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[101086701] Discovery Space:
An AI-Enhanced Classroom for Deeper Learning in STEM

D.4.1 Practice Scenarios-First Version

Work Package 4: Implementation Scenarios, Pilots and Impact Assessment

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Executive Summary

This document is the first version of the Discovery Space D.4.1 Practice Scenarios. It presents a collection of scenarios designed to enhance STEM education by providing students with interactive and engaging learning experiences. The work presented is developed in the framework of WP4 (Implementation Scenarios, Pilots and Impact Assessment). It presents a summary of the methodology adopted to create the scenarios, a summary of the scenarios and a more in depth navigation of the various scenarios created. The presented scenarios offer opportunities for hands-on experimentation, virtual simulations and reflection on key scientific concepts. Monitoring and guidance are incorporated as a differentiated way for educators to support students in developing key problem solving competencies.

The introduction presents the methodology adopted and the structure used to build each of the scenarios, which adopts the Inquiry and Problem Based Learning approaches (IBL and PBL). These scenarios are designed to integrate a differentiated approach where students receive different levels of support.

Chapter 2 highlights the importance of improving the students' learning experiences with the introduction of conversational agents and the adoption of tailored learning experiences. The phases adopted by the scenarios are presented in more detail.

Chapter 3 presents the curriculum opportunities for the implementation of each of the scenarios in the countries where the project will be piloted.

The analytic detail of each scenario is presented in the annexes.

List of Terms and Abbreviations

Term/Abv.	**Definition**
IBL	Inquiry based learning
PBL	Problem-based learning
STEM	Science Technology Engineering Mathematics

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1. Introduction

The initial set of Discovery Space scenarios, incorporating the Inquiry Based and Problem Based approaches are presented in this document. The first materialised ideas are prepared to be embedded in the learning environment, being developed by the project, where interactive features will enrich the students' learning experiences. These scenarios enable the adoption/adaptation to different curriculum opportunities and present within their structure various opportunities for differentiation of student's learning experiences, to support their journey, regardless of their initial competence profile. These scenarios are targeting STEM curriculum content and embed in their structure online experiments (virtual or remote) that enrich and help contextualise the proposed learning goals. Each scenario is created considering its possible further adoption for different learning environments and infrastructures. A teacher might adopt them for classroom use, to be a travel companion to complete a learning experience, to enrich a science centre visit, etc. They can also serve as inspiration for the creation of new learning scenarios using the same structure and design. Each of the scenarios provide information about the curriculum opportunities, in the countries piloting the project, guidelines for the teacher implementation and all necessary references to support educators. The content is presented in a modular way, following the phases of an Inquiry Based Learning (IBL) approach. These scenarios will be further enriched in co-creation opportunities with educators in support for their implementation and optimisation in real learning opportunities. This initial set of scenarios will be instrumental for the next steps of implementation. Their use in the various pilot sites will help reflect on their use, revise them and learn from their integration and support the creation of the future scenarios. In this document we present the methodology adopted for the creation of the initial set of scenarios.

The first set of scenarios are bringing a sample of topics that will invite students to become familiarised with the research method adopted by scientists. After being presented with a set of initial ideas, aiming to inspire students and create curiosity about the scenarios, students will be invited to propose their own hypothesis and use online laboratories (virtual or remote), to design their experiments and validate their ideas. They will be invited to reflect on their results, reach conclusions and discuss their findings with their peers.

Teachers will be able to identify the different levels of their students' problem solving competencies and to provide the necessary guidance to support their evolution. These scenarios are completely in line with a recent OECD report "Reimagining Education, Realising Potential" were the importance of the IBL and PBL approach for improving the student's real world problem solving skills, as a means to encourage a big picture approach to open-ended problems and challenges. The document also mentions the importance of conversational agents as a means to offer genuine learning and for its power for students' motivation and engagement while at the same time promoting a more personalised education. In line with these ideas, each scenario presents alternative paths for students where students will have the opportunity to navigate the same IBL scenario with different levels of challenges, guidance and support. Students will navigate through individualized pathways which the algorithm will guide them through based on their initial and evolving level of mastery.

The structure of the scenarios adopts a modern approach to engage students in innovative learning experiences where they are the lead of the process and can move forward according to their knowledge and competence profile levels.

2. Discovery Space Scenarios enhanced with conversational agents and differentiated inquiry-based methods.

As already presented in D2.2 the introduction of a conversational agent during the students learning experiences can be a transformational experience. The conversational agent can assess the student knowledge or competence related to a certain topic or problem being addressed and facilitate the work of the teacher, providing differentiated experiences depending on the student knowledge and competence profile (Fig.1).

