responsible for their content.

Further resources and information about the STExperiMents project can be found at: https://stexperiments.pedf.cuni.cz/

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Welcome to the STExperiMents Toolkit

This is the STExperiMents Toolkit, a collection of 8 carefully designed, interdisciplinary STE(A)M experiments developed by four universities. The experiments invite students aged 10–18 to engage with real-world scientific questions through hands-on investigation, virtual simulations, creative thinking, and collaborative problem-solving.

Each experiment is rooted in a core scientific phenomenon — from the optics of rainbows to the engineering challenge of keeping vaccines cold in remote settings — and connects that phenomenon to Technology, Engineering, Arts, and Mathematics. Together they form a coherent pedagogical toolkit that supports you in delivering lessons that are both scientifically rigorous and genuinely engaging.

The experiments come in two formats: physical (hands-on laboratory or classroom activities) and virtual (digital simulations using tools such as Algodoo and PhET Colorado).

About the STExperiMents Project

STExperiMents is a European collaborative educational project bringing together teacher educators, subject-matter specialists, and curriculum designers from four universities: Bahcesehir University (BAU), Charles University (CUNI), Johannes Kepler University (JKU), and the University of Jyväskylä (JYU). The project's central goal is to develop innovative, inquiry-based science experiments that genuinely integrate all five STE(A)M disciplines and are suitable for secondary / high school classrooms across Europe. The experiments in this toolkit emerged from multiple rounds of design, classroom testing, and iterative revision. Each partner contributed experiments reflecting both their regional scientific traditions and the specific learning challenges they observed in their students. The result is a collection of activities that are diverse in topic, format, and difficulty — but unified by a shared commitment to inquiry-based, student-centred learning.

What is STE(A)M Education?

STE(A)M stands for Science, Technology, Engineering, Arts, and Mathematics. It is an educational approach that brings these five disciplines into dialogue, encouraging students to use knowledge and methods from across all of them to investigate questions, solve problems, and create things. Rather than treating each subject as a separate silo, STE(A)M recognises that the most interesting and important challenges — in science, in society, in technology — require multiple ways of thinking at once.

SCIENCE	Exploring natural phenomena through observation, hypothesis, and experiment. Understanding the principles behind how the world works.
TECHNOLOGY	Using and critically evaluating tools, software, and instruments to investigate phenomena and communicate findings.
ENGINEERING	Designing, building, and testing solutions to real-world problems under constraints of materials, time, and safety.
ART	Applying creativity, visual thinking, and aesthetic judgment — making findings visible, communicating data through design, and connecting science to culture.
MATHEMATICS	Quantifying, measuring, representing patterns, and reasoning abstractly to deepen understanding across all other disciplines.

In the STExperiMents experiments, every activity makes explicit which STE(A)M disciplines are primarily involved. Teachers are encouraged to use this as a starting point for dialogue with colleagues from other subject areas, and to extend the connections further depending on their students' context.

Using the Toolkit: Pedagogical Principles and Practical Guidance

The toolkit is designed to be flexible. You can pick up a single experiment and use it as a standalone lesson, or you can combine multiple experiments into a longer inquiry unit. Below are a few practical suggestions.

Pedagogical Principles of the Toolkit

The STExperiMents Toolkit is based on the idea that students learn science most effectively when they actively investigate phenomena, formulate questions, test ideas, interpret evidence, and communicate their conclusions. For this reason, the experiments are designed as inquiry-based learning activities rather than as demonstrations of ready-made facts.

Across the toolkit, students are encouraged to take the role of researchers, designers, problem-solvers, and communicators. They make predictions, collect and analyse data, compare alternative solutions, discuss results with peers, and reflect on the meaning of their findings. This process supports not only conceptual understanding, but also the development of broader competences such as collaboration, creativity, critical thinking, communication, and evidence-based reasoning.

The activities also follow a design-oriented approach. In many experiments, students are not expected to find one single correct answer immediately. Instead, they test ideas, identify limitations, revise their approach, and improve their solutions. Mistakes and unexpected results are therefore treated as valuable parts of the learning process.

Teachers are encouraged to create a classroom atmosphere in which students feel safe to ask questions, propose hypotheses, challenge explanations, and learn from trial and error. In this sense, the toolkit supports a shift from teacher-centred instruction towards active, student-centred STE(A)M learning.

The Role of the Teacher

In the STExperiMents activities, the teacher acts primarily as a facilitator of learning. This means guiding students through the inquiry process, asking productive questions, supporting group work, ensuring safety, and helping students connect their observations to scientific concepts.

Rather than providing immediate answers, teachers are encouraged to prompt students to explain their reasoning, compare evidence, reconsider assumptions, and justify their conclusions. Questions such as *"What do you notice?", "Why do you think this happened?", "How could you test this idea?",* and *"What evidence supports your conclusion?"* can help students move from observation to deeper understanding.

The teacher also plays an important role in adapting the activities to the classroom context. Depending on students' prior knowledge, available time, and access to materials or digital tools, the experiments may be simplified, extended, or connected to other curriculum topics.

Assessment and Reflection

Assessment in this toolkit should focus not only on the final product or correct answer, but also on the learning process. Students' ability to ask meaningful questions, plan investigations, collaborate with peers, record and interpret data, revise ideas, and communicate findings should be considered important evidence of learning.

Teachers may use a combination of observation, student worksheets, group presentations, peer feedback, and short written reflections. Reflection questions help students become aware of how their thinking developed during the activity. They also support metacognition by encouraging students to identify what they learned, what challenged them, and how they might improve their investigation in the future.

Where appropriate, teachers may also assess STE(A)M competences separately. For example, scientific understanding, use of technology, engineering design, visual communication, and mathematical reasoning can each be observed within the same activity. This makes assessment more holistic and better aligned with the interdisciplinary character of STE(A)M education.

Safety and Classroom Management

Before implementing any physical experiment, teachers should review the materials, classroom conditions, and potential risks involved. Activities involving heat, flames, glassware, chemical substances, electrical devices, or sharp tools should always be carried out under teacher supervision and in accordance with the school's safety regulations.

Students should be informed about safe handling procedures before the activity begins. Where necessary, protective equipment such as safety goggles, gloves, or lab coats should be used. Teachers should also ensure that students understand how to behave during group work, how to share materials responsibly, and how to report accidents or unexpected situations immediately.

For virtual experiments and digital tools, teachers should consider students' access to devices, internet connection, data privacy, and age-appropriate use of online platforms. Clear instructions and time limits can help students stay focused and use technology purposefully.

How to Use This Toolkit

Start with One Experiment

Browse the overview table on the next page. Choose the experiment whose topic aligns most closely with your current curriculum unit. Read the full experiment guide before the lesson — each one contains teacher moves, discussion prompts, potential misconceptions, and tips for differentiation.

Use the Student Worksheets

Every experiment includes a student worksheet. These are structured to guide students from initial prediction, through observation and data collection, to reflection and connection to real-world applications.

Structure of Each Experiment Entry

Each experiment entry in this toolkit is organized as follows:

Grade Level & Duration: The recommended age group and approximate time needed.
STEAM Connections: A table showing which disciplines are engaged and how.
Key Concepts: The scientific and cross-disciplinary concepts at the core of the activity.
Prerequisites: What students should already know before starting.
Resource List: All materials needed (physical or digital).
Development of the Experiment: Step-by-step teacher and student instructions.
Assessment: Observation criteria and reflection questions.
Adaptations: Ideas for simplifying or extending the activity.

Overview of the Experiments

The following table provides an overview of all eight experiments. Each experiment is identified by its partner institution, topic, recommended age group, and format.

#	Experiment Title	Partner	Grade	Format
1	**Keeping Vaccines Cool: How do you keep vaccines cool in warm weather with a limited power supply?**	BAU University	6th-8th Grade (aged 11 – 14)	Physical
2	**From Walking to Falling: Investigating Acceleration**	BAU University	9th Grade (aged 14 – 15)	Virtual
3	**When Does a Candle Stop Burning?**	CUNI	Lower and Upper - Secondary School	Physical
4	**Become a pH Detective!**	CUNI	Lower and Upper - Secondary School	Virtual
5	**Materials Race: Exploring Gravity and Friction with**	JKU	5th-7th Grade (aged 10 – 12)	Physical
6	**How Does a Rainbow Happen? Light and its Properties…**	JKU	5th-9th Grade (aged 10 – 14)	Virtual
7	**Light and Colours: RGB Colour Mixing and Diffraction**	JYU	Middle to High School	Virtual
8	**Creating Colourful Shadows: Exploring RGB Light Colour Mixing and Diffraction**	JYU	Middle to High School	Physical

Keeping Vaccines Cool: How do you keep vaccines cool in warm weather with a limited power supply?

Nilay Ozturk, Sezin Esfer, Ayse Gul Celenk

Grade Level	6th — 8th Grade (students aged 11–14)

Activity Duration	Two class periods (30 min + 60 min) or one 90-minute session with streamlined activities.

Competencies and Skills	**Critical Thinking:** Evaluating the effectiveness of different insulating materials and design strategies. **Problem-Solving:** Addressing challenges in maintaining temperature without continuous power. **Collaboration:** Working in teams to design, build, and test the insulated container. **Creativity:** Developing innovative solutions to a real-world problem. **Data Analysis & Arts Integration:** Recording, interpreting temperature data over time, and visualizing findings using graphs, infographics, or creative representations.

Experiment Description	In this hands-on experiment, students will work in teams to design, construct, and test an insulated container capable of maintaining a temperature between 2°C and 8°C. This simulates the real-world challenge of keeping vaccines viable in warm environments with limited access to power. Students will use various materials to build their containers and assess their effectiveness by monitoring internal temperatures over time.

General Objectives of the Experiment	● Understand the importance of temperature control in vaccine storage. ● Evaluate the importance of vaccines for human health. ● Discuss the limited health opportunities in underdeveloped countries. ● Apply principles of heat transfer in a practical context. ● Develop problem-solving and teamwork skills through collaborative design and testing. Integrate mathematical data visualization and artistic representation into scientific inquiry.

Concepts for STE(A)M Disciplines	
Science	● Temperature ● Heat transfer ● Vaccines and human health
Technology	● Use of thermometers and/or temperature probes
Engineering	● Design and construction of insulated containers
Art	● Visualization of data through infographics, sketches, or posters ● Exploring traditional insulation techniques used in various cultures
Mathematics	● Measurement and data analysis ● Graphing temperature changes over time

Prerequisite Knowledge	
Science	● Basic understanding of heat transfer and insulation
Art	● Basic understanding of visual storytelling or graphical representation
Mathematics	● Ability to measure temperature and record data

Learning Outcomes	
Science	● Explain how insulation reduces heat transfer. ● Describe the significance of temperature control in preserving vaccine efficacy.
Technology	● Demonstrate accurate use of temperature measurement tools.
Engineering	● Design and build an effective insulated container.
Art	● Visualize data through infographics, sketches, or posters.
Mathematics	● Collect, record, and interpret temperature data over time.

Resource List
Recommended for groups of 4 students: ● Small containers to represent vaccine vials (e.g., film canisters or plastic test tubes) ● Thermometers or temperature probes ● Glass jars with lids ● Insulating materials (e.g., foam, cotton, fabric, bubble wrap, aluminium foil) ● Cardboard boxes or plastic containers for constructing the insulated box ● Ice packs or frozen gel packs ● Timers or clocks ● Access to a warm environment (a heat lamp) to simulate warm climate conditions ● Notebooks and pens for recording data ● Graph paper or software for data visualization ● Art supplies (optional: for creative data presentation)

Development of the Experiment

SESSION 1: Introduction to the concept of heat transfer and insulation (30 minutes)

Teacher-led introduction (10 minutes):

Teacher move-1

Start the lesson by starting a discussion on the importance of vaccines and the necessity of maintaining them within a specific temperature range. Ask the following questions: "Why do we receive vaccines, and how do they impact public health?" and What would the world look like without vaccines? This section is to arouse curiosity among students, no detailed explanations needed.

Then, explain the basic mechanisms of vaccination.

Notes for the teacher:

Definition: Vaccines are biological preparations that provide immunity against specific diseases.

Mechanism: They stimulate the immune system to recognize and combat pathogens without causing the diseases themselves.

Benefits:

Individual Protection: Reduces the risk of contracting diseases.

Herd Immunity: When a significant portion of the population is vaccinated, the spread of disease is curtailed, protecting those who cannot be vaccinated.

Teacher move-2

Then discuss the historical impact of vaccines and address common controversies and misconceptions:

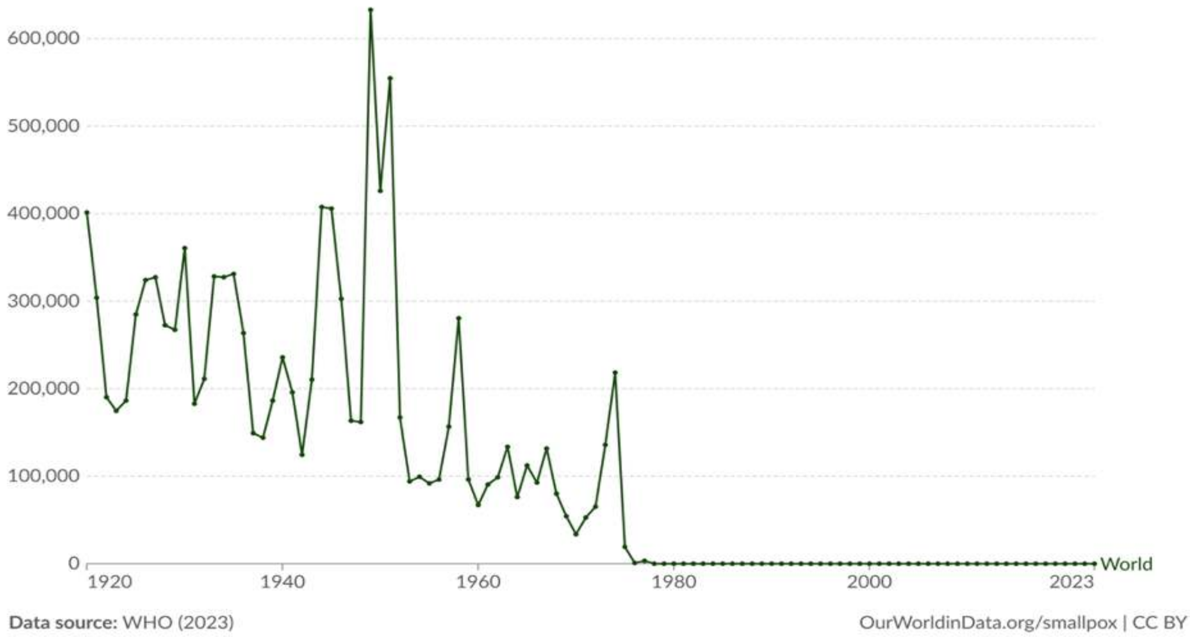
Smallpox Eradication: Highlight how vaccination led to the global eradication of smallpox.

Polio Reduction: Discuss the significant decrease in polio cases worldwide due to vaccination efforts.

Graph activity:

Provide students with the below graph showing the global decrease in the number of smallpox cases after the smallpox vaccine is invented. Ask the following questions to discuss the data presented in the graph:

What patterns do you notice in decreasing smallpox cases reported over time?



Graph: Smallpox cases reported worldwide

Information about Smallpox vaccines:

The smallpox vaccine was invented in 1796 by Edward Jenner, an English physician. Jenner observed that milkmaids who had contracted a mild disease called cowpox did not get smallpox. He hypothesized that exposure to cowpox could provide immunity to smallpox. To test this, he inoculated a young boy, James Phipps, with material from a cowpox sore. Later, he exposed the boy to smallpox, and the boy did not develop the disease. This breakthrough laid the foundation for modern immunology and vaccination practices. The smallpox vaccine is considered the world's first successful vaccine.