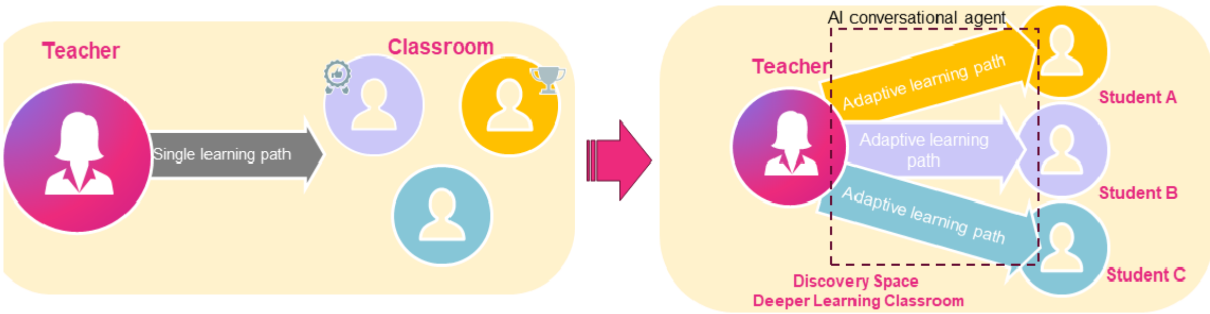


Figure 1 The transformation of the traditional classroom to the deeper learning classroom as presented in D2.2.

The document also presents a complete discussion on problem solving competencies and how to assess the student's evolution throughout their engagement in the proposed activities. To accomplish this vision, each scenario has to be built with the necessary characteristics and possibilities to enable such a rich and complex environment.

The learning approach adopted by DSPACE is based on inquiry-based learning (IBL) and problem-based learning (PBL) where students are invited to follow the scientific method to build their learning path. Students will be introduced to a specific topic, challenge, experiment, etc., and invited to reflect on it and design an experiment to collect and analyse data to validate their hypothesis, followed by a conclusion and discussion phase where the foreseen content knowledge should be properly understood and the problem solving competence of the student improved or perfected. As it was thoroughly discussed in D2.2, IBL can take on different models and different names. For Discovery Space scenarios the adopted phases are **engagement, hypothesis, experiment, analysis, and reflection**.

The flow for the design of the Discovery Space scenario was presented in D2.2 with the Simple Pendulum example. This scenario served as a template for the future scenarios providing the initial framework for the design of the material that will be the central part of the students' learning experience. The scenario presents a concrete example of a conversational agent guiding the students throughout the phases, directing each of them to the future steps according to their knowledge and problem solving competence in each of the IBL steps. Students take different paths according to an initial verification and the necessary guidance is provided to ensure each student will progress towards a complete understanding of the presented topic and improve their problem solving competencies accordingly. The scenario follows the 5 IBL phases outlined above:

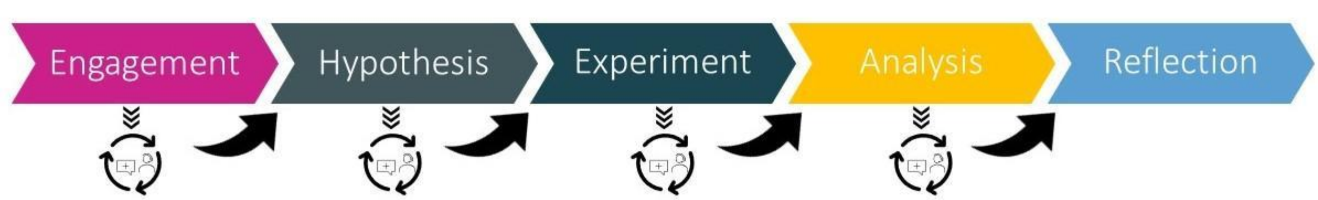


Figure 2 The 5 phases of IBL adopted by Discovery Space for the construction of the scenarios.

1. Engagement: A phenomenon is presented to the students through an appropriate demonstration, in order to spark their interest and motivate them to work on its understanding.
2. Hypothesis: The students are asked to make a hypothesis in order to explain the phenomenon by identifying the main parameters for its explanation.
3. Experiment: At this stage the students are performing experimental work, using either a virtual or a remote lab, in order to see the effect that each identified parameter has on the phenomenon under discussion.
4. Analysis: The sets of data collected at the previous phase are now analysed and conclusions are drawn, which either reject or validate the hypothesis made at the second step above.
5. Reflection: At this stage the students reflect on what they have learned so far, while they are presented with a series of more demanding questions aiming to test how confident they are on their understanding.

In this document we present again the Simple Pendulum, for reference, and further scenarios that will be presented to teachers to initiate the co-creation efforts of Discovery Space. These scenarios will be uploaded in the Discovery Space Learning Environment. Each author adapted their scenarios to fit the purpose of their target learning environment and national/local curriculum specification. Different styles were adopted by the various authors that contributed to the creation of the scenarios presented in this document.

Our hope is that educators will find them valuable for the delivery of the specific topics, with the necessary adaptation to their local needs and preferences.

3. Discovery Space Initial Scenarios

This chapter presents the initial set of scenarios. We present the basic structure of each scenario and in the annex a complete description. These scenarios will be further enriched and adapted by educators piloting the project in their schools. Co-created solutions will emerge from this process and these new enriched scenarios will populate the Discovery Space learning platform. More scenarios are currently in production and will enrich the collection for the beginning of the new school year. (2024/2025).

3.1. Curriculum opportunities

The presented scenarios were created by the different countries implementing the project. They are produced considering opportunities in each of the countries piloting the project. The table below presents the curriculum implementation opportunities for the selected topics for the selected countries.

Table 1 Curriculum Implementation Opportunities

SCENARIO	Country	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY
Simple Pendulum	Germany	11th	Physics	Vibration & waves						
	Greece	7th	Physics	Experiments in Physics	9th	Physics	Vibrations and mechanical waves			
	Portugal	11th	Physics & Chemistry	Forces and motions	12th	Physics	Mechanics: Kinematics and Dynamics in 2 Dimensions			
	Spain	2º (3-4) EP (Primary Education)	Natural Sciences	Time, period	3º ESO (Secondary Mandatory Education)	Physics & Chemistry; Technology and Digitalization	Project development			

SCENARIO	Country	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY
Photoelectric Effect	Germany	12th	Physics	Static electric and magnetic fields						
	Greece	12th	Physics	Introduction to quantum theory						
	Portugal	12th	Physics	Modern Physics: Introduction to Quantum Physics (Photoelectric Effect)						
	Spain	2º B	Physics & Chemistry	Introduction to quantum mechanics						
Newton's Laws	Germany	8th	Physics	Dynamics						
	Greece	10th	Physics	Dynamics	8th	Physics	Forces			
	Portugal	9th	Physics & Chemistry	Forces and motions	11th	Physics & Chemistry	Forces and motions	12th	Physics	Mechanics: Kinematics and Dynamics in 2 Dimensions
	Spain	2º EP	Natural Sciences	Forces and motions	4 ESO	Physics & Chemistry; Technology and Digitalization	Newton's Laws			
Phases of the Moon	Germany	7th	Natural Sciences	Optical phenomena	10th	Physics	Basics of optics			
	Greece	5th-6th	Physics	Modern Physics, Technology, Environment, Space						

SCENARIO	Country	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY
	Portugal	3rd	Environmental studies	Nature: Understand the phases of the moon	7th	Physics & Chemistry	Space: Earth, Moon and gravitational forces			
	Spain	1º-2º EP	Natural Sciences	The Earth in the Universe						
Seasons	Germany	1st-2nd	Natural Sciences	Animals, plants, habitats	10th	Geographics	Climate and vegetation zones of the tropics and arid subtropics			
	Greece	6th	Geography	The Earth as a celestial body						
	Portugal	3rd	Environmental studies	Nature: Understand the phases of the moon	Nature: Understand the phases of the moon	Physics/Chemistry	Motions on the Solar System			
	Spain	1º - 2º EP	Natural Sciences	Earth rotation and its consequences	1º ESO	Physics & Chemistry	Motions on the Solar System			
Simple Machines: Pulley	Germany	10th	Physics	basics of dynamics II	13th	Physics	basics of dynamics II			
	Greece	10th	Physics	Forces	12th	Physics	Rigid body dynamics			
	Portugal	9th	Physics/Chemistry	Movements on Earth/Forces, Movements and Energy	11th	Physics & Chemistry	Forces and motions			

SCENARIO	Country	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY	GRADE LEVEL	SUBJECT DOMAIN	CURRICULUM OPPORTUNITY
	Spain	3º - 4º EP	Natural Sciences	Mechanical Advantage, simple machines, pulley	1º - 2º ESO	Physics; Technology	Pulley: simple machines			
Ohm's Law	Germany	7th	Natural Sciences	Electric Current	9th	Physics	Electrical Engineering (optional)			
	Greece	9th	Physics	Electric current	11th	Physics	Electricity & electric current			
	Portugal	9th	Physics/Chemistry	Electric current, electrical circuits, effects of electric current and electrical energy	10th	Physics/Chemistry	Energy and electrical phenomena			
	Spain	1º, 2º and 3º ESO	Technology	Scientific and technical resources: electrical / electronic components, functions and basic circuits.	3º ESO	Physics & Chemistry	Electricity and society: Electric current/electrical circuit basics			
Population Genetics	Germany	12th	Biology	Mechanics of the evolution						
	Greece	12th	Biology	Genetics						
	Portugal	12th	Biology	Genetic Heritage						
	Spain	4º ESO	Biology & Geology	The Life evolution: DNA and Molecular Genetics, Human genetics, Genetic Engineering.	2º B	General sciences	Biology of the 21st century			

3.2. Simple Pendulum Scenario

This scenario was presented in D2.2 and is added in this deliverable as a template for the other scenarios presented next.

Table 2 The pendulum scenario in a nutshell.