Source:
https://www.who.int/news-room/spotlight/history-of-vaccination/history-of-smallpox-vaccination
Vaccine Hesitancy: Some individuals are reluctant or refuse to vaccinate due to various concerns.

Notes for the teacher:
Common Misconceptions: --
Safety Concerns: Address fears about side effects and emphasize that vaccines undergo rigorous testing to ensure safety.
Autism Myth: Clarify that extensive research has found no link between vaccines and autism.
Misinformation: Discuss how false information spreads, especially through social media, and the importance of consulting credible sources.

Teacher move-3a

After these discussions, teacher presents (either read it, share a digital copy, or give students as a handout) the problem that students will need to solve:

“You are a team of scientists and logistics experts working to deliver vaccines to a remote village in a country. Electricity is unstable, refrigerators are unavailable. Let’s design an insulated container that can maintain a "vaccine" (represented by a vial filled with water) within the temperature range of 2°C to 8°C for 3 hours.”

Then the teacher makes the students realize that to be able to solve this problem, they need to know about the concept of heat and the ways to stop heat loss.
Teacher starts the following activity to introduce the concepts of heat transfer and insulation:

Student hands-on activity (20 minutes): Heat Transfer and Insulation Activity

Teacher move-3b

Discuss with students why do we need cold chain to keep and transport vaccines safely. Give examples from daily life that shows what are the results of any failure in the cold-chain such as cold chain failure during COVID-19 vaccine transport to Africa.

Connect the example to the heat transfer and insulation activity below:

Materials needed: 5 identical glass jars with lids, Thermometer, measuring cup, Hot water, Stopwatch or timer, Insulating materials (Aluminium foil, Bubble wrap, Wool fabric or scarf, Paper, one jar left unwrapped (control), Tape, Notebook and pen for recording data.

Provide students with some insulating materials. Cut each insulating material into pieces large enough to wrap around a jar three times. Wrap each jar with a different material, securing it with tape. Leave one jar unwrapped to serve as the control.

Fill each jar with an equal amount of cold water (chilled with ice beforehand), so the activity matches the goal of keeping the vaccine cold. Measure and record the initial temperature of the water in each jar using the thermometer. Seal the jars with their lids.

Place all jars on a classroom table, ensuring they are exposed to the same room temperature conditions. Start the timer. Measure and record the temperature of the water in each jar every 5 minutes (at 0, 5, 10, and 15 minutes) to observe how it changes over time.
Calculate the temperature change for each jar by subtracting the final temperature from the initial temperature. Compare the results to determine which material provided the best insulation (i.e., the smallest temperature change).

- Explain how heat moves from warmer objects to cooler ones through conduction, convection, and radiation.
- Discuss how insulating materials can slow down this process by providing resistance to heat flow.

- Discuss how proper insulation is crucial in medical settings, especially for maintaining the efficacy of temperature-sensitive vaccines.

Temperature change recording table

Time (Minutes)	Temperature (Celsius)	Notes
0		
5		
10		
15		
…		

SESSION 2: Design, Testing & Presentation (60 minutes)

a-Design (20 min)

Teacher move-4

Remind the problem: “You are a team of scientists and logistics experts working to deliver vaccines to a remote village in a country. Electricity is unstable, refrigerators are unavailable. Let’s design an insulated container that can maintain a "vaccine" (represented by a vial filled with water) within the temperature range of 2°C to 8°C for 3 hours.”

Divide students into small groups (4 students in each group recommended) and provide them with the materials (See the materials in the Resource List). Give each group a vaccine vial, thermometer, 2 ice packs, a heat lamp, timer, and notebook and pen for recording data. Encourage each group to brainstorm and sketch their design for an insulated container, considering factors such as insulation effectiveness, size, and ease of transport.

Have each group construct their insulated container based on their design plans. Ensure that the container can hold the "vaccine" vial and an ice pack or frozen gel pack.

b- Testing and Retesting (20 min)

Teacher move-5

Insert the vial and two pre-cooled ice packs into the insulated container. Place a thermometer or temperature probe inside the vial. The teacher could measure the initial temperature for each group. Have students measure the temperature by following the steps described below.

Seal the container and place it in a warm environment (put it under a heat lamp with one 40-watt bulb) to simulate transportation in a hot climate. Start timing the 5 minutes for testing when teams place their vaccine coolers under the heat lamps. Have students measure the temperature of the vaccine vial at 5-minute intervals and record in the table given below. Students in each group should then open the coolers, remove the vial of vaccine, and measure the temperature of the liquid inside the vial (this time they open the lid of the vial and measure the temperature of the inside water). Now they have the initial and final measurement of the temperature of the vaccine vial.

Temperature change recording table

Time (Minutes)	Temperature (Celsius)	Notes
0		
5		
10		
15		
20		
…		

During testing, students will connect a digital temperature sensor to the vial for continuous monitoring.

Use an Arduino (ecord the temperature every 5 minutes, manually or — as an optional extension — using a digital temperature sensor (e.g., Arduino). Note for the teacher: this short test is a scaled-down model. Rather than verifying the full 2–8 °C-for-3-hours target, students compare designs by how slowly the temperature rises and discuss what would be needed to extend protection to several hours. Teachers without access to digital sensors could use manual measurement (pen-and-paper data recording).

Have students graph the temperature drop using Excel or Google Sheets.

Ask the following questions for discussion: Which design kept the vial coolest? Why? How did the ice pack arrangement and overall container design impact the results?

Students can compare temperature differences across groups and analyze which designs were most effective.

After the testing period, have students analyse their temperature data to determine how well their container maintained the desired temperature range. Encourage groups to discuss what worked well and what could be improved in their designs.
Allow time for redesigning and retesting their containers based on their findings. Also, ask them what they should further do to prolong the hours to keep vaccines cool (more than 3 hours).

c- Sharing (20 min)

For group sharing, each group presents their design process, test results, and any modifications they made through a digital poster. They will use Canva, Adobe Express or other tools to prepare the digital poster. Students will use the photos and videos they took and the measurement they took during the design process.

For Arts integration: Create visual infographics, digital posters, or hand-drawn representations of findings.

Teacher move-6

Have students present their digital posters and during poster presentations of each group, ask questions regarding the challenges of vaccine storage in real-world scenarios and the importance of innovative solutions. The questions that might be asked to the groups during the sharing step could be:

1. Why do vaccines require strict temperature control?

………

………

2. How do insulation materials work in real-world applications?

………

………

3. What challenges exist in distributing vaccines to underdeveloped countries?

………

………

Further questions to ask:

- What was the biggest challenge in designing the insulation?
- How would this problem be solved in real-world vaccine distribution?
- What was the most important thing you learned from this activity?

The expected result:

Students will develop an understanding of how different insulating materials and design strategies affect temperature maintenance. They will present their findings and reflect on the effectiveness of their designs in maintaining the required temperature range for keeping vaccines cool in warm climates with limited power. Students will also be able to explain the importance of vaccines for human life.

Adaptations for Different Levels
● For Younger or Less Experienced Students: Provide a narrower selection of materials and a more guided design process. Offer templates or examples of insulated containers to help them get started. ● For Older or More Advanced Students: Encourage independent research on advanced insulation techniques or materials. Introduce constraints such as weight limits or cost considerations to increase the challenge.

Assessment
● Observation: Monitor group collaboration, participation, and adherence to the scientific method during the activity. ● Data Analysis: Evaluate the accuracy and completeness of recorded temperature data and the ability to interpret results. ● Presentations: Assess the clarity, organization, and depth of understanding demonstrated during group presentations.

Worksheet-1 Notes for the instructor:

Definition: Vaccines are biological preparations that provide immunity against specific diseases. Mechanism: They stimulate the immune system to recognize and combat pathogens without causing the diseases themselves.

Information about Smallpox vaccines:

The smallpox vaccine was invented in 1796 by Edward Jenner, an English physician. Jenner observed that milkmaids who had contracted a mild disease called cowpox did not get smallpox.

He hypothesized that exposure to cowpox could provide immunity to smallpox. To test this, he inoculated a young boy, James Phipps, with material from a cowpox sore. Later, he exposed the boy to smallpox, and the boy did not develop the disease. This breakthrough laid the foundation for modern immunology and vaccination practices. The smallpox vaccine is considered the world's first successful vaccine.

Worksheet

Part 1: Whole Class Discussion – Let's start!

Task: Carefully look at the graph below. It shows the global decrease in the number of smallpox cases after the smallpox vaccine was invented.

Teacher starts a discussion regarding the importance of vaccines and their storage conditions using the following guiding questions:

1. How can we interpret the decrease in reported smallpox cases over time as shown in the graph?
2. Why are vaccines important for human health?
3. What might happen when vaccines are exposed to improper transport and storage conditions?

Part 2: Are All Insulating Materials the Same?

Task: Choose one material from the available materials to insulate a jar filled with cold water and test whether they are suitable for keeping cold water cold. Keep one jar as control, without any insulation material. Measure the temperature at 5-minute intervals. Record the results in the table.

Among the insulation materials given to you, which one do you predict will insulate the best or the worst?

………

Table for measurement data

	Chosen Insulation	**Initial Temperature (°C)**	**5 min (°C)**	**10 min (°C)**	**15 min (°C)**	**Δ t**
C	none (only water)					
1						
2						
3						
4						

Which material was the best insulator?

……

Did your prediction come true?   Yes – No

Does an insulator work equally well for keeping things cold and keeping things warm?

……

Part 3: Design a box to keep vaccines cool

Task a: You are a team of scientists and logistics experts working to deliver vaccines to a remote village in a country. Electricity is unstable, refrigerators are unavailable. Let's design an insulated container that can maintain a "vaccine" within the temperature range of 2°C to 8°C for 3 hours.

Draw your design for a box that acts as a super-insulator and allows you to transport a vaccine vial:

Box design:

Task b: Based on your drawing, design the box with the given materials to test the functionality of your cooling box. Place the box near a heat source. Measure the temperature of the vaccine vial at 5-minute intervals and record in the table:

Table for measurement data

Time (min)	**Temperature (°C)**
0	
5	
10	
15	
20	

At the end of the test, was the vial's temperature still between 2–8 °C? Yes – No

When you complete your measurements, answer the following question:

Do you have any ideas for improvements after building your box?

……

……

Part 4: Presentation and Reflection

Task: Prepare a digital poster by using Canva or Adobe Express. Use the photos, videos and the measurements you took during the design process. Make a presentation and share your digital poster with your peers.

During your digital poster presentation, answer the following questions:

1. What makes your design a good design to keep vaccines cool?
2. What are your experiences during the design process: What worked well, what did not work well?
3. What challenges exist in distributing vaccines to underdeveloped countries?

After each group presents, answer the following questions:

Which design from another group impressed you and why?

………

………

What could still be improved to keep the vaccine cool for more than 3 hours?

………

………

From Walking to Falling: Investigating Acceleration

Nilay Ozturk, Sezin Esfer, Ayse Gul Celenk

Grade Level	9th Grade (students aged 14–15)

Duration	2x40 minutes or 80 minutes

Competencies and Skills	**Critical Thinking:** Interpreting data and drawing conclusions. **Problem Solving:** Generating solutions to problems during the measurement and app development process. **Collaboration:** Sharing responsibilities and working effectively in groups. **Creativity:** Developing different movement examples and original solutions **Data Analysis & Art Integration:** Presenting data through graphs and creating visually appealing outputs.

Experiment Description	In this activity, 9th grade students will learn the concept of acceleration through hands-on tasks. They will examine the relationship between constant motion, speeding up, slowing down, and acceleration; they will also interpret velocity-time and acceleration-time graphs. Students will also learn how accelerometers in mobile devices work.

General Objectives of the Experiment	● To understand the concept of acceleration and the relationship between acceleration, speeding up, and slowing down. ● To identify and give examples of acceleration in daily life. ● To draw and interpret velocity-time and acceleration-time graphs for uniformly accelerated motion. ● To learn how censors such as accelerometers in mobile devices work.

Concepts for STE(A)M Disciplines	
Science	● To understand the concepts of acceleration and instantaneous velocity.
Technology	● To use accelerometer sensors in mobile devices.
Engineering	● To analyse motion through graphs and understand how sensors work and are designed; to develop suggestions related to transportation safety, energy efficiency, and sports training.
Mathematics	● To work with velocity-time and acceleration-time graphs.

Prerequisite Knowledge	
Reading and drawing graphs	Having basic knowledge of speed and acceleration.

Learning Outcomes	
Science	Explains the concept of acceleration through everyday life examples and interprets how acceleration changes in different types of motion.
Technology	Explains the working principle of the accelerometer sensor in mobile devices and uses or develops a digital application to collect acceleration data.
Engineering	Designs, tests, and improves a mobile application for measuring acceleration in different motion situations based on the obtained results.
Mathematics	Interprets the characteristics of motion by analysing velocity-time and acceleration-time graphs.

Resource List
● Smartphones /tablets /Computers with Internet connection ● Access to MIT App Inventor platform (via Google account): https://appinventor.mit.edu/ ● YouTube video on acceleration: https://www.youtube.com/watch?v=Rfxk_LFqYxI&ab_channel=BeyzaTA%C5%9E%C3%87I ● Access to an LMS platform (Canvas): https://canvas.instructure.com/courses/11174793 ● YouTube Video: https://youtu.be/Rfxk_LFqYxI ● Consensus AI: https://consensus.app/search/ ● Perplexity AI: https://www.perplexity.ai/ ● H5p: https://h5p.org/, https://phyphox.org/ ● If students want to develop a mobile application themselves: MIT App Inventor Guide: https://docs.google.com/document/d/1Nf9s6n5VHf3Da6vmZPkeryW8O8x4_CBp/edit?usp=sharing&ouid=107598796497155774869&rtpof=true&sd=true

Development of the Experiment
First, we can begin with questions that help us ensure that the basic concepts, formulas, and examples are remembered. The task to be given to students in the worksheet is as follows: *"A transportation research team is examining acceleration patterns in different types of motion in order to better understand energy efficiency, safety, and motion dynamics. To contribute to this work, you will use a mobile application that can measure and analyse acceleration in various situations encountered in daily life, and by working as a research team, you will use a mobile application to measure acceleration in different types of motion. As you know, understanding acceleration and its relationship with speeding up and slowing down is of great importance in various real-life applications such as vehicle design, public transportation, and sports performance. You will analyse the data you collect and present your findings in a way that could be used, for example, in transportation research or technological development."* Then, to relate the concept of acceleration to real life, you will record examples of acceleration that you encounter throughout the day. These may include: ● Riding an elevator (acceleration at the start of motion and during stopping) ● Riding a bus (acceleration while starting, braking, and turning) ● Walking, running, and cycling (differences in acceleration at different speeds) ● Dropping an object and sliding an object on a table (comparing acceleration under different conditions) You will make comparative measurements to determine how acceleration differs in these scenarios. **Experiment: Measuring and Comparing Acceleration in Different Situations** Instead of collecting random acceleration data, you will carry out structured tests under various conditions: ● Walking, running, and sprinting: How does speed affect acceleration? ● Cycling and braking: How is acceleration now of starting and stopping compared? ● Dropping an object and sliding an object on a table: Which forces affect acceleration? ● Bus or elevator ride: How does acceleration change during transportation? After collecting the data, you can analyse the following questions: ● When is acceleration positive, negative, or zero? ● How do different types of motion affect acceleration? **Graph Analysis and Interpretation** At this stage, you will do the following: ● Before taking measurements, you will predict what the acceleration and velocity-time graphs will look like for each type of motion. ● You will compare different graphs and analyse how the slopes change depending on the type of motion. ● You will examine sample graphs with explanatory notes added. Try to answer the following questions: ● What does a velocity-time graph look like in accelerating motion? ● What does a negative slope mean?

- How does a flat acceleration-time graph show constant acceleration?
- What does the graph of uniformly accelerated motion look like?
- How can braking be identified on a velocity-time graph?
- What happens to acceleration when an object moves at a constant speed?