Problem Solving Process	Scenario Phase	Questions of the Scenario	Educational Objective
Exploring and understanding	*Engagement*	**Q1**: To achieve the most accurate measurement of the period of the pendulum? **Q2**: Which pendulum swings faster if there is no friction?  **Q3**: Which pendulum swings faster if there is no friction? 	The problem that the students are called to explore is the pendulum itself. Students need to understand the physical meaning of the period and see its importance for measuring time. Students start to connect Mathematics with Physics. Q1 aims to check if they have understood which is the source of errors during the measurement. High performers have understood that errors are caused by the reflexes of the experimenter, as he/she operates the stopwatch, thus by choosing option A, such erros are minimized. Low performers need help to understand the importance of repeating a measurement and moderate performers need guidance to understand the source of inaccuracy. In addition, students start thinking which are the main parameters that determine the pendulum's period, in other words they decompose the system to identify its components. A constructionist approach is applied. Q2 and Q3 test how well students can identify the role of each parameter without having any previous knowledge about the pendulum.
Representing and formulating	*Hypothesis*	**Q4**: What can you say about the length of the rope? **Q5**: What can you say about the bob-mass?	Check if the students can identify the role of key parameters and formulate a correct hypothesis about the dependence of the period on the length and the mass. Check indirectly if the relation between the speed of the pendulum and its period is understood. Students need to employ correlational reasoning skills. HIGH perfromers in Q4 and Q5 have a correct representation of the phenomenon in mind. Check whether or not students with low or moderate performance in the previous phase can create a correct mental representation after using the virtual lab to conduct experimental work.
Planning and executing	*Experiment*	**Experiment 1**: Design an experiment to check your hypothesis on the relationship between the pendulum's period and length. Could you reach to a reasonable conclusion if you vary both the length and the mass simultaneously. **Experiment 2**: Design an experiment to check your hypothesis about the relationship between the mass of the pendulum and its period.	At this phase, clear goals should be set and plans should be executed to achieve them. The first goal is to clarify the relationship between the pendulum's period and its rope length. An appropriate experiment should be designed and accurate measurements will take place so that the dependence will be obvious in the results. The importance of the previous steps is becoming obvious now. Accordingly the students will need to investigate the dependence between the bob-mass and the pendulum's period. The process aims to assess how well the students can perform experiments and whether or not they can perform the experiment in a correct way, by varying a single parameter and not several, so they can see the impact of the specific parameter. It should also be perfectly clear which are the parameters to be varied.
Monitoring and reflecting	*Data analysis*	**Q6**: Which one of the following do you observe according to your measurements? **Q7**:According to your measurements, which of the following statements is correct, about the relation between the mass of the pendulum and its period?	Analyse the results obtained during the experimental procedure and check whether or not they validate or reject the hypothesis made at phase 2. Check for unexpected results, evaluate if additional information is necessary and employ either deductive or inductive reasoning skills to draw conclusions. No matter which their previous responses were, students with high performance at this stage demonstrate that they can correclty interpret experimental results and use them as a guide to create correct models. Students with low and moderate performance will need to repeat the experiment in the first case, or go through the hints provided in the experiment instructions to understand how the experiment can be performed better, in the latter case.
	Reflection	**Q8**: So far, we have established that the mass of the pendulum does not affect its period. Suppose now that you need to hang a second mass from the pendulum. In your opinion, which is the best way to do that, out of the four shown in the image?  **Q9**: Does the period of the pendulum depend on the suspended mass?	The knowledge created by the students so far is challenged. At this phase students need to look back and think what they have learnt throughout the scenario. First the physical intuition of the students is checked by asking them how to attach an additional weight. Those who answer correctly this question demonstrate a good grasp of the pendulum's setup, as it is crucial to let the center of mass intact when attaching the additional weight. Then by presenting to them data which contradict their conclusions, we aim to test how confident they are on their knowledge. Students at this phase are reevaluating their understanding, reflecting on the different possible solutions of the problem and are employing multidimensional thinking. There is also a need for additional clarifications at this stage, as in order to answer correctly both questions Q8 and Q9 the meaning of center of mass should be clearly understood. Students who fail to answer these questions correctly will need to have the teacher explain to them in detail why it is crucial how we attach the additional weight so that the bob-mass has no effect on the pendulum's period.

The full explanation of the scenario can be found in Annex 5.1

3.3. Photoelectric Effect

This scenario intends to introduce students to the photoelectric effect and the necessary setup for its observation. It uses the PHET platform for the virtual experiment. Students are expected to understand the photoelectric effect equation and its relative graphs and learn about its different applications. Below we present a table explaining how the whole cycle of Inquiry-Based Learning was implemented

Table 3 Phases of the Photoelectric Effect

Problem Solving Process	Scenario Phase	Questions of the Scenario	Educational Objective
Engagement	Exploring and understanding	**Q1**: Assume that the Sun is behaving like a black body. Then according to Planck hypothesis: **Q2**: What do you think happens so that the amperometer records current?	At this stage we aim to check whether or not students have an in depth understanding of a previously taught subject, namely the Planck explanation of the black body radiation and the Planck hypothesis. The latter is of crucial importance so that students are able to see the differences between the Classical and the Quantum Physics, which will be highlighted through the study of the photoelectric effect. In addition we attempt to check whether or not students can infer the transfer of energy from light to the electrons, thus starting slowly to draw the picture of the photoelectric effect in their minds.
Hypothesis	Representing and formulating	**Q3**: Considering the demonstration with the ping-pong balls and the basketball. The object falling from the table, then: **Q4**: With Planck hypothesis in mind, which of the following is correct?	At this stage students start creating hypotheses and recognize the fundamental parameters for the explanation of the photoelectric effect. As the explanation is based on the Planck hypothesis, we want to check if the students can understand that a single basketball (single photon) is enough to throw the object from the table (eject an electron) and no matter how many ping pong balls are going to be thrown (low energy photons) the object will never fall. Accordingly, we are testing their understanding on the Planck formula, E = nhf, for n=1. High performers at this stage can immediately that the frequency is the only parameter deafening the energy of the packet.
Experiment	Planning and executing	**Experiment 1 - Vary the frequency (wavelength) of the light** **Q5**: What do you observe according to your measurements? **Q6**: As you decrease the wavelength, the energy of the light beam is? **Q7**: As the wavelength decreases, the number of the ejected electrons is? **Q8**: The value for which you observe the ejection of electrons in the plot and the one obtained from your table are?	At this stage we want to check the ability of students in performing an experiment correctly, and whether or no they can create new mental pictures which are supported by the experimental data. High performers should immediately recognise that the frequency is the only crucial parameter for the ejection of photoelectrons. Moderate performers have performed the experiment correctly, thus by varying only one parameter, yet they have not fully realized that the ejection of a photoelectron depends only on the frequency of the incoming light, and believe that both the frequency and the intensity play a role. Low performers fail to identify the dependence of the electron ejection on the frequency, thus they need to receive help by the AI agent. Q6 aims to check if students can make sense of the equations that they see. As the wavelength decreases the frequency increases, thus the energy of the light beam should increase. Students who fail to answer this question correctly need to revisit the Planck hypothesis, as well as the wave theory. At Q7 high and moderate students should observe that as the wavelength decreases more electrons are ejected, while high performers will realize that this is because light can eject more tightly bound electrons at deeper energy levels. If the experiment has not been conducted correctly, then answering Q8 should be straightforward, as the value recorded in Q5 should be very close to the frequency value recorded in the graph.
		Experiment 2 - Vary the intensity of the light **Q9**: According to your measurements, as the light intensity decreases? **Q10**: As the intensity decreases, the kinetic energy of the ejected electrons? **Q11**: What can you say from the plot that you obtained?	At this point the goal is for students to observe the effect that the variation of the intensity has on the ejected photoelectrons. High and moderate performers understand that by varying the intensity the number of the ejected photoelectrons is changing, while low performers fail to observe that. In Q10 high performers can also understand that the kinetic energy of the electrons remains the same, as the frequency is not changing. Moderate performers are still connecting the kinetic energy of the electrons with intensity, thus they get the impression that electrons become slower, while low performer have probably varied both the frequency and the intensity, thus fail to give the correct answer. Finally, as was the case in the previous experiment, Q11 aims to check for one more time whether or not more than one parameters have been varied. High performers should see immediately that the plot they get is in line with the values tabulated on their tables and the same should hold for moderate performers.
		Experiment 3 - Vary the applied voltage **Q12**: When the value of the applied voltage is negative? **Q13**: From the plot that you get with the intensity at 50%, what do you observe? **Q14**: From your measurements, what can you say?	At this stage of the experiment the voltage applied in the setup will be varied. At first we aim to check whether or not students can see the impact of changing in the voltage value in the experimental setup, thus if the can observe the charge of the anode and the cathode and of course if the can identify the anode and the cathode. High performers should see directly how the variation of the voltage value affects the charge on the anode and the cathode. Accordingly we check whether or not students can quantify their results and interpret the obtained plots. For that reason it is crucial that the experiment has been performed correctly. The last question is a crucial one, as students are called to identify the cutoff voltage and determine its value. By performing the experiment correctly, high performers will identify that for a certain voltage value no photoelectrons can make it to the anode, for the chosen wavelength value.