Understanding How Accelerometers Work:

You will use your phone's accelerometer and learn how it works.

- A short video will explain how the small sensors inside your phone detect motion.
- You will rotate and shake the phone to observe how the sensor responds to different movements.

Critical Thinking Task:

- What would happen if a phone did not have an accelerometer?
- How do accelerometers improve smartphone features, vehicle airbags, and game controllers?

Relating Acceleration Data to Vehicle Testing and Engineering:

Instead of sending the data to a car company, you will relate your findings to real-life applications:

- How do engineers test acceleration in vehicles?
- How do factors such as road conditions, vehicle weight, and speed affect acceleration?
- How does understanding acceleration improve transportation safety, energy efficiency, and sports training?

This connection will help you understand how acceleration data is used to design better bicycles, automobiles, and public transportation systems.

Information Gathering:

Before trying the application, students will conduct research individually or in groups on acceleration and its real-life applications.

The Basics of Acceleration:

- What is acceleration and how is it related to speeding up and slowing down?
- Where do we experience acceleration in daily life? (for example, cycling, running, driving a car, using an elevator)

Understanding Sensors and Measurement Accuracy:

- How do accelerometer sensors in mobile devices work?
- In which real-life areas are accelerometers used? (for example, smartphones, game controllers, fitness trackers, airbag sensors)
- Which factors affect the accuracy of acceleration measurements?

Graph Analysis and Interpretation of Motion:

- Can we predict acceleration patterns before taking real measurements?
- How can velocity-time and acceleration-time graphs be used to represent motion?
- How can we interpret the slopes of these graphs to identify different types of motion?
- Can we predict acceleration patterns before taking real measurements?

Product Development:

Acceleration is the rate of change of an object's velocity. If something is speeding up or slowing down, it is accelerating.https://phyphox.org/

By trying this application, you will be able to measure acceleration and observe it in real life. During the product development stage, students are expected to write a research report.

Testing and Discussion:

At this stage, students:

- will conduct three different structured acceleration measurements and record their data.
- will compare their results across different types of motion.
- will answer the following discussion questions:

  What did we discover about acceleration in real life?

  How can we improve measurement accuracy?

Students will find the answers to the three questions above using tools such as Perplexity or Consensus.ai and then share their findings with one another.

Adaptations for Different Levels
● For Advanced Students: Adding new features to the application (for example, saving data or sharing results). Improving the design and functionality of the mobile application. Analysing additional scenarios or collecting more data for deeper investigation. ● For Students Needing Support: Providing step-by-step guidance for each part of the application development process. Providing peer support during group work.

Assessment
Teacher assessment is carried out using a rubric focused on data accuracy, graph analysis, and making connections with real life. ● Peer feedback sessions are held in which groups compare their results and discuss points for development and improvement. ● Open-ended reflection questions: What surprised you about acceleration in real life? What additional experiments would you like to conduct later?

Worksheet

From Walking to Falling: Investigating Acceleration

Acceleration plays an important role in many situations – from transport and sports to everyday movement. You will work as a research team using a mobile app to measure acceleration in different types of motion and analyse the collected data and present your findings so they can be applied, for example, in transportation research or technological development.

Part 1: Acceleration Around Us

Task: Write down situations where you encounter acceleration.

Situation	Description of the motion (what is happening?)
Riding a roller coaster downhill	
Airplane take-off	
Taking a bus	
Dropping an object	

Part 2: Motion Patterns

Task: Imagine the following types of movement and sketch how their graphs might look:
Velocity (v) over time (t) and Acceleration (a) over time (t)

Type of Motion	v-t graph (sketch)	a-t graph (sketch)
Walking-constant speed		
Sprint-acceleration		
Elevator ride		
Object falling		

Part 3: Measurement and Data Recording

Task: Acceleration Measurement App
Watch the following video (via QR code) and answer these questions:

● Which sensors are built into smartphones?

………

● What is an accelerometer and what is it used for?

………

● In which devices can we find accelerometers? (List at least 3)

………

● What factors can affect the accuracy of acceleration measurement?

………

Part 3.1: Your Own Measurement

Task: Planning and recording data

1. Plan your experiment
Think about how you will measure acceleration using an app in various situations. Focus on which types of motion you want to investigate and what conditions you will need.
List the equipment you will use:

Write at least 2 steps of your procedure:

Alternative: Create your own app
Use the MIT App Inventor.
Follow the instructions at https://appinventor.mit.edu/ to create your own acceleration measurement app. Based on the guide (QR code), design a simple user interface. The app must display real-time acceleration.

2. Choose and describe three different situations to measure acceleration

Think of at least 3 situations where you will measure acceleration, for example: walking, running, sudden stop, elevator ride, jumping, etc. Write them down.

Situation	Brief description of the measurement process
1	
2	
3	

3. Carry out the measurement
Use the app to record acceleration in your selected situations. Conduct each measurement as accurately as possible and record your data in the table.

Situation	Initial moment of acceleration (m/s^2)	Maximum acceleration (m/s^2)	End of acceleration (m/s^2)	Notes
1				
2				
3				

Do you have any ideas for improving the procedure after completing the measurement?

……

Part 4: Create Graphs and Visualizations

Task: Based on the data measured with the app for each type of motion, create acceleration–time (a–t) graphs.

Part 5: Discussion and Reflection

● How do the graphs from Part 2 differ from those in Part 4?

………

………

● What differences did you notice in acceleration patterns across the various types of motion?

………

● Why is understanding acceleration important in transport or sports?

………

Part 6: Presentation and Real-World Application

Task: Create a short research report to present to your classmates. Your group's report should include:

● Name of your research team and team members
● Description of the app, its capabilities and limitations
● Measurement results
● Examples of real-world use of acceleration (e.g., airbags, sports training)
● Your own recommendations for applying the results
● Conclusion

Final Reflection

● List 3 things you learned about acceleration:

……

● Suggest an alternative method for measuring acceleration if the phone does not have an accelerometer:

……

……

When Does a Candle Stop Burning?

Martin Rusek, Tadeáš Matěcha, Dominika Koperová

Grade Level	Lower and upper-secondary school

Activity Duration	2 x 45 minutes or 90 minutes

Experiment Description	Students will investigate the conditions under which a candle stops burning. They will observe a teacher demonstration with and without sensors, analyse the role of oxygen and carbon dioxide, and conduct experiments to test hypotheses about the influence of different gases on burning.

General Objectives of the Experiment	● To develop an understanding of combustion and the role of oxygen and carbon dioxide in sustaining or extinguishing a flame. ● To foster critical thinking and hypothesis testing. ● To improve experimental and observational skills. ● To encourage teamwork and group discussions for analysis.

Competencies and Skills	**Critical Thinking:** Evaluating evidence, questioning assumptions, and forming logical conclusions. **Scientific Inquiry Skills:** Formulating hypotheses, designing experiments, and analysing data. **Scientific Communication:** Presenting findings, defending arguments, and engaging in discussions. **Real-World Application:** Connecting scientific concepts to everyday life and making evidence-based decisions.

Concepts for STE(A)M Disciplines	
Science	● Combustion reactions ● The properties of oxygen (O_2) and carbon dioxide (CO_2)
Technology	● Use of O_2 and CO_2 sensors
Engineering	● Designing and executing experiments with controlled variables
Mathematics	● Measuring and comparing the variables ● Working with a graph, arithmetic mean ● Unit conversation

Prerequisite Knowledge	
Science	Gas properties and chemical reactions.
Technology	Basic understanding of sensors and their usage.
Engineering	
Art	
Mathematics	Time measurement and comparison. Reading from a graph Working with a graph.

Learning Outcomes	
Science	Students explain the conditions necessary for combustion and the role of oxygen and carbon dioxide.
Technology	Students demonstrate the ability to interpret data from sensors.
Engineering	Students design appropriate experimental setting to test specific hypotheses.
Mathematics	Students compare measured values, read data from graphs and work with them. Student accurately master unit conversation.

Resource List
● Candles ● Large beakers ● Matches or lighters ● Petri dishes ● Manganese dioxide (MnO_2) ● Hydrogen peroxide (H_2O_2) ● Baking soda ● Vinegar ● O_2 and CO_2 sensors ● Stopwatch

Development of the Experiment
Initial ideas Ask students: What makes a candle burn? Discuss briefly. Present the worksheet's first question: When does a candle stop burning? Students brainstorm their ideas and write them down (expected when there is no oxygen). **Teacher Demonstration** Light a candle and cover it with a large beaker. Ask students to observe and describe what happens. Guide them to specify their initial ideas, why the candle reacted the way it did. Students discuss their suggestions about verifying their ideas, the discussion is guided to use of sensors. Perform the demonstration again, this time attaching O2 and CO2 sensors to the beaker. Guide students to notice how oxygen decreases, and carbon dioxide increases as the candle burns following the students 'worksheet. Writing and sharing the (dis)prove of initial ideas. **Students 'Experiments** Students work in group of 3-4. Initial discussion about gases (not) supporting the burning. Introduce student the two groups of starting materials (MnO_2 + H_2O_2 and baking soda + vinegar) and then ask to guess the produced gas, then verify their guesses using sensors. Students form hypotheses about how long the candle will burn in three scenarios: "only candle", "surplus of O2", "surplus of CO2 ". Students perform the experiments using stopwatches to measure burning time, making notes into table, then they write down their findings about the effect of different gases. Students perform the experiment with produces oxygen and measure the concentration of gases, making notes into table. After measurement students share their data with other groups and then in group calculate specific results for one chosen gas and time of measurement. Discuss the differences/similarities. **Reflection** Lead a class discussion reflecting on: Initial expectations versus measured results, Factors influencing burning times, Problems encountered and how they were solved. Summarize the results as a class by writing values and observations on the board. Discuss any unconfirmed initial ideas and why they might have occurred.

Adaptations for Different Levels
Lower levels: Provide guided instructions and simpler explanations of the science behind candle burning processes. Higher levels: Include advanced discussions on gas exchange, chemical equations, or energy transfer. Also, in Part 2b: Teacher Demonstration students can design their own graph curves for O_2 and CO_2 concentrations over time. They will then compare their predicted curves with the actual curves observed during the demonstration. E.g.: Provide two empty graphs (one for CO_2 and one for O_2) with only labelled axes—x (time) and y (concentration). Students first sketch their predicted trends using one colour and then, using another colour, plot the actual trends as displayed by the teacher on the board during the demonstration. In Part 3, instead of using a table with specific time points, students can also utilize the potential of graphical representation.

Assessment
Modification of IMI questionnaire

Teacher's Methodological Guide
Objective: Students will: • Understand the role of oxygen and carbon dioxide in combustion. • Practice observing, predicting, and analysing experimental data. **Materials:** Candles, large beakers, matches or lighters, O2 and CO2 sensors, stopwatch, manganese dioxide (MnO2), hydrogen peroxide (H2O2), baking soda, vinegar **Lesson Overview** This lesson guides students through scientific inquiry on what causes a candle to stop burning. It follows a structured sequence: initiating curiosity, guided teacher demonstrations, student-led experiments, and collaborative analysis. The teacher should facilitate discussions, ensure safety, and encourage critical thinking. Students work in groups (3-4 students). **Part 1: Spark Initial Ideas** Teacher Moves: • Ask students: What makes a candle burn? Discuss briefly. • Ask the students: When does a candle stop burning? • Give students 2-3 minutes to individually write down their thoughts. • Encourage sharing in small groups (3-4 students) and let them identify similarities or disagreements in their ideas. • Collect a few responses and write them on the board (not necessarily). • Do not confirm or correct ideas at this stage – the goal is to generate curiosity.

Part 2a: Teacher Demonstration (Initial Observations)
Materials: candle, large beaker, lighter

Teacher Moves:

- Light a candle and let it burn steadily.
- Ask: What do you think will happen if I cover the candle with a beaker?
- Place a beaker over the candle and let students observe.
- Ask students to describe their observations in their worksheets. If students struggle to articulate observations, ask guiding questions: Did the flame change size? Colour? Flicker? How long did it take to extinguish?
- Facilitate discussion: Why did the candle react this way? (Link to combustion, oxygen use, carbon dioxide buildup.) How could we test our ideas further? (Prompt students to suggest variations.)
- Ask groups to share ideas on how to modify the experiment to gain deeper insights. If students propose testing multiple ideas, note them for later experiments.
- When students are truly lost, you can use a set of these guiding questions:
- What role does oxygen play in combustion?
- Where does the oxygen inside the beaker come from?
- What do you think happens to the oxygen level as the candle burns?
- Would the candle burn forever if it had an unlimited supply of oxygen? Why or why not?
- If oxygen is being used up, what is being produced instead?
- What gases do you think are inside the beaker after the candle goes out?
- If you could measure the air inside the beaker before and after, what differences would you expect?
- What material is wax made of?

Part 2b: Teacher Demonstration (Data Collection with Sensors)
Materials: Oxygen and carbon dioxide sensors, data-logging software.

Teacher Moves:

- Repeat the demonstration but now use gas sensors inside the beaker.
- Show real-time oxygen and carbon dioxide concentration changes on a whiteboard (or by projecting it on a screen or displaying it on a projector).
- Guide students through a discussion (and follow up their worksheet tasks):
- What can you see in the graph?
- What does the x-axis represent?
- What does the y-axis represent?
- What changes do you observe over time?

Worksheet tasks:

- How does the oxygen concentration change during the candle burning?
- How does the carbon dioxide concentration change during the candle burning?
- Let students write their conclusion into the worksheet.
- After writing conclusion students should go back to their ideas (in Part 2) and compare if their hypotheses were correct or not. Discussion recommended.

Part 3: Student Experiments (Testing Different Gases)

Materials (for each group): Manganese dioxide + hydrogen peroxide (producing oxygen), baking soda + vinegar (producing carbon dioxide), multiple candles, stopwatches

Teacher Moves:

- Assign each group a material and instruct them on safety.
- Let students work on Part 3 of the worksheet independently or in groups. Your task is to walk around, assist them, and provide ongoing formative assessment and discuss about task: Verify your guess, discuss your step with teacher (in the worksheet).
- Discuss observations: What happened to the flame in each condition? Did the results match your predictions?
- Guide students through conducting the next experiment – with reaction producing oxygen, ensuring safety measures.
- Have students record measured concentrations in a table.
- Guide students to sharing the specific data, to calculate the range and arithmetic mean.
- Discuss the factors that could explain the differences in their results. If students record very different times, discuss possible measurement errors and encourage repeated trials.

Part 4: Summarization & Reflection

Teacher Moves:

- Ask: Under what conditions did the candle burn the longest?
- Ask: Under what conditions did the candle extinguish the fastest?
- Have students reflect on their original ideas: Were your expectations correct? If not, how would you change them?
- Instruct students to summarize key takeaways: List 2-3 main conclusions about how gases affect burning. If students struggle to formulate conclusions, revisit their collected data and guide them through structured comparison. Describe any surprising findings.
- Facilitate a closing discussion connecting this experiment to real-world applications (e.g., oxygen use in respiration, fire safety, controlled environments like submarines or space stations).

Worksheet

When does a candle stop burning?

Part 1: Initial Ideas
Task: When do you think a candle stops burning? Write down your hypotheses.

……

……

Part 2a: Demonstration
Task: Watch the demonstration performed by the teacher and answer the questions.

What did you observe when the candle was covered with a beaker? Describe what happened.

……

……

Why do you think the candle behaved the way it did when covered with the beaker?
Try to explain based on your knowledge (about air, fire, combustion, etc.).

……

……

How could you verify your ideas? Suggest a way to test your hypotheses.

……

……

Share your ideas with other groups. Discuss which ones could be practically tested.
Summary:

Part 2b: Designing an Experiment

Task: Design, draw, and construct an experimental setup (apparatus) using sensors for data collection. Answer the questions below.

How does the oxygen concentration change during the burning of the candle?

………

How does the carbon dioxide concentration change during the burning of the candle?