Data analysis	Monitoring and reflecting	**Q15**: According to the explanation that you received and your experimental findings? **Q16**: From the plot that you obtained and the photoelectric equation, the value of the threshold frequency should be? **Q17**: According to the explanation that you received, the light in the photoelectric effect behaves like?	After students have gone through the experimental phase, we are going to check their ability in rejecting or validating previously made hypotheses based on the experimental outcomes. High performers at this stage should understand that the obtained results are contradicting fundamental principles of wave theory, namely the frequency (wavelength) of the incoming light affects the kinetic energy of the electrons not the ejection rate as classical theory predicts, while the intensity of the incoming light, being directly related to its amplitude affects the ejection rate of electrons and not their kinetic energy. The questions at this phase are checking how self-confident students are on their understanding, as from the obtained results it is straight forward that classical physics fails to interpret the photoelectric effect, thus students who have developed their critical thinking should identify that, instead of trying to give an explanation according to the classical theory or discard their measurements.
Reflection		**Q18**: What should be the maximum kinetic energy of an electron assuming a cutoff voltage Vo? **Q19**: From the photoelectric equation, the formula giving the threshold frequency and your answer in the previous question, the cutoff voltage should be equal to?	In this last phase, the reflection phase, only high performers in all the previous phases are expected to reach. The reflection phase is split in two parts. In the first part we want to check the abilities of students in handling more demanding mathematics in order to predict the maximum kinetic energy of a photoelectron for a given value of cutoff voltage. Students should recall here that the maximum kinetic energy is given by $K_{max} = qV_0$ and combine that with the photoelectric equation. Accordingly, in order to find the right answer for Q19, the work function should be written as $\Phi = hf_0$, f_0 being the threshold frequency and then substitute in the photoelectric equation.
		Q20: The applied voltage helps us to? **Q21**: You have a piece of metal of an unknown element and you would like to figure out from which element it consists of. You irradiate it with light, the frequency of which is 6.2×10^{14} Hz. The kinetic energy of the ejected electrons is measured at 3.28×10^{-20} J. Using the table given below, which is the element of the metal? **Q22**: If the piece of the metal is an alloy, consisting of several elements, is the frequency selected above suitable in order to identify other metals listed on the table?	In the second part we ask the students even more demanding questions, aiming to bring them to the edge of their understanding. In Q20 students should identify that the applied voltage is a means to either decelerate or accelerate the ejected photoelectrons and measure a critical kinetic energy value. Accordingly students are introduced to real-life applications of the photoelectric effect. In Q21 they are asked to recognise a chemical element from well-known tabulated work function values. By knowing the photon energy and measuring the kinetic energy, the work function can be found. Such experiments are actually taking place in large scale scientific facilities and students are indirectly introduced to the principles of photoelectron spectroscopy. Moreover, we have the chance to check how capable students are in performing numerical operations with exponents and if they can use the correct units to describe each parameter. Finally, in the last question we aim to check whether or not students can understand the complexity of a realistic sample, consisting of several elements, and how a higher photon energy could eject photoelectrons from such elements having higher values of work function, allowing for the identification of all elements.

The full explanation of the scenario can be found in Annex 5.2

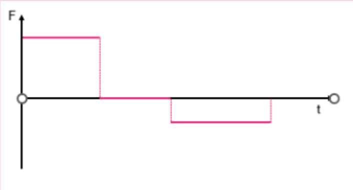
3.4. Newton's 1st and 2nd Laws

The objective of this scenario is to introduce students to the Newtonian notion of forces and how they can be represented.

Table 4 Phases of the Newton 1st and 2nd Laws Scenario

Scenario Phase	Problem Solving Process	Questions of the Scenario	Educational Objective
Engagement	Exploring and understanding	**Q1.** Imagine that you would like to guide a robot to push a very heavy box. Which info do you need to pass to the robot? **Q2.** You want to calculate the net force of several co-axial forces. You get the result ΣF=-10 N. What does this mean?	Before asking the students to make hypotheses, we need to make sure that they can understand that forces can be represented by vectors. In addition, we need to make sure that students can handle mathematical operations with vectors and most importantly, that a negative value means that the vector has a direction opposite to the one defined as positive. By introducing a way to precisely describe a force, students start to think about the impact that an applied force has on the state of motion of a body.

Hypothesis	Representing and formulating	*1st Newton's Law* **Q3.** Which forces are exerted on the crate? By which body is each of them exerted? Why are they at equilibrium? **Q4.** An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction (it maintains its state of motion): *2nd Newton's Law* **Q5.** If there is no friction or air drag and a constant horizontal force is applied on an object which is at rest: **Q6.** Which of the following do you think is correct concerning the net force exerted on an object?	At this stage we start asking the students to make their own hypotheses about the impact that a force has on the state of motion of a body. First, we need to check that students can understand which forces are exerted on a body and then whether they can recognize which is the "source" of each force. Finally, we check if students can understand why a body is inequilibrium once they have described the forces. Accordingly, we try to see if students can understand Newton's first law themselves, thus the question is when the state of motion of a body is changing. Moving forward, we want to ask the students to make a hypothesis about what happens when a constant force is applied on a body. At this point, we want to address a common misconception of students relating the applied force to the velocity of the body. High achievers at this stage should start correlating the applied force with the acceleration of the body. Once students have answered this question, then we want to ask them what the result of the net force is. Thus, we try to guide them again to reach Newton's second law by themselves, either by making the correct hypothesis from the beginning or by making a hypothesis which is not correct and will be rejected once they have obtained their experimental data.
Experiment	Planning and Executing	**Experiment 1** (1st Newton Law). Design an experiment to check your hypothesis on the relationship between resultant force on the crate and its state of motion. **Experiment 2** ((2nd Newton Law). Design an experiment to check your hypothesis on the relationship between resultant force on a body and its acceleration OR between the resultant force on different bodies and their acceleration.	The importance of the previous steps is becoming obvious now. Therefore, the students will need to investigate the validity of Newton's laws. The process aims to assess how well the students can perform virtual experiments using the PhET platform. Accordingly, they will be asked to answer questions based on their results.
Data Analysis		*1st Newton's Law* **Q7.** What do you observe when you select the "friction" option? **Q8.** When you select the "no friction" option and the net force is zero: **Q9.** Which conclusion you draw from your experiment: *2nd Newton's Law* **Q10.** In the two experiments, which parameters do you control? **Q11.** Which one of the following can you say:	Once students have performed experimental work using the PhET platform, we aim to check whether or not they can interpret their experimental results. Q7 aims to test whether students can understand that a body in motion will stay in motion if no force is exerted on it. Because of the friction the body will eventually stop moving. This is why we ask them what they observe when there is friction. Then, we ask them what they observe if there is no friction and the net force on the body is zero. They should observe at this point that the body will never stop moving. In this way we proceed with Q9. While students were performing the experiment in order to discover Newton's second law for themselves, we want to make sure that they are fully aware of the parameters that they are varying. It should be clear to them that they can only control the applied force and the mass of the object, but they cannot control the acceleration. Then we want to see if they can quantify Newton's second law, thus they should identify that a constant force results in a constant acceleration. Students who correlate the force with the velocity at this point will need to receive additional help and explanations from the teacher and the agent. Finally, Q12 aims to test if students can understand that mass is a proportionality factor connecting the applied force with the acceleration of the body.