………

Based on your results, explain why the candle goes out.

………

………

Return to your original hypotheses in Part 2a. Were your ideas about what happens when the candle is covered confirmed or disproved?

………

………

Part 3: Experiments

Question: Which gases support combustion – and which do not?

……

……

Task: You have two sets of starting materials - Manganese dioxide and hydrogen peroxide (producing oxygen) and baking soda and vinegar (producing carbon dioxide). Carry out the appropriate measurements and record the results (measured times under different conditions) in the table below.

Time (in seconds)	Candle only		Candle + O_2		Candle + CO_2	
	Concentration					
	O_2	CO_2	O_2	CO_2	O_2	CO_2
0 s (lighting the candle)						
15 s						
30 s						
60 s						
90 s						
… s (candle extinguished)						

Based on the table information, create a graph.

Within your group, choose one of the three measurements and ask other groups to share their data with you. Write these additional data down for comparison.

Task: Analyse the measured and shared data. Calculate the range (difference between the maximum and minimum values) and the arithmetic mean of the gas concentrations over time for the selected measurement.

Discuss within your group what factors might affect the differences in the results. Write down your group's conclusions.

……

……

Part 4: Reflection

Task A:
Based on the experiments and observations you conducted, summarize the key findings.

……

……

Task B:
How could the experiment be improved based on your experience?

……

How should the sensors be placed to ensure the most accurate measurements?

……

How should the size of the container be chosen to easily observe changes in concentration?

……

How can measurement errors be minimized?

……

Become a pH Detective!

Martin Rusek, Tadeáš Matěcha, Dominika Koperová

Grade Level	Lower and upper secondary school

Activity Duration	2 x 45 minutes or 90 minutes

Experiment Description	Students will explore the concept of pH, classify various substances as acidic or basic, and verify their predictions using a pH simulation tool. They will investigate the effect of dilution on pH, analyse data, and graph pH changes to deepen their understanding of acids, bases, and their significance in real-world contexts.

General Objectives of the Experiment	● To introduce students to the concept of pH and its role in determining the acidic or basic nature of substances. ● To improve students' abilities to predict, measure, and analyse pH values. ● To develop skills in interpreting and graphing data. ● To connect scientific principles to everyday phenomena.

Competencies and Skills	**Critical Thinking:** Evaluating evidence, questioning assumptions, and forming logical conclusions. **Scientific Inquiry Skills:** Formulating hypotheses, designing experiments, and analysing data. **Scientific Communication:** Presenting findings, defending arguments, and engaging in discussions. **Real-World Application:** Connecting scientific concepts to everyday life and making evidence-based decisions.

Concepts for STE(A)M Disciplines	
Science	● Properties of acids and bases ● The pH scale and its significance ● pH of some compounds of daily use
Technology	● Use of virtual simulation tools to measure and analyse pH.
Mathematics	● Graphing and interpreting data related to pH changes

Prerequisite Knowledge	
Science	Basic understanding of acids, bases, and the pH scale.
Technology	Familiarity with online simulations or digital tools. Work with applications (tablet, computer).
Engineering	
Art	
Mathematics	Skills in creating and interpreting graphs.

Learning Outcomes	
Science	Students understand the properties of acids and bases of everyday use and how dilution affects pH.
Technology	Students use virtual simulations to perform experiments and collect data.
Engineering	Students design way how to test specific hypotheses.
Art	
Mathematics	Students analyse and graph pH changes to identify patterns.

Resource List
PhET simulation "pH Scale: Basic", computer or tablet with internet access.

Development of the Experiment
Introduction Students are working in pair or in small groups. They read introductory texts. **Classifying Substances** Students classify given substances as acidic or basic based on their prior knowledge, they guess the most acidic and most basic substances. **Measuring pH** Students use the simulation to measure the pH of substances to verify their previous classification. They discuss discrepancies between their predictions and measured results. They identify "water" as a neutral substance. **Investigating Dilution** Students estimate how dilution will affect the pH of different solutions. Using the simulation, students will add water and record the pH changes. They discuss the relationship among the dilution and pH. **Graphing pH Changes** Students solve the given task; they fill the table with the data and then construct graphs to visualize pH changes during dilution. They discuss patterns observed in the graphs.

pH Detective Testing

Students read a short text. After, they follow the instruction, measure the dilution of selected substance. They predict the data the PhET simulation do not obtain, then they confront the prediction with the attached graph, and the lead to concept of neutralisation.

Reflection and Conclusion

Discuss and compare results, the significance of pH, and the examples of pH in real-life conditions (health, environment etc.).

Adaptations for Different Levels
Lower levels: Simplify tasks by providing fewer substances and guiding graph creation. **Higher levels:** In the detective task with Timo, students can not only estimate the number of litters needed to dilute the vomit, but they can also derive the logarithmic function from the graph, which describes how pH is calculated. A deeper exploration of this concept is appropriate. If high school students experience cognitive flow, the concept of neutralization can already be introduced within this lesson unit.

Assessment
Modification of IMI questionnaire.

Teachers' Methodological Guide

Objective:

Students will classify substances as acidic or basic, measure pH and verify predictions, investigate how dilution affects pH, analyse data to deepen understanding of pH and its significance.

Materials:

computer/phone/tablet with access to PhET simulation "pH Scale: Basic"
https://phet.colorado.edu/en/simulations/ph-scale-basics

Lesson Overview

This lesson guide students through the concept of pH, classify substances, measure pH, effect of dilution to pH, and possible real-world scenarios related to acids and bases.

The teacher should facilitate discussions, ensure safety, and encourage critical thinking. Students work in pairs or in small groups (3-4 students).

Part 1: Classifying Substances

Teacher Moves:

• Initiate students' curiosity, read the initial text first. Lead a brief discussion on everyday experiences with acids and bases.

• Instruct students to sort substances into acidic, basic, or unsure, based on prior knowledge.

• Encourage small-group discussion about their choices.

• Facilitate discussion, ask students to share reasoning: Why do you think coffee is acidic? Why is soap basic? Do not confirm or correct ideas at this stage – the goal is to generate curiosity.

Part 2: Measuring pH
Teacher Moves:

- Demonstrate how to use a pH meter in applet. Show proper functions and measurement.
- Guide students through testing, divide students into groups.
- Assign student to measure the pH values. Instruct them to record data and compare it with their initial predictions.
- Discuss findings, ask: Were your predictions correct? What surprised you?
- Address misconceptions (e.g., Milk is not as acidic as expected—why might that be?).

Part 3: How Does pH Change with Dilution?
Teacher Moves:

- Ask students to predict outcomes: What do you think will happen if we add water to an acidic substance? A basic one?
- Have students write down their hypotheses.
- Guide students through dilution experiments, in each group with an acidic and a basic substance from applet. Instruct them to measure pH before and after adding water.
- Analyse results, ask: Did the pH change as expected? Why or why not?
- Address the misconception that dilution always neutralizes a substance.

Part 4: Graphing pH Changes
Teacher Moves:

- Introduce data collection, explain how to record pH changes as water is added step by step, to most acidic and most basic substance.
- Provide a data table template for tracking values.
- Guide students in graph creation.
- Discuss trends: How does the curve change as dilution increases? What can we conclude about how pH responds to dilution?
- Compare student graphs and highlight patterns.

Part 5: pH Detective Testing (Real-World Scenarios)
Teacher Moves:

- Present the scenario – the situation with heartburn (reflux).
- Guide students through testing – continuously diluting the juice or the vomit to simulate stomach acid dilution and record pH changes.
- Discuss real-world solutions, if necessary, ask Besides water, what other methods could reduce acidity?

Part 6: Reflection and Discussion
Teacher Moves:

- Facilitate discussion: What does pH tell us about a substance? Why is understanding pH important?
- Encourage real-world connections: Where do we see pH in daily life? (e.g., food, cleaning, medicine, environment).
- Summarize key takeaways: What were the most surprising findings from today's experiments?

Worksheet

pH— Acid vs. Base

When was the last time you heard about pH? In a soap commercial, a toothpaste ad, or somewhere else?
Imagine you're taking care of a swimming pool, an aquarium, or choosing the right facial cleanser. In all these situations, pH plays an important role. It determines how acidic or basic the environment is, and affects health, cleanliness, and functionality.
Today, you'll test different substances, determine their pH, observe how pH changes when diluted, and analyse what this means in everyday life.

Part 1: Acidic or Basic?

Task: Classify the following substances based on whether they are acidic or basic.

orange juice – soda – hand soap – milk – coffee – drain cleaner – vomit – saliva – water – chicken soup – blood

Acidic	Basic	Not sure

Select the three most acidic and three most basic substances.
Most acidic:

………

Most basic:

………

Why do you think so?

………

Part 2: Measuring pH
Task: Use the pH meter in the applet to verify your classification of the substances.
Add the measured pH values to the table below.

Was your initial guess correct? Circle your answer in the table.

Substance	pH	Acidic/Basic	Was your guess correct?
			Yes — No
			Yes — No
			Yes — No
			Yes — No
			Yes — No
			Yes — No
			Yes — No
			Yes — No
			Yes — No
			Yes — No
			Yes — No

Based on your measurements, determine the most acidic and most basic substances.

Most acidic:

………

Most basic:

………

Compare your initial classification with your measurements. How are they similar or different?

………

………

Based on your measurements, is there one substance that is neither acidic nor basic? We usually call this ‘neutral’. Which one is it?

………

Part 3: What Does Water Do to pH?

Estimate how the pH will change when 500 ml of water is added to 200 ml of a basic substance.

……

Estimate how the pH will change when 500 ml of water is added to 200 ml of an acidic substance.

……

Task: Use the pH meter (in the applet) to measure pH after adding 500 ml of water to the substances.

Substance	Initial pH	pH after adding water

What happens to the pH when you dilute an acid with water?

……

Was your initial estimate correct? Circle: Yes – No If not, explain why.

……

What happens to the pH when you dilute a base with water?

……

Was your initial estimate correct? Circle: Yes – No If not, explain why.

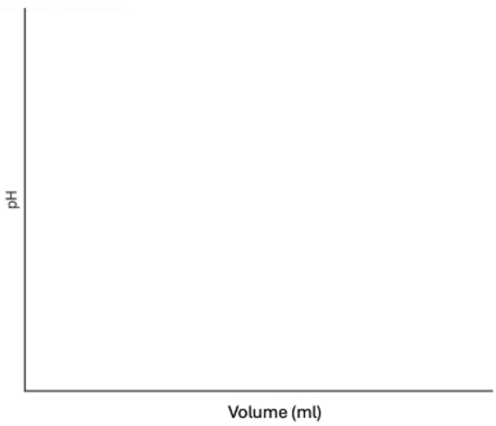
……

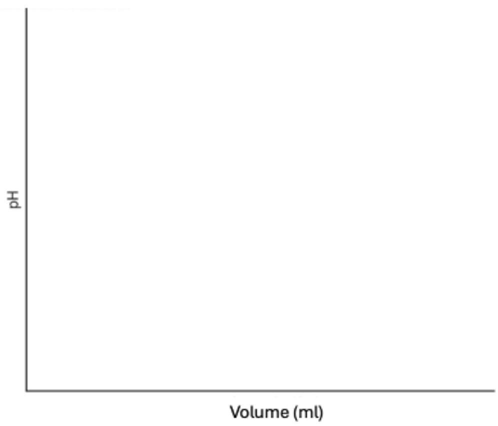
Part 3.1: pH in Pictures (optional)

Task: Track how pH changes as you gradually add 100 ml of water to your chosen 100 ml acidic and 100 ml basic substance. Record your data.

Substance	Added water (ml)	pH
Acidic substance:		
Basic substance:		

Create a graph showing your results.





Based on the graph, describe how pH changes with dilution:

……

Part 4: Can Water Help?

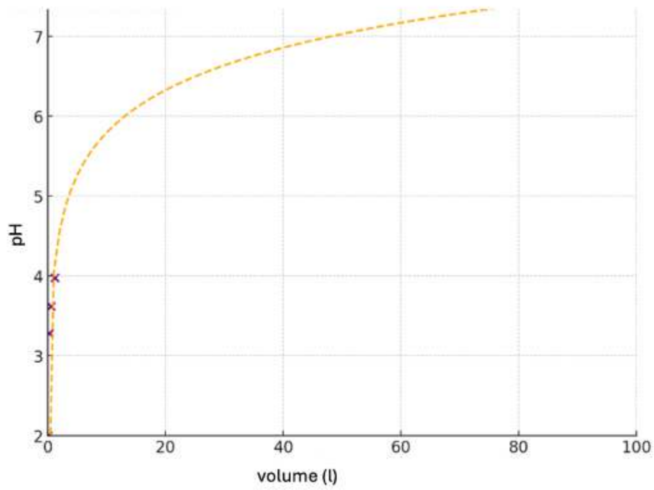
After vomiting, Timo felt a sour taste in his mouth. He found out that stomach acid can damage tooth enamel. He wanted to reduce the acidity in his mouth quickly but only had water—so he decided to try it. Can Timo reach a neutral pH in his mouth just by rinsing with water? How much would he need?

Use a simulated acidic solution (vomit) as stomach acid and check whether water can raise the pH above 5.5 – the threshold where enamel starts to break down.

Task: Dilute 100 ml of the acidic solution gradually with water up to 1 litter and record pH changes. What was the highest pH you reached in the applet by dilution?

………

Roughly how much water would Timo need for the vomit to stop being acidic? Use the graph to



estimate.

Is there another way to neutralize the pH faster? Discuss your ideas.

………

………

Part 5: Reflection

What does the pH value represent?

………

………

Why is it important to understand the meaning of pH?

………

………

In what other everyday situations (besides those already mentioned) do we encounter pH?

………

………

Materials Race: Exploring Gravity and Friction with Racetracks

Cecília Russo, Abril Armenta-Franco, Eva Ulbrich

Grade Level	5th-7th Grade (students aged 10–12 or older, see extension)

Activity Duration	90 minutes or 2x45 min

Competencies	Critical Thinking and Problem Solving Creativity Communication Collaboration

General Objectives of the Experiment	What if you had to design a racetrack to make cars go super-fast or stop almost instantly? How would you choose the materials and slope to be fastest?

Each team will build a unique ramp using different materials, which will be tested. Each ramp is tested by each team to compare ramp designs and material roughness to determine the best material for "fastest ramp" and "slowest ramp."
Students will test gravity and friction and their impact on race cars tested on the ramp. They learn about the two main forces involved in their everyday lives, their interaction with objects and their properties through experimentation.
They will develop observation-, and kinesthetics learning skills when relating through tactile perception of materials to their frictional properties. They will also use their muscle memory by relating positions of their arms to angles; acute (spitzer Winkel), right (rechter Winkel), and obtuse (stumpfer Winkel).
Creativity, Collaboration and engineering abilities will be broadened through designing and constructing a ramp per group and testing all ramps.

Experiment Description	Students discover how gravity and friction affect car movement on racetracks (ramp).

Getting to Know Materials: Exploring different materials eg. fur, cloth, sandpaper, plastic, cardboard, by touching and comparing to understand differences between rough and smooth.
Designing a Racetrack: Students work in teams to design, build, and decorate an inclined racetrack using different materials to create a ramp where a car can roll down.
Testing and Measuring: Each team will test each racetrack to

- Adjust the ramp's angle using a handmade protractor from nearly flat to steep.
- Measure how long the car takes to reach the bottom.
- Record observations and results in a table.

Sharing Results: Teams present their findings in a 5-minute presentation explaining how the track they designed and built worked and sharing their observations of all other tracks.
Reflection: All groups discuss what they learned about gravity and friction in a plenum.

Concepts for STE(A)M Disciplines	
Science	Friction, Gravity, Velocity, Rough Surface, Smooth Surface
Technology	Build adjustable racetracks that optimize the effects of friction and gravity. Construction of the paper protractor.
Engineering	Design of a racetrack (ramp) whose inclination angles can be changed.
Art	Development of creative skills in the design of the racetrack.
Mathematics	Geometry: Understanding of the characteristics of a scalene triangle rectangle and its angles.

Prerequisite Knowledge	
Technology	Know how to use a chronometer/timer.
Mathematics	Know how to take and read measurements, like time and angles.

Learning Outcomes	
Science	Identify and name the frictional properties of the materials and their possible purpose in everyday life and technology. Learning about forces involved in everyday lives, gravity and friction, and their interaction with objects and their properties. Having a first approach to the scientific method through observation, proposal of hypothesis, experimentation, conclusions.
Technology	Understanding the importance of materials' properties for designing and engineering of real-life applications.
Engineering	Design and construct inclined planes that meet specific criteria, such as adjustability of angle and material variation.
Art	Development of students' creativity by personalising and decorating the ramp.
Mathematics	Connect ideas with SI units (m, dm, cm, mm, min, s), interpret; measure, or estimate quantities. Record results with corresponding units, find relationships in between. Usage of geometrical wording (angle, right angle/obtuse angle, acute angle, etc ...).

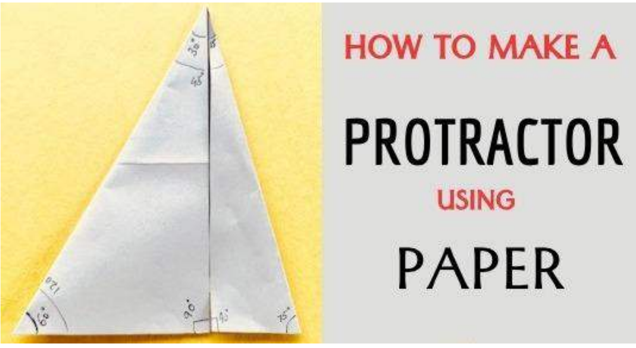
Resource List	
Building of the Racetrack and the Exploration of Materials' Frictional Properties:	
Activity 1: Frictional Properties Exploration	**Activity 2:** Racetrack Construction
● Sandpaper ● Plastic ● Different types of fabric (silk, satin, cotton, linen, burlap, synthetic fur) ● Shoe soles ● Aluminium Foil ● Wax paper/Baking paper	● Cardboard Boxes ● Geometry set (Geometrie-Dreieck) ● Paper ● Pencil ● Colours ● Glitter ● Sequins ● Leaves ● Old/Used Magazines ● Sandpaper ● Plastic ● Different types of fabric (silk, satin, cotton, linen, burlap, synthetic fur) ● Shoe soles ● Aluminium Foil ● Velcro Sheets ● Wax paper/Baking paper ● Glue ● Tape ● Scissors ● Toy car/racing cars: one for each team ● Chronometer/Timer

Experiment

Pre-class Home Task:

The students will design their own paper protractor. During the building of the racetrack (ramp), students will use the paper protractor to measure and set up the inclination angles of the ramp.

You can find the instructions in the following link: How to make Protractors And a video here: The Paper Protractor!



Activity 1: Learning about Angles (20 minutes)

Objective:
Students will be introduced to the concepts of angles; acute angle, and obtuse angle, they will be hinted towards their importance, and possible applications in real life.

Teachers can introduce angles using a fun game, making the concept interactive and engaging. Students look at real-world examples, such as road signs, to learn to recognize different angles in their daily lives.

1. Information: Teachers explain angles and how they can be measured by eg. showing them a Geometry set (Geometrie-Dreieck).

2. Game: Ask students to stand up and start walking along the classroom. Tell them that they will have to freeze with their arms in the correct position whenever you say one of the following words: Right angle, Acute angle, Obtuse angle. The position of the arms is described in the next paragraph. Repeat several times to activate body memory.

Use the Body to Form Angles

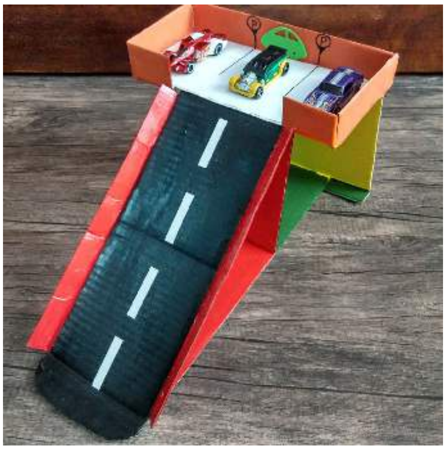
- Right angle (rechter Winkel) → one arm up and the other extended to the side, forming an "L."
- Acute angle (spitzer Winkel) → arms forming a small "V."
- Obtuse angle (stumpfer Winkel) → arms wider apart, like a clock showing 10:10.

3. Reflection: Ask students to take a seat where they are at that moment and show them the following pictures of steep streets. Let them estimate the angles of the streets they consider steep.

Ask them questions such as: Do you think the angle of 35.6% in the image with the bicycle corresponds to the inclination of the street?

Additionally, show the students the following image and ask them to reflect on the following questions:

1. Have you ever seen this traffic sign before? Where?
2. Do you think the angle displayed in the image is correct?
3. Which angle do you think this traffic sign should have?

Activity 2: Create a ramp (40 minutes with 15 minutes for testing the racetracks)


The teacher starts the lesson by asking the following question:

> If you had to design a racetrack to make cars go super-fast or stop almost instantly, how would you choose the materials and the slope to win the race?

Before answering this question, let's try a little activity! Ask the students to go to the Worksheet and answer the Make a Prediction section.

After the activity the students, divided by teams, must design two racetracks of with the idea of optimizing them to answer the aforementioned question, and considering the following conditions:

- Two racetracks must be designed: One for the toy car to go as fast as possible, the second one for it to go as slow as possible.
- The toy car must start on the top "of a hill": Starting Line must be higher than the Finish Line.
- The toy car must always touch the inclined plane to win this race.
- The toy car must just use natural forces such as gravity and friction to favour its displacement.
- The inclined plane (racetrack) must have mobility and allow the students to measure its inclination angle.
- The materials chosen by one group used for their racetrack, cannot be repeated by another group.

Note: The students are allowed to check anywhere in books or computers to search about the most proper material for the inclined planes (racetracks).

After dividing the students by teams and giving the conditions to the students, ask them to go to the Worksheet again and start working on the section Test it!, to build the racetracks and fill the tables once they are finished with the construction.

Instructions for the Teachers:

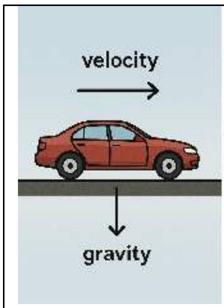
1. The students will have 30 minutes to design and construct a racetrack and 15 minutes to take measurements. Explain to them they should imagine it to be the world famous Großglockner street (Großglockner being Austria's highest mountain) and people in the cars should get down the Großglockner safely. Discuss with them, which angles in the Großglockner street could make a car roll down fast and which angles are safer perhaps?

2. Each team will design the racetracks using cardboard and will cover the surface with a chosen material (plastic, balloons, aluminium foil, fabric, etc). Each racetrack is covered with a different material. The racetracks should be designed so that its inclination with respect to the horizontal can be changed and measured. They should also be personalized to the wishes of the groups to reflect their setting. A general setting is a street in the mountains, children can, however, choose any other setting.

3. After 30 minutes where the teams designed and constructed each race track the teams should show their progress to each other and compare with the other teams 'tracks estimating which track could be the fastest.
Important! The students should use their favourite toy cars and make sure they can go down the ramps, they must decorate and colour their ramps to fulfil their favourite design (a street on a mountain, a futuristic ramp, a skiing path, etc) The students are free on the design, using colourful stones, feathers, glitter, etc, ... to personalise their ramps.

4. With the paper protractor the students prepared during the home task, they must set the racetrack to the each of the angles from the protractor (Θ= 30°, 60°) and record the time that the car needs to reach the finish line. (Avoid very steep angles approaching vertical: the car would simply fall rather than roll down the track.) The data must be recorded in the tables provided in the Worksheet. The time must be recorded for each racetrack and for each team's racetracks in the section Test the Other Racetracks! and Compare Your Results!

Justification:
What is really happening? How does gravity (angle) and a material affect the toy car's motion?
The students will learn through observation that the two main factors affecting the "timing" of the object when reaching the bottom are the material which they chose to construct the racetracks, and gravity. When the material of the racetrack interacts with the toy car's tires, it would increase the force of friction between them if the materials chosen are rough, and for friction to decrease if the materials are smooth. If there is too much friction then the tires of the toy car might not roll along the racetrack and might stay still. If there is too little friction, then the tires might not roll but slide along the racetrack, which can cause an accident in real life as the brakes of the car can't control the tires anymore. If there is "enough" friction the tires will roll faster than in the first case and slower than in the second one, but in conditions in which the car will go down the slope safely. On the other hand, gravity affects the time of the moving car depending on the value of the angle of the racetrack, the smaller this angle is, the smaller the incidence that gravity has on the moving car. For example, when the angle of the race track is of 0°, even if the force of gravity is always there, it does not affect the displacement of the car, as it is moving sideways (on an horizontal direction, as in the image on the left) and gravity just affects the toy car's when its movement goes on a vertical direction, or said in simpler words, when it goes down (as in the image on the right), in the same direction the force of gravity is pulling the car.



Reflection and Outcome : (Poster Preparation and Questions 25 minutes)
Using the data collected in their tables, the students must rank the race tracks on a podium designed by them. Taking into account the properties (materials) used for the fastest race track and the slowest race track in the second case.

Ask the students to answer the questions in the section Think Like a Scientist! Ask them to design and create a poster to showcase their results and conclusions. With the acquired knowledge the students are able to present on the poster which are the factors they think they should consider when designing the Winning Race Track. The poster should include a clear headline, an illustration of the fastest and slowest race track, their conclusions, and the previously designed podium. This will allow other children in the school to see and learn from their discoveries.

Evaluation and Recognition:
Students' work including their race track, poster, presentation, and teamwork will be valued and recognized by the teacher. The recognition will be based on several categories, including:

- Best Design – Creativity and functionality of the race track.
- Best Decoration – Visual appeal and effort in decorating the track.
- Most Accurate Prediction – Correctly predicting which track will allow the car to reach the finish line first and last.
- Best Teamwork – Demonstrating strong collaboration and cooperation.
- Most Creative Poster – Unique and visually engaging design.
- Most Clear and Understandable Poster – Easy-to-read and well-organized information.
- Best Presentation – Clear, accurate, and engaging explanation of results.

During the poster presentation, the students should be able to use the new terms and explain how the changes of the angles and the different materials of the race tracks affected the outcome of the car.

Each team will be recognized in at least one category, ensuring that all students feel encouraged and appreciated for their efforts.

Assessment
Time: (10 minutes per team) Next class, children will present their poster and their results (including the filled worksheet). They should use appropriate terms and names, know the basics of friction related to their chosen material and slopes and should be able to explain how to measure chosen angles by the paper protractor. This assessment activity should encourage discussion of their findings and its connection with what they have learned about friction, and gravity with their peers and the teacher. For advanced groups of older children: Students will take pictures of the experiment the have performed and upload them in an online space such as Popplet. They will also have to give a couple of examples in which the materials they have experimented with are used in everyday life. For example, rubber is used in the soles of our shoes to have a better grip and avoid slipping and falling. The idea is to share and briefly discuss their results and thoughts with the rest of the group.

Adaptations for Different Levels
Alternative activity for students of lower grades Feeling Smoothness and Roughness (20 minutes) This is an introductory activity in which the students will get acquainted to two different properties of the materials; “Smoothness” and “Roughness” by touching, tangible experiences, exploring and classifying the materials into one of the two options of surface texture of the material. It is important that the students can try these two properties as they affect the frictional force between two moving materials in contact. To help very young students grasp the concept of friction, they can explore various materials with different textures. Students might learn to recognize roughness as a physical characteristic through touch. ● Bring to the classroom a box with the different types of materials listed above. ● Ask the students to sit down on the floor to form a circle, in the middle of the circle set up two boxes, one with the legend: SMOOTH, and a second one with the legend: ROUGH. ● Start the lesson by passing each of the materials to the students so they will touch them and get acquainted with them. ● After everyone has tried them, ask them the following questions to guide them to be aware of the characteristics of the materials and their use. For example: How did the synthetic fur feel? Was it smooth or rough at the touch? Do you think an object can easily slide over this material? Do you think the sorted materials in rough and smooth have a relation with friction? How smooth/rough do they estimate an average road? ● After doing this round of questioning and comparing each of the materials ’characteristics, ask them to classify them and set them inside the corresponding box. Alternative for students of higher grades Students should get an introduction into basics of forces, of the laws of motion and calculating angles. They should be introduced to how to take measurements and how to analyse them. Teachers should make sure to have a couple of phones with installed Phyphox and Algodoo and watch these videos to understand the basics of the applications

Activity 1: For students in higher grades, students should design different types of tires. Additionally, they should use the Optical Sensor of their phone connected to the app Phypox, to calculate the car's average velocity. Here is a link to the detailed instructions of the activity: Adaptations for different levels JKU Experiment Changes Round 1

Teacher's Preparation
Before the activity, the teacher will use the provided links and additional readings (if needed) to familiarize themselves with key concepts related to friction. This includes understanding Newton's Laws of Motion and the role of friction in movement. The teacher will then prepare a simple, engaging introduction for the class, using clear language to explain terms like "roughness" and "smoothness." Videos: Newton's Laws of Motion Friction: What is it? Friction and Materials' Properties: Experiment

Worksheet

Make a Prediction!

Before testing, look at the materials and predict which ones will make the car go the fastest and which ones will slow it down the most.

Think about it:

- Which materials feel smooth?
- Which materials feel rough?
- Which ones do you think will create the most friction?

Write down your predictions in the table below.

Material	Do you think the car will go FAST or SLOW?	Why
Example: Sandpaper	SLOW	It is rough and will create a lot of friction.

Test the Race Tracks! 🏆

👉**Test your car in each of the ramps designed by each team.**

✏️ **Record your new results below.**

Team's Name:							
Material 1 :	**Inclination Angle: 15°**						
Position (cm):							
Time (s):							
Material 1 :	**Inclination Angle: 45°**						
Position (cm):							
Time (s):							
Material 1 :	**Inclination Angle: 60°**						
Position (cm):							
Time (s):							
Material 2 :	**Inclination Angle: 15°**						
Position (cm):							
Time (s):							
Material 2 :	**Inclination Angle: 45°**						
Position (cm):							
Time (s):							
Material 2 :	**Inclination Angle: 60°**						
Position (cm):							
Time (s):							

Think Like a Scientist!

Answer these questions based on your experiment:

Prediction Questions:

1. Which materials do you think are the best for making the car go fast?

……

2. Which materials do you think are more prone to slow down the car the most?

……

3. Which of the three suggested angles do you think will make the car go faster and why?

……

Data Analysis Questions:

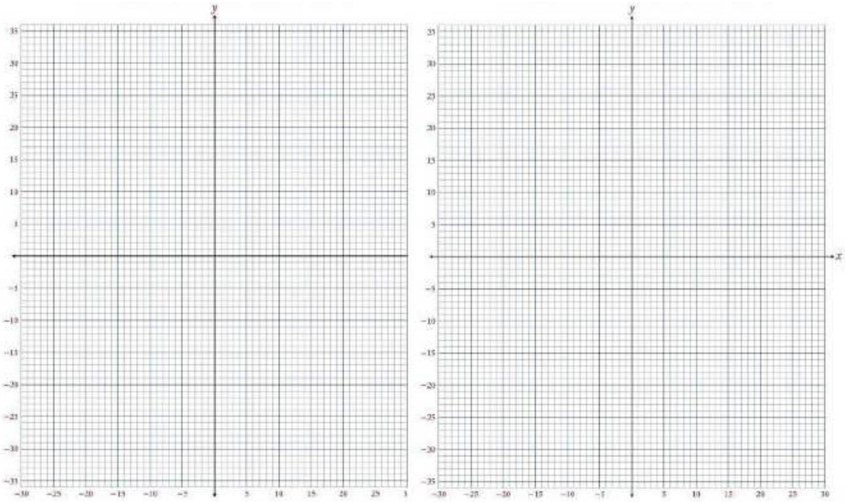
4. What is the shape of the distance–time graph? Can you explain why?