Reflection	Monitoring and Reflecting	**Q12.** From the two experiments what do you observe, for the relation between the mass and the acceleration, when the force is constant: **Q13.** From Newton's second law you can get the first law, for a body of mass m. This is: **Q14.** The plot shows a force applied on a body as a function of time. What can you say by looking at the plot:  **Free fall** **Q15.** You have learned that when there is no air resistance, every object, *independently of its mass,* is falling with a constant acceleration, which is the gravitational acceleration g. Having in mind Newton's second law, why do you think this happens? **Q16.** Consider now two objects with m1<m2 and a force of the form F=-k, where k is a constant, describing the resistance of air. What should hold for their accelerations and the gravitational acceleration?	Accordingly, we describe to the student both the first and the second Newton's law and then we aim to see if they can perform certain mathematical operations. From the second law one can get the first law. Setting the net force equal to zero means that the acceleration of the body will be zero (the mass cannot be equal to zero), thus the body either stays at rest or moves with a constant velocity, thus they can reach Newton's first law. Then a plot like the one shown in the previous column is presented to the students. Here the key point for students is to understand that the applied force is not the same at all times. First the force is constant and positive, thus the body will accelerate, then the force becomes zero, thus the body will move with a constant velocity. Finally, when the force becomes negative, as described in the beginning of the scenario, means that the direction of the force is now different from the one defined as positive, thus in this case the body will start to decelerate. For the final phase (reflection phase), the free fall was chosen as an example in order to show the students that in the absence of air resistance, during free fall, all objects independently of their mass have the same acceleration which is the gravitational acceleration g (Q15). The weight of a body can be written as mg, thus from Newton's second law we get ma=mg, thus a=g. This is not something obvious, as students observe heavier objects falling faster. In Q16 we ask them to quantify this phenomenon and explain why heavier objects are falling faster. A constant force being the air resistance is given to them, thus they need to write Newton's second law, describe correctly the net force, the components of which are weight and air resistance and solve for the acceleration a. Students who will perform these actions correctly will see that the heavier object has a higher acceleration and falls faster.

The full explanation of the scenario can be found in Annex 5.3

3.5. Phases of the Moon

This scenario intends to introduce students to the phases of the moon. The scenario starts with an invitation for students to reflect on their perception related to the phases of the Moon and reflect on the reason for the existence of this phenomenon. We start by presenting the summary table of the whole journey to allow a more fluid navigation through the scenario:
Below we present a table explaining how the whole cycle of Inquiry-Based Learning was implemented

Table 5 Phases of the Phases of the Moon Scenario

Scenario Phase	Problem Solving Process	Questions of the Scenario	Educational Objective
Engagement	Exploring and understanding	**Q1:** What is the primary reason for the occurrence of Moon phases?	Students are invited to explore the phases of the Moon. Although it is a common phenomenon, it is not rare to find many misconceptions related to the reason for the existence of phases. It is even more complicated to perceive the difference between the phases and another related phenomenon, the lunar and solar eclipses. So, students are invited to explore, manipulate the elements and use a virtual simulation to help them understand it. The first question aims to recognise the level of understanding a student has related to the topic. Students with less understanding will start by performing a hands-on activity with physical materials and then later proceed to a second activity, using a virtual experiment. Those with a better understanding will go directly to the second activity, where they will have a more in-depth understanding of the phenomena. Those with a good understanding will be invited to go to the next activity where the inclination of the orbit of the Moon, in relation to the orbit of the Earth around the Sun, will be explored and the sequence of phases more carefully explored. **Problem-Solving Competencies Activated: Scientific Understanding** (students are invited to test their knowledge about the phases of the Moon and reflect on a scientific phenomenon).
Hypothesis		**Q2a**: What are the possible solutions to place the Earth, the Moon and the Sun? (you can choose more than one option).	The question aims to encourage students to think critically about the relationship between the 3 celestial bodies and their spatial relationship. By considering the multiple possibilities students will explore the various possibilities and be invited to come up with possible solutions. This question is designed for the students that presented a lack of understanding of the theme as a way to spark their curiosity and promote a more in depth understanding of its causes and effects. This experiment helps students materialise their mental representations and confirm or modify their