……

5. Describe and sketch the expected velocity graph for each angle.

……

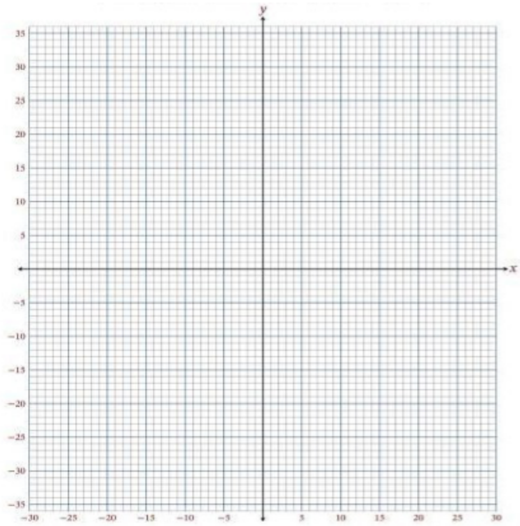
……



6. Based on your understanding, predict the shape of the acceleration graph and explain why. Then, draw a sketch to support your answer.

……

……



7. Using a rough estimate, analyse your position–time graphs and the slopes of your velocity–time graphs. Which car do you think is the fastest [1]? Explain your reasoning, referring to the shapes and inclinations of the graphs.

……

……

8. Discuss the relationship between the material of the inclined plane and the car's velocity. If you raise the angle of the inclined plane, how do you think it will influence the velocity of the car?

……

……

Compare Your Results!

Look at your predictions and compare them with what actually happened.

Were your predictions correct?

- YES! What did you learn?
- NO? Why do you think the result was different?

Write down your reflections:

………

………

Think Like a Scientist!

Answer these questions based on your experiment:

1. What did you learn about friction?

………

………

2. What did you learn about gravity?

………

………

3. Which materials were best for making the car go fast?

………

4. Which materials slowed the car down the most?

………

5. If we did this experiment on the Moon (where gravity is weaker), how would the results change?

………

6. Where do we see these ideas in real life? (Roads, tires, sports tracks, etc.)

………

………

How Does a Rainbow Happen? Light and its Properties…

Cecília Russo, Abril Armenta-Franco, Eva Ulbrich

Grade Level	5th—9th Grade (students aged 10–14)
Activity Duration	2 classes of 45 min (90 min)
Competencies	Critical Thinking Communication Collaboration
General Objectives of the Experiment	Developing a deeper understanding of the principles of reflection, refraction, and dispersion of light by exploring their role in the formation of rainbows. Using the simulation software Algodoo, students will manipulate light sources, prisms, and different materials to explore their interaction with light. Through guided discussions, hands-on, problem-solving, and collaborative analysis, they will connect theoretical concepts with visual simulations. At the end of the lesson, students present their findings, discuss patterns they observed, and answer guiding questions to demonstrate their understanding of the concepts of reflection, refraction, and dispersion.
Experiment Description	In this virtual lesson, the students will use the applet Algodoo to simulate the experiment they could do in a lab session. Having a simulation applet has certain advantages: it allows the students to modify the variables rapidly; it also allows them to have the materials in hand in case there's no availability in the classroom. The simulation is a tool used to predict phenomena. They will start by discussing some phenomena observed in daily life, such as rainbow formation in the sky, "reversing" of images, and the quality of the reflections in a lake. These examples constitute a visual representation of the physical phenomena that make a rainbow happen; Reflection, Refraction and Dispersion. As having a visual representation of a concept is important to lead the student towards the understanding of it. Then the students will proceed by simulating Newton's Prism Experiment in Algodoo. They will choose lasers of different colours and observe the angle of refraction of light (how much the light beam crooks when crossing different media) is affected by the choice of colours. They will finish the simulation by exploring in a water tank and observing what happens with the laser's light when they play varying the index of refraction of

	water. Then, the students will have 10 minutes to consolidate their findings during the simulation by making the experiment of Newton's Prism in real life. At the end of the lesson, the students will collect images on the web and make 1 slide with them about the real-world applications that they believe are connected to these three phenomena: Reflection, Refraction and Dispersion.

Concepts of STE(A)M Disciplines	
Science	Materials and Light – Learning how different materials (water, glass, air) change the direction in which light moves.
Technology	Optical Devices – Understanding how principles of refraction are used in glasses, cameras, and microscopes.
Mathematics	Angles and Geometry – Through the simulation, visualizing how light changes its direction when it enters a new material (Snell's Law in a basic form).

Prerequisite Knowledge	
Science	Students learn about the concepts of light, refraction, index of refraction. Students learn about and reflect on the phenomenon that light behaves differently when interacting with different materials.
Technology	Digging deeper on the use of the applet Algodoo as a simulation tool.
Engineering	Using Simulations – Experimenting with Algodoo as a tool to test ideas, like how engineers use digital models.

Resource List
Simulation Spaces: ● Algodoo ● PHET Colorado Hands-On: ● CD/DVD/Prism Deliverable: ● Google Slides: https://workspace.google.com/products/slides/

Development of the Experiment

Activity 1 (30 minutes):
Start the lesson by asking the students to pair up with another partner and show them the following pictures:

Figure 1

During observation, ask them the following questions:

- What do both pictures share? Which natural phenomena is being displayed in both cases?
- Do you have any idea on how these natural phenomena (Rainbows) happen?

Give them 10 minutes to reflect on the questions and to write down their observations and answers. During the next 20 minutes, discuss with the students their answers and observations, and introduce them to the concepts of reflection, refraction and dispersion of light.

Discussion:
Rainbows happen due to a combination of phenomena; Dispersion, Reflection, and Refraction of light.

Reflection: Is a phenomenon that occurs when light encounters another material, causing the light to bounce back from it. The reflection can be specular or diffuse. It is specular, and it happens when the surface is completely smooth, which is also called a mirror-like surface. It is diffuse when the surface is too rough and the rays or light are scattered into different directions. During the discussion, show the students the following pictures and ask them to classify them into specular reflection or diffuse reflection:

Figure 2

Refraction: is the property of light to change its direction when traveling along a different medium.

Show the students the following pictures and ask them the following questions:

- Why is the path crooked?
- Why is the arrow shifted?
- Do you think the effect that you're observing has something to do with the liquid inside the glass?
- If so, what do you think will happen if we change the liquid?

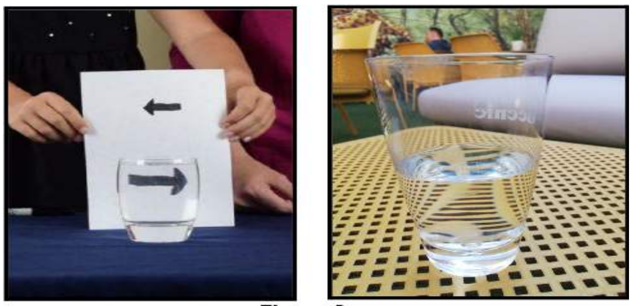


Figure 3

It is the bending of light (refraction) that when passing from the water to the glass, to the air, which gives the human eye the optical illusion that both, the arrow and the path along the yellow table, are shifted in direction.

Dispersion:
Refers to the property of white light to divide and spread up in different directions, and it occurs thanks to a combination of refraction and reflection.
Ask the students to write their ideas of the aforementioned concepts and to give an example of their daily lives where they observed these phenomena.

Real-Life Applications of Light Phenomena
Light behaves in predictable ways, which allows us to create devices that help us see better or understand the world around us. Here are some examples of how refraction, reflection, and dispersion are used in real life:

- Refraction in Eyeglasses and Microscopes: Eyeglasses use lenses that bend light to correct vision problems. Microscopes use multiple lenses to magnify tiny objects. Without refraction, these tools wouldn't work.
- Reflection in Mirrors and Periscopes: Mirrors allow us to see ourselves and are also used in devices like periscopes (used in submarines) and rearview mirrors in cars, which help drivers see behind them.
- Dispersion in Rainbows and Prisms: When white light passes through raindrops or a prism, it spreads into different colours, creating a rainbow effect. This helps scientists study the properties of light and understand the composition of stars.

Activity 2 (60 minutes):
Explain the structure of the next 45 minutes and hand out a printout of a simple data table for tracking observations (found in the Appendix). Explain how observations should be tracked and later collect the data tables to go through the observations and discuss them later, correct misconceptions and use the tables as impulses for a later reflective discussion in the last 15 minutes.

Ask the students to open the software Algodoo and explore the concepts by simulating them.

Specular Reflection and Diffuse Reflection:

- Ask the students to use the Polygon Tool and draw an uneven surface like the one in Figure 5a.
- Use the Polygon Tool but do it now while pressing the SHIFT key to draw straight lines and form a smooth surface like the first triangle in Figure 5a.
- Now, use the right click in the mouse over each figure (smooth and rough one) to open a window and in the tab, Material change the value of the Refractive Index to an infinite number like in Figure 5b.

Note: Changing the Refractive Index towards infinite is like making the surface behave like a mirror.

- Ask the students to add to the scenery two lasers of white light with the tool Laser Pen Tool. Point each laser towards each one of the surfaces. With the right button pressed over the lasers, choose the option Appearance and then the colour white to make it a white light lamp like in Figure 5c.

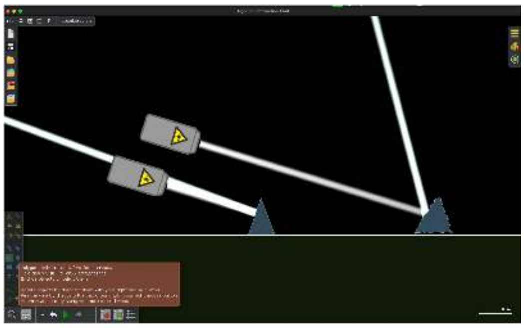


Figure 5a.

Figure 5b.

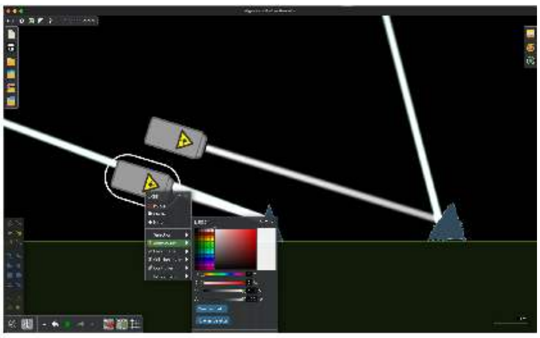


Figure 5c.

Now ask them to move each surface vertically and see what happens to the reflected light. Ask them to write down their observations as they answer these questions:

- Does the reflected light beam changing direction, or does it go back in the same direction as it arrives at the surface?
- In which case does the reflected light beam go back along the same path from where it came (the smooth surface or the rough one)?
- Which of the reflections is specular and which one is diffuse?
- What is the characteristic of each reflection (specular and diffuse reflections) in each case? Write down your observations during the simulations.

Refraction and Dispersion of Light:

Now the students will have the opportunity to explore the concept of refraction and diffraction by simulating the formation of a Rainbow. Ask them to copy and paste the smooth triangular prism they use in the previous experiment. Ask them to restore the prism's index of refraction to the value of 1.5, which is the index of refraction or glass. Now they can also add a laser of their choice of colour, pointing towards the prism. The students can choose the angle or incidence of the laser using the tool Rotate Objects and Water, as is shown in Figure 6.

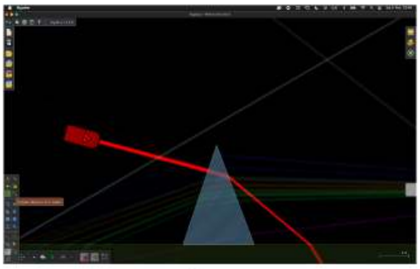


Figure 6

Ask the students to discuss with their classmates what's happening to the laser's beam as it is crossing from the air, into the glass, and into the air again.

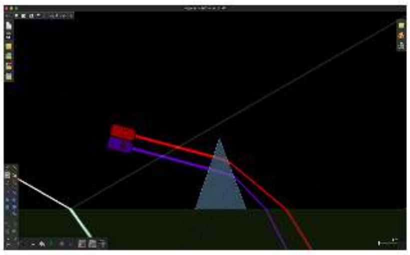


Figure 7

As the next step, ask the students to add a second laser of a different colour of their choice, see Figure 7. Ask them the following question:

- What is happening now? Which laser beam bends more?
- Add a 3rd laser of a different colour and in your notes classify the lasers from the least bendable one to the most bendable one. For example: 1. Red, 2. Orange, 3. Violet. (being the red laser which bends less and the violet laser which bends the most).
- Do you think that the bending of the light depends on the colour? Can you find a pattern? Write it down.

As a last step, copy and paste the triangular prism and add a third laser facing the prism, this time, make the laser a white-light lamp, as shown in Figure 8.

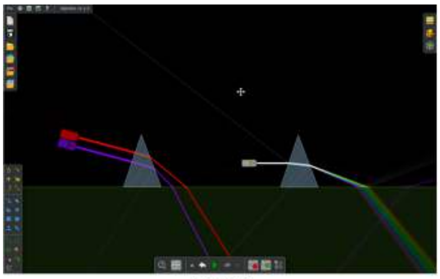


Figure 8

Ask your students to answer the following questions in the working sheet:

- What is happening with the white light as it goes from air, into the glass triangular prism, and into air again?
- Can you see a pattern in the colours? Do you recognise that pattern? Where have you seen it before?
- From what you previously discussed in class, which phenomena can you observe in this simulation?

Assessment

In the plenum, use reflective questions like this to connect what they learned to what they might encounter later:

- What differences did you observe between smooth and rough surfaces in the reflection experiment?
- Which colours bent the most in the refraction experiment? Why?
- How does dispersion relate to the order of colours in a rainbow?
- How could we apply these principles in designing glasses, cameras, or telescopes?

Help the students relate what they observed during simulations and during the previous discussion about reflection, refraction and dispersion. By giving them a prism (or even a CD/DVD) and going outside the classroom and using sunlight or a flashlight to see if they can create a small rainbow. Ask them to draw what they observe and explain why this happens.

Final Discussion:
Discussing with them, hearing their answers to the questions, and their reasonings, help them notice that a rainbow in a droplet of water (see Figure 9) is formed by the 3 phenomena together. Sunlight enters a raindrop and refracts (bends) as it crosses from air into water (about 1.0003 for air versus 1.33 for water). It then reflects once off the inside back wall of the drop and refracts again as it leaves. The key point is that the amount of bending depends on the colour: the drop's refractive index is slightly larger for shorter wavelengths, so violet light bends a little more than red light. This separation of white light into its colours is called dispersion. Because of the geometry of that single internal reflection, each colour leaves the drop at a slightly different angle relative to the incoming sunlight — about 42° for red and about 40° for violet. As a result, the observer receives red light from drops higher in the sky and violet light from drops lower down, which is why the primary rainbow always runs from red on the outer (upper) edge to violet on the inner (lower) edge: Red, Orange, Yellow, Green, Blue, Violet.

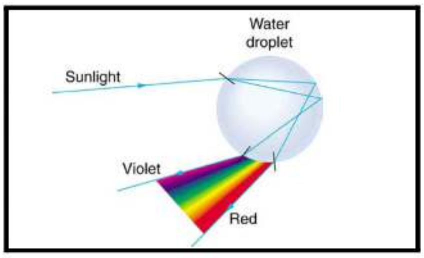


Figure 9

Task: Ask the students to collect images on the web and make 1 slide with them about the real-world applications that they believe are connected to these three phenomena: Reflection, Refraction and Dispersion. Ask them to set the slide on google slides.

Adaptations for Different Levels

As an alternative for students of higher grades

Activity 1:
For students in higher grades, the activity could be adapted by asking them to play with the index of refraction of the prism, and relate it (by making a research) to the materials in real life, for example, the index of refraction for diamond (2.41), the index of refraction for water (1.33), for air (1.003), for amber (1.55), etc, and observe the behaviour of light (white light and monochromatic light) for each case.

Activity 2:
It is suggested for the students to play with the Applet PHET Colorado and observe the correlation of the frequency and the colour each laser (counting the number of wavelengths per square of 500 nm), and ask them if they can find a relation with frequency and its bending when coming out of the prism in Newton's Prism
Experiment.

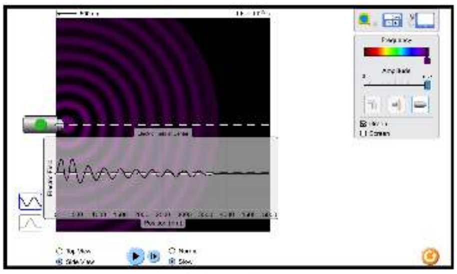


Figure 10

Worksheet

How Does a Rainbow Happen? — Light and its Properties…

1. Refraction (Bending of Light)

Question 1: What happens when light passes from air into water or glass?

……

……

……

Question 2: Why do lenses in eyeglasses or microscopes rely on refraction? What would happen if there were no refraction?

……

……

……

2. Reflection (Bouncing of Light)

Question 3: How do periscopes and rearview mirrors use reflection to help people see in different directions?

……

……

……

Question 4: Imagine you are in a dark room with a flashlight and a mirror. What would happen if you shined the flashlight at the mirror at an angle? Draw and describe the result.

……

……

……

3. Dispersion (Splitting of Light)

Question 5: Why does a prism create a rainbow? What happens to the different colours of light?

……

……

……

Question 6: Why do we see rainbows in the sky after it rains? How is this similar to what happens in a prism?

………

………

………

Question 7: Can you think of other situations where dispersion of light happens? Provide an example.

………

………

………

4. Simulation in Algodoo

Question 8: What's happening with the white light as it goes from air, into the glass triangular prism, and into air again?

………

………

………

Question 9: Can you see a pattern in the colours? Do you recognise that pattern? Where have you seen it before?

………

………

………

Question 10: From what you previously discussed in class, which phenomena can you observe in this simulation?

………

………

………

Question 11: What differences did you observe between smooth and rough surfaces in the reflection experiment?

Question 12: Which colours bent the most in the refraction experiment? Why?

………

………

………

Question 13: How does dispersion relate to the order of colours in a rainbow?

………

………

………

Question 14: How could we apply these principles in designing glasses, cameras, or telescopes?

………

………

………

References:

- https://micro.magnet.fsu.edu/primer/lightandcolor/reflectionintro.html
- LYUBLINSKAYA I, et al. (2017), College Physics for AP Courses, OpenStax, Rice University, Houston, Texas.

Light and Colours: RGB Colour Mixing and Diffraction

Kristof Fenyvesi, Josephine Lau, Maria Fisk

Grade Level	Middle to High School (students aged 13–18)

Activity Duration	90 minutes

Experiment Description	In this two-part virtual experiment, students explore two key behaviours of light: RGB colour mixing and diffraction. First, they use the PhET Colour Vision simulation to investigate how red, green, and blue light sources combine to create secondary colours and white light. Then, they transition to the PhET Wave Interference simulation to visualize how light waves diffract and interfere when passing through slits—deepening their understanding of light as a wave. This activity can complement corresponding physical experiments and encourages scientific thinking through prediction, simulation, reflection, and creative application.

General Objectives of the Experiment	● Understand the additive colour model and the creation of secondary colours and white light using RGB light sources. ● Explore how light intensity and filters affect observed colours. ● Introduce the wave nature of light through diffraction and interference. ● Develop skills in using virtual simulations to model and understand physical phenomena. ● Foster observation, prediction, and analytical thinking aligned with real-world applications in art, technology, and physics.

Concepts for STE(A)M Disciplines	
Science	RGB colour mixing, properties of light, wave behaviour, diffraction, interference. Prediction of colour outcomes.
Technology	Use of interactive simulations to model physical phenomena.

Art	Creative expression through virtual light art design using RGB colour mixing.
Mathematics	Interpretation of wave interference patterns, spatial reasoning.

Prerequisite Knowledge	
Science	Basic understanding of light as a wave and part of the electromagnetic spectrum. Familiarity with visible light and colours.
Technology	Basic navigation and interaction within web-based simulations.
Art	Getting an experience of artistic research.
Mathematics	Interpreting angles, overlaps, and patterns visually.

Learning Outcomes	
Science	Describe how primary RGB colours combine to form secondary colours and white light. Explain how light behaves when filtered or altered in intensity. Recognize diffraction because of light's wave nature. Compare diffraction patterns based on slit spacing and wavelength.
Technology	Use PhET simulations to investigate and model physical phenomena.
Art	Create and analyse visual outcomes using light patterns and colour blending.
Mathematics	Interpret visual data from simulations to identify patterns and relationships.

Resource List
● Computers or tablets with internet access ● PhET Colour Vision Simulation: https://phet.colorado.edu/en/simulations/color-vision ● PhET Wave Interference Simulation: https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_all.html ● Student worksheet or digital document for notes included in the description below. ● Optional: screen recording or screenshot tools for documentation

Development of the Experiment

Part A – RGB Light Mixing with PhET "Colour Vision" (45 minutes)

Introduction and Hypothesis Development (10 min):

Begin with a quick review of the additive colour model (RGB) and the difference between additive and subtractive colour mixing.

Ask students to write down their hypotheses:

- ○ What colour will appear when two or more RGB lights overlap?
- ○ How will intensity affect the outcome?

Hands-On Simulation (25 min):

Open the Color Vision simulation: https://phet.colorado.edu/en/simulations/color-vision

Students will:

1. Activate red, green, or blue lights individually and observe the result.
2. Combine two lights and record resulting secondary colours.
3. Combine all three to observe white light.
4. Adjust light intensity sliders to explore brightness effects.
5. Add filters to see how different materials interact with coloured light.

Data Collection Table Example:

Light Sources	Intensity	Observed Color	Prediction	Result
Red + Green	Medium	Yellow	Yellow	✅
Green + Blue	Low + High	Cyan	Cyan	✅

Students can use this data collection sheet:
https://docs.google.com/document/d/1GdHnPT-7jlo_VCzgTIBe0XIJmjdUtZRw3RfP502BCJI/edit?usp=sharing

Reflection Questions (5 min):

What colour combinations surprised you?

How did intensity change the perceived colour?

How does this relate to the colour you see on digital screens?

Optional Extension – Light Art Challenge (5-10 min):

Students design a "virtual light mural" using overlapping lights and filters.

Screenshot their creation and describe their setup.

Part B – Diffraction and Wave Interference with PhET "Wave Interference" (45 minutes)

Introduction to Diffraction (5 min):

Explain that diffraction occurs when waves bend around edges or through slits.

Light behaves as a wave, and diffraction is evidence of that wave nature.

Simulation Activity (30 min):

Open the Wave Interference simulation: https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_all.html

Switch to the Light tab.

Tasks for students:

1. Choose single slit and observe the resulting diffraction pattern.
2. Try double slit and notice interference fringes.
3. Adjust wavelength and slit spacing, observe how the patterns change.
4. Compare wave types: what do water, sound, and light share in terms of behaviour?

Student Exploration Prompts:

- How does increasing the wavelength affect the diffraction pattern?
- What happens when slit spacing decreases?
- What is the difference between one-slit and two-slit patterns?

Advanced Challenge (Optional):

- Predict the pattern before running the simulation.
- Sketch or screenshot results and compare with predictions.

Students can use this data collection sheet:
https://docs.google.com/document/d/14uq79GIf-YAORI9cMuGd6YB71WPTKsuzKd7BbD5T1SY/edit?usp=sharing

Wrap – Up & Discussion (5–10minutes):
Recap the key ideas:

- RGB colour mixing creates new colours based on light wavelengths.
- Diffraction shows light bending and forming patterns because it acts like a wave.

Discuss real-world applications:

- Colour mixing: Screens, theatre lighting, photography
- Diffraction: CDs, spectrometers, scientific instruments

Adaptations for Different Levels

Younger Students (13–15):
- Focus primarily on colour mixing and qualitative observations.
- Use fewer variables and fixed light setups.

Older Students (16–18):
- Introduce wavelength-related calculations, predictions, and pattern analysis.
- Have them connect diffraction behaviour to mathematical relationships (e.g., spacing vs. fringe width).

Assessment

Reflection Questions:
● Which colours did you expect but didn't see? Why?
● How do your results compare to your predictions?
● How do slit width and light wavelength affect diffraction patterns?

Rubric Criteria:

Criteria	Excellent (5)	Good (4)	Satisfactory (3)	Needs Improvement (2)
Accurate Data Collection	✅			
Understanding of RGB Color Mixing	✅			
Understanding of Diffraction	✅			
Creativity in Light Art Design	✅			
Quality of Reflection Responses	✅			

Worksheet

Part A – RGB Light Mixing with PhET "Colour Vision"

Introduction

In this part of the experiment, you will explore how red, green, and blue light sources combine to create secondary colours and white light. Follow the instructions below and record your observations in the tables provided.

Hypothesis Development

Before you start, write down your hypotheses:

1. What colour will appear when two or more RGB lights overlap?

Your prediction:

………

2. How will intensity affect the outcome?

Your prediction:

………

Hands-On Simulation

1. Open the Colour Vision simulation: PhET Colour Vision Simulation

2. Activate the Lights:

- Turn on the red light.
- What colour do you see?

………

3. Combine Lights:

- Combine Red + Green.
- What colour do you see?

………

- Combine Green + Blue.
- What colour do you see?

……

- Combine Red + Blue.
- What colour do you see?

……

- Combine All Three colours (Red, Green, Blue).
- What colour do you see?

……

4. Adjust Light Intensity:

- Change the intensity sliders for each light.
- How does increasing or decreasing intensity affect the colours you see?

……

5. Add Filters

- Experiment with adding filters. What happens when you place a filter over the lights?

……

Data Collection Table

Light Sources	Intensity	Observed Color	Prediction	Result
Red + Green	Medium (50)			
Green + Blue	Low + High			
Red + Blue	Medium (50)			
Red + Green + Blue	Full Intensity (100)			

Reflection Questions

1. What colour combinations surprised you?

………

2. How did intensity change the perceived colour?

………

3. How does this relate to the colour you see on digital screens?

………

Optional Extension – Light Art Challenge

Design a "virtual light mural" using overlapping lights and filters.

1. Screenshot your creation:
(Paste your screenshot here or describe your setup)

………

2. Describe your setup:

………

Part B – Diffraction and Wave Interference with PhET "Wave Interference"

Introduction

In this part of the experiment, you will explore how light waves diffract and interfere when passing through slits. This will help deepen your understanding of light as a wave and its behaviour in different scenarios. Follow the instructions below and record your observations.

Hypothesis Development

Before you start, write down your hypotheses:

1. What do you think will happen to the light pattern when it passes through a single slit?
Your prediction:

……

2. What do you think will happen when the slit width changes?
Your prediction:

……

Hands-On Simulation

1. Open the Wave Interference simulation: [PhET Wave Interference Simulation]

2. Single Slit Observation:

- Select the Single Slit option.
- What pattern do you see?

……

3. Double Slit Observation:

- Switch to the Double Slit option.
- Describe the interference pattern you observe.

……

4. Adjust Wavelength:

- Change the wavelength of the light.
- How does the pattern change with different wavelengths?

……

5. Vary Slit Spacing:

- Adjust the spacing between the slits.
- What happens to the interference pattern as you change the slit spacing?

……

Data Collection Table

Slit Type	Wavelength	Slit Width	Observed Pattern	Prediction	Result
Single Slit					
Double Slit					

Reflection Questions

1. How does increasing the wavelength affect the diffraction pattern?

……

2. What happens when slit spacing decreases?

……

3. What is the difference between one-slit and two-slit patterns?

……

……

Advanced Challenge (Optional)

1. Before running the simulation, predict what the pattern will look like:

……

2. After observing the results, sketch or screenshot the patterns:

……

3. Compare your predictions with the actual results:

……

……

Creating Colourful Shadows: Exploring RGB Light Colour Mixing and Diffraction

Kristof Fenyvesi, Josephine Lau, Maria Fisk

Grade Level	Middle to high school (students aged 13–18)

Activity Duration	90 minutes

Experiment Description	This experiment introduces students to the fascinating interplay between light, colours, and diffraction using simple RGB light sources and common materials. ● Students will create colourful shadows by overlapping red, green, and blue light sources and learn how the primary colours of light mix to produce secondary colours. ● They will explore how light interacts with various objects and how RGB colour mixing works and diffraction patterns are created. The activity is designed to connect STE(A)M concepts, including physics (optics), technology (light sources), art (colour blending), and mathematics (geometry of light paths). This experiment is designed to be adaptable across a wide range of student age groups and curricular levels. We encourage teachers to tailor the guiding questions, challenges, and extension activities to meet the specific learning objectives and cognitive development of their students.

General Objectives of the Experiment	● Introduce the concept of colour mixing and light diffraction. ● Foster creative thinking by encouraging students to experiment with overlapping colours. ● Develop problem-solving skills by exploring how different materials interact with light. ● Connect scientific concepts to real-world applications, such as displays, lighting design, and optics.

Concepts for STE(A)M Disciplines	
Science	Additive colour mixing (RGB light model). Principles of light diffraction, reflection, and refraction.
Technology	Using RGB LED lights and understanding how devices like projectors and screens work.
Art	Creation of colourful patterns and understanding artistic applications of light and colour.
Mathematics	Geometry of light paths and angles of incidence and diffraction.

Prerequisite Knowledge	
Science	Basic understanding of the electromagnetic spectrum and properties of light.
Technology	Familiarity with LED light sources.
Art	The introduction of the traditional and innovative practices of shadow theatres is not a prerequisite, but an interesting opportunity to explore with the students.
Mathematics	Basics of angles and geometric concepts like overlapping shapes.

Learning Outcomes	
Science	Students will explain how light behaves when it passes through different materials and mixes. Students will describe how RGB colours create secondary colours and white light.
Technology	Students will understand how RGB lights are used in modern technology like screens.
Art	Students will study additive colour mixing (RGB light model) and create and analyse artistic patterns using light and diffraction.
Mathematics	Students will calculate angles and distances to predict shadow formations and light overlaps.

Resource List
1. RGB LED flashlights or light sources. 2. White screen or blank wall. 3. Opaque objects of various shapes (e.g., paper cutouts, hands, or toys). 4. Transparent or translucent materials (e.g., plastic sheets, glass, or cellophane). 5. Rulers and protractors for measuring angles, worksheets for observations and calculations.

Development of the Experiment

Background material for teachers:

To support your preparation, we recommend watching these short, step-by-step videos, which demonstrate simple and effective classroom implementations of the activities:

Figure 1: Watch this video for a simple classroom implementation of this topic: https://www.youtube.com/watch?v=3CN-gaePa_A

An explanation of additive light mixture is available in the video linked here: https://www.youtube.com/watch?v=eKj1EwJ7THU

The accompanying materials below are intended to provide inspiration and flexible entry points for exploring the concepts of light, colour mixing, and diffraction in a creative and inquiry-based way.

The Problem or Situation Presented to Students:

"How can we create colourful shadows using RGB light sources? What patterns and colours emerge when we overlap different coloured lights?"

Steps to Carry Out the Experiment

Part A – Exploring Colour Mixing and RGB Shadows

Introduction and Setup:

Begin with an introduction to light as part of the electromagnetic spectrum, focusing on visible light and the additive colour model.