			understanding. **Problem-Solving Competencies Activated:** Students are thinking creatively about the proper spatial arrangement of the celestial bodies and considering possible solutions.
	Representing and formulating	**Q2b**: Why the orbit of the Moon around the Earth is causing the phases of the Moon? A. Because of the shadow of the Earth projected on the Moon B. Because of the inclination of the orbit of the Moon around the Earth, in relation to the orbit of the Earth around the Sun. C. Because of the different parts of the Moon illuminated by the Sun along its orbit.	The question aims to encourage students to think critically about the relationship between the 3 celestial bodies and their spatial relationship. By considering the multiple possibilities students will explore the various possibilities and be invited to come up with possible solutions. This question is designed for the students that presented a lack of understanding of the theme as a way to spark their curiosity and promote a more in depth understanding of its causes and effects. This experiment helps students materialise their mental representations and confirm or modify their understanding. **Problem-Solving Competencies Activated:** Students are thinking creatively about the proper spatial arrangement of the celestial bodies and considering possible solutions.
		Q2c How often do the phases of the Moon change ? A. The phases of the Moon change once per month. B. The phases of the Moon change every week. C. The changes of the phases of the Moon is a continuous process	The aim of the question is to assess the student's understanding of the lunar cycle and how the phases of the moon change. **Problem-Solving Competencies Activated:** Students have to think critically about the presented phenomenon and present evidence of their scientific literacy. They are activating previous knowledge as per the duration of the Moon's orbit around the Earth, confirming their understanding of the lunar cycle and the frequency of the changes. The correct answer is C. At this stage, all students will progress to the next phase.
Experiment	Planning and Executing	**Experiment 1 - Position the Earth, Moon and Sun** **Q3a**: While trying to confirm your hypothesis how did you vary the elements?	During the experiment, students have to explore the possible relative position of the Earth, Moon and Sun and achieve a good representation of the phases of the Moon by using the material provided. By now it is expected that students understand that the orbit of the Moon is inclined in relation to the orbit of the Earth around the Sun. And that only in a couple of parts of the orbit the Earth's shadow is reaching the surface of the Moon. Q3a aims to help students reflect on how they performed the experiment and invites them to understand that changing more than one variable at a time makes it difficult to isolate the element that is responsible for the observed changes. It is also a way to assess their understanding of the scientific method and their critical thinking skills. They are invited to vary elements and observe the outcomes. **Problem Solving Competencies Activated:** This experiment is helping students activate their experimental design skills. Students are involved in hands-on experiments to help them test their understanding of a scientific topic

		Experiment 2 - Use the Lunar Phase Simulator to validate your hypothesis. **Q3b**: While trying to confirm your hypothesis how did you vary the elements?	The virtual simulation provides an interactive means for the student to test their understanding and reinforce their knowledge on the topic. Q3b encourages students to think about the variables they can control and how altering them affects the observed results. This experience will help them develop a methodological approach to experimentation. **Problem Solving Competencies Activated:** During the experiment students will use digital technology to improve their knowledge. Students will review their scientific methodology and model of investigation. They will reflect on the experimental process and reflect on how the variation of the different elements led to different results or different understanding of the phenomenon being observed.
		Experiment 3 – Using Stellarium to Explore the phases of the Moon **Q3c:**During our experiment what have you discovered related to the time it takes for the phase of the Moon to change? A. By changing the parameters I could observe that the phase of the Moon changes every week. B. By changing the parameters I could observe that the phase of the Moon changes every day. C. By changing the parameters I could observe that the phase of the Moon are constantly changing. It is a continuous process.	This experiment is designed for the students who either answered the most complete choice in Q1 or the ones who successfully finalised paths A and/or B. Students are invited to get acquainted with the software Stellarium, the virtual simulation that will be used to support the experimental phase. Students are supported to create their hypotheses. They use Stellarium to conduct their experiment. A new question is presented, teasing students to reflect on what they have observed. The most complete answer is C. Students who select this answer demonstrate an understanding of the phases of the Moon, they don't change abruptly, it is a gradual transition from one phase to the other as part of a continuous cycle. Stellarium reflects real-time observations and students have the possibility to explore the sky in their location, move forward and backwards in time. These features are key to helping students explore the phenomenon. **Problem-Solving Competencies Activated:** Students will activate their observation skills while improving their ability to observe and describe changes in the appearance of the Moon over time. By breaking down their results into smaller parts they are working on their analytical thinking. Their science literacy will increase with the new understanding of this astronomical concept. They will build on their critical thinking by evaluating the results and drawing conclusions.
Data Analysis		**Q4a**: After doing