Briefly explain how red, green, and blue (RGB) light combine to form secondary colours (cyan, magenta, yellow) and how all three together create white light.

Demonstration (Teacher-led):

Show a quick demonstration using three overlapping RGB lights on a white surface. Allow students to observe how the different colours mix in the overlapping zones.

Student Experiment – Creating Colourful Shadows:

- Step 1: Set up three RGB light sources (or coloured flashlights with filters) so that their beams overlap on a white wall or screen.
- Step 2: Place opaque objects (hands, cutouts, toys) in front of the lights. Students observe the coloured shadows formed and note how blocking one light source changes the shadow colour.

For ideas and guidance to create the cut-out shapes, this online resource can be helpful: https://www.sciencebuddies.org/teacher-resources/lesson-plans/shadow-play

- Step 3: Have students sketch and label the resulting colour patterns on their worksheets.
  - Example question: "What colour shadow appears when the red light is blocked?"

Observation and Recording:

Students measure distances between the lights and the screen, and record angles of incidence if relevant (for more advanced students). Encourage them to note how placement affects overlap and shadow intensity.

Creating colourful shadows in a Finnish school.

Part B – Investigating Light Diffraction Through Materials

Introduction to Diffraction:

Explain that diffraction is the bending and spreading of light as it passes around edges or through narrow openings. Clarify how this differs from refraction and interference and note that visible diffraction effects are easier to observe with certain translucent or structured materials.

Student Experiment – Diffraction Exploration:

- Step 1: Replace or supplement opaque objects with translucent materials (e.g., frosted plastic, tissue paper, thin fabrics, or diffraction gratings if available).
- Step 2: Shine a single light source (or white light) through or around these materials to observe how the light spreads or forms colourful patterns.
- Optional Advanced Step: Introduce a CD or DVD surface, or a laser pointer and hair setup to observe more defined diffraction effects.

Observation and Analysis:

- Have students document any patterns or spreading of light, comparing them to the shadow formations in Part A.
- Guide them to discuss questions such as: *“What do you notice about the edges of the light patterns?” “How does the material affect the way light travels or bends?” “Is the pattern symmetric? What colours are visible and why?”*

Discussion and Synthesis

- ● Facilitate a class discussion to compare the phenomena observed in Part A (colour mixing and shadows) with those in Part B (diffraction).
- ● Encourage students to establish tangible connections between these phenomena and their practical applications in real-world scenarios. This can be facilitated through a mini research project and presenting the results on topics like:
  - ● RGB pixels in screens (colour mixing).
  - ● CDs and soap bubbles (diffraction and interference).
  - ● Stage lighting and shadow art (combined concepts).

Expected Final Result:

Students will observe colourful shadows with primary and secondary colours, understand how light interacts with objects, explore the additive colour mixing (RGB light model), and see how diffraction and reflection create artistic and scientific patterns.

Creative STE(A)M Project: Designing Light Art Using RGB Shadows

Objective:

Students will apply their understanding of RGB colour mixing, light diffraction, and shadow formation to design and create a piece of light art. This activity incorporates artistic creativity with the scientific principles explored in the experiment, making the concepts tangible and visually engaging.

Activity Name: "Painting with Light: Creating a Colourful Shadow Mural"

Materials

1. RGB LED lights or flashlights (one for red, green, and blue).
2. A white wall, screen, or large piece of poster paper.
3. Translucent materials (e.g., coloured plastic sheets, tissue paper, or cellophane).
4. Opaque objects of various shapes and sizes (e.g., cardboard cutouts, toys, or hands).
5. Scissors, tape, and glue for crafting materials.
6. Rulers and protractors for positioning light sources and objects.
7. Optional: Smartphone or camera to capture the final designs.

Instructions:

1. Plan the Light Art Design:

   Ask students to sketch their idea for a colourful light mural using shadows and overlapping RGB colours.

   Encourage creativity! For example:
   - ● A scene (e.g., a forest, cityscape, or underwater world).
   - ● Abstract patterns and shapes.
   - ● A themed design related to a topic they're studying (e.g., space exploration or nature).
2. Build the Scene:

   Use opaque objects (cut-out shapes, toys, or hands) to create distinct shadows.

   Incorporate translucent materials to alter how the light passes through and create unique diffraction patterns or blended colours.

   Position objects at varying distances from the wall to see how it affects the sharpness and size of shadows.

Shadow Play: Move closer to the wall for sharper, smaller shadows — move farther away to create larger, blurrier ones. Explore how distance changes light behaviour

3. Experiment with Light Placement:

Position the red, green, and blue lights to overlap on the white background. Adjust the angles and distances of the lights to maximize the visibility of secondary colours (cyan, magenta, yellow) and to create dynamic patterns.

Encourage students to experiment:

- Move lights closer or farther away.
- Change angles to create gradients or brighter regions.
- Use reflective materials (mirrors or foil) to bounce light and add more complexity.

4. Document the Process:

Take pictures or videos of the evolving light art to track how different setups produce different effects.

Students can annotate their sketches to reflect changes they made to their designs.

5. Display and Reflect:

Once the light art is finalized, capture the final mural with a photo or invite the class to observe and discuss the work.

Ask reflection questions like:

- How did you use the RGB light mixing to achieve specific colours?
- What surprised you about the way light and shadows behaved?
- How might this concept be used in real-world applications, like theatre lighting or digital displays?

Adaptations for Advanced Students:

Add a mathematical challenge by asking students to calculate angles and distances to predict shadow positions before setting them up.

Introduce the concept of wavelengths and ask students to think about how other parts of the electromagnetic spectrum (e.g., UV or infrared) could be incorporated into similar artistic projects.

Real-World Application Connections:

Theatre and Stage Design: Explain how stage designers use coloured lights and shadows to create immersive environments.

Digital Screens and Technology: Link RGB light mixing to the way pixels on a screen produce colours.

Art Installations: Highlight how modern artists use light and shadow to create dynamic works, like projection mapping or light sculptures.

Outcome:
By the end of this activity, students will have created a vibrant, collaborative art piece while reinforcing their understanding of light properties (diffraction, mixing, and shadows) in a hands-on and engaging way!

Adaptations for Different Levels

Younger Students:
Focus on observing and describing the patterns and colours without detailed calculations.
Older Students:
Include measurements and quantitative analysis of angles and distances, emphasizing the geometry of light.
Advanced Students:
Explore wavelength and frequency of light to deepen understanding of diffraction.

Optional Advanced Experiment: Exploring Diffraction Patterns
For older students, introduce a follow-up activity to observe diffraction:

- Objective: Observe the diffraction of light through narrow slits or diffraction gratings.
- Materials: Laser pointer, CD/DVD, human hair, ruler, dark room, white screen, cardboard slit, flashlight.
- Setup 1 (CD): Hold a CD under white light or sunlight and observe the rainbow pattern caused by the diffraction of different wavelengths.
- Setup 2 (Laser & Hair): Shine a laser pointer past a single hair onto a white wall to observe the interference pattern (light and dark fringes). Detailed description of this experiment: https://www.snexplores.org/blog/eureka-lab/measure-width-your-hair-laser-pointer

- Discussion Questions for the Advanced Experiment:
  - What do the patterns tell you about the wavelengths of light?
  - How is diffraction different from refraction and interference?
  - How does the distance between the fringes relate to the thickness of the object or slit?

Differentiated Questions by Level

- For Middle School (ages 13–15):
  - What happens when two coloured lights overlap?
  - Can you name all the secondary colours created by RGB lights?
  - Where have you seen colourful shadows before?

- For Upper Secondary / Pre-University (ages 16–18):
  - Calculate the angle of incidence and predict shadow positioning.
  - How would using a laser of known wavelength help analyse diffraction patterns?
  - Can you derive an estimate for fringe spacing using basic diffraction equations?

Assessment
Rubric for Evaluation: Observation and Recording (25%): Accurate sketches and descriptions of shadows and patterns. Understanding Concepts (30%): Clear explanations of how RGB colour mixing works and how light interacts with objects. Critical Thinking (25%): Ability to relate observations to real-world applications like technology and art. Engagement and Creativity (20%): Active participation and creative exploration of light patterns. Reflection Questions: 1. What colours did you observe when different lights overlapped? 2. How did the position of the objects change the colours of the shadows? 3. How can the concepts of RGB light mixing be applied to everyday technologies?

Worksheet

Exploring RGB Light Colour Mixing, Shadows and Diffraction

Inquiry challenge
How can we create colourful shadows using red, green and blue light sources? What colours and patterns appear when we overlap lights, block one light source, and shine light through different materials?

Part 1: Initial ideas and predictions
Task A: Think first.
Before using the lights, predict what you expect to see. You do not need to be correct. Your predictions will help you compare your ideas with evidence. Write your ideas below.

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Light combination or situation	Your prediction: What colour or pattern will appear?	Why do you think so?
Red light only		
Green light only		
Blue light only		
Red + Green overlap		
Green + Blue overlap		
Red + Blue overlap		
Red + Green + Blue overlap		
An object blocks only the red light		

Task B: Research-team question. Choose one question your group especially wants to investigate.

☐ How does moving an object closer to or farther from the screen change the shadow?
☐ How does moving the lights closer together or farther apart change the colour overlaps?
☐ How do different object shapes create different shadow patterns?
☐ How do translucent materials change the colour, brightness or edges of light?
☐ Our own question: ____

Part 2: Set up the RGB shadow experiment

Do not shine bright lights or lasers into anyone's eyes. Keep cables and tripods stable. Darken the room only as much as needed.
Setup:

- Place the white screen or choose a blank wall.
- Position the red, green and blue lights so that their beams overlap on the screen.
- Place one object between the lights and the screen.
- Adjust the distances until the overlapping colours and shadows are visible.
- Agree who will measure, sketch, record observations, and who will take photos.

Draw your experimental setup.
Label the screen, the three lights, the object, and the main distances.

Variable	**Measurement / description**	**Unit or notes**
Distance: lights to screen		cm
Distance: object to screen		cm
Distance: lights to object		cm
Approximate angle between light beams		degrees
Object used		shape/material
Room lighting		dark / dim / normal

Part 3: Observe RGB colour mixing and colorful shadows
Task A: One light at a time. Turn on each light separately. Record what you observe on the screen and how the shadow looks.

Light(s) on	**Colour on screen**	**Shadow colour / appearance**	**Notes about brightness or edges**
Red only			
Green only			
Blue only			

Task B: Combine lights. Turn on two or three lights and record the colour in the overlap zone. Then compare with your predictions from Part 1.

Light combination	Observed overlap colour	Did it match your prediction? Yes/No	What evidence helped you decide?
Red + Green			
Green + Blue			
Red + Blue			
Red + Green + Blue			

Task C: Block one colour. Place an object where it blocks one light source at a time. Describe the shadow colours that appear.

Blocked light	Which lights still reach the screen?	Observed shadow colour(s)	Explanation
Red blocked			
Green blocked			
Blue blocked			
Two lights blocked: ________________			

What colour shadow appears when the red light is blocked?
My answer:
……………………………………………………………………………………………………….
Why does this colour appear?
……………………………………………………………………………………………………….

Sketch and label one colourful-shadow pattern.
Use labels such as red, green, blue, cyan, magenta, yellow, white and dark shadow.

Part 4: Change one variable and test again

Choose **only one variable to** change while keeping the others as similar as possible. This helps you make a fair comparison.

☐ Variable we will change: object distance / light distance / light angle / object shape / material / other: ___________________

☐ What we will keep the same:

____

☐ Our prediction:

____

Trial	What changed?	What stayed the same?	Observation: colour, size, sharpness, brightness	Quick measurement
1 (original setup)				
2 (changed setup)				
3 (changed setup)				

What pattern did you notice after changing this variable?

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How confident are you in your result? Circle one: low / medium / high Why?

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Part 5: Investigate diffraction and light spreading through materials

How does light change when it passes through or around different materials and narrow structures?

Test at least three materials. Use a single light source or white light.
Optional advanced materials: CD/DVD, diffraction grating, comb, narrow slit, or laser-and-hair setup under teacher supervision.

Material / structure tested	What did you see? pattern, colours, spreading, symmetry	Edge sharpness: sharp / blurred / fringes	Possible explanation
Translucent material 1: ____________________			
Translucent material 2: ____________________			
Thin fabric / tissue / plastic: ____________________			
CD/DVD or grating (optional)			
Other: ____________________			

Sketch one diffraction or spreading pattern.
Label colours, bright/dark regions, symmetry, and edges.

Compare Part 3 and Part 5.
How are colourful shadows different from diffraction or spreading patterns?

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Part 6: Creative STE(A)M challenge - Painting with light

Create a small light-art composition or shadow mural using RGB lights, objects and/or translucent materials. Your artwork should intentionally use at least two scientific ideas from this worksheet.

Planning prompt	**Your response**
Title of your light-art composition	
Theme or story (for example forest, city, space, abstract pattern)	
Which RGB colour mixtures will you use intentionally?	
Which shadows, materials or diffraction effects will you use?	
What measurements or setup choices are important?	

Plan your light-art composition.
Label lights, objects, materials and expected colours.

After testing your design, what did you change and why?

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Part 7: Reflection and real-world connections

Reflection question	Your answer
1. What was your most important discovery about RGB light mixing?	
2. Why can a shadow have colour when several coloured lights are used?	
3. How did distance, angle or object shape affect the shadow?	
4. What did you learn about how materials affect light?	
5. Where do people use RGB colour mixing in everyday technologies?	
6. Where could artists, designers or engineers use colourful shadows or diffraction?	

Final claim-evidence-reasoning. Write one scientific claim from your investigation. Support it with evidence from your observations and explain your reasoning.

Claim	Evidence from our data/observations	Reasoning: why the evidence supports the claim

OPTIONAL ADVANCED EXTENSION

- Measure an angle of incidence and predict where a shadow edge will appear on the screen.
- Estimate how shadow size changes when the object moves twice as far from the screen.
- Use a CD/DVD or diffraction grating to compare colour order and spacing.
- Research one real-world application: RGB pixels, theatre lighting, projection mapping, cameras, spectrometers, CDs, soap bubbles, or optical sensors.

Advanced investigation	Prediction	Result	What this suggests
Angle / distance test			
Diffraction / colour-order test			
Real-world application mini research			

Group presentation checklist

☐ We can explain our setup clearly.

☐ We can show at least one sketch, photo or measurement table.

☐ We can describe one result that confirmed our prediction and one result that surprised us.

☐ We can explain one real-world use of RGB light mixing, colourful shadows or diffraction.

☐ Every team member contributes at least one sentence during the presentation.

Summary of the Toolkit and Suggestions for Further Use

The STExperiMents Toolkit presents eight interdisciplinary STE(A)M experiments developed to support inquiry-based and student-centred learning in secondary education. The activities combine scientific investigation with technology, engineering design, artistic expression, and mathematical reasoning. Through hands-on and virtual experiments, students are encouraged to ask questions, formulate hypotheses, collect and interpret data, design solutions, communicate findings, and reflect on the relevance of science in everyday life.

The toolkit is designed to be flexible and adaptable. Teachers may use individual experiments as standalone lessons or combine several activities into broader learning units. Each experiment can be modified according to students' age, prior knowledge, available resources, and classroom context. The physical and virtual formats provide multiple entry points for schools with different levels of equipment and digital access.

Beyond providing classroom-ready materials, the toolkit aims to inspire further STE(A)M practice. Teachers are encouraged to adapt the experiments, collaborate across subject areas, and invite students to extend the activities through additional investigations, design improvements, creative presentations, or real-world applications. Emphasis should be placed on the learning process: questioning, testing, revising, discussing, and drawing evidence-based conclusions.

Overall, the STExperiMents Toolkit demonstrates how STE(A)M education can make science learning more engaging, meaningful, and connected to real-world challenges. By integrating experimentation, creativity, collaboration, and reflection, the toolkit supports students in developing the competences needed to understand and respond to complex problems in contemporary society.

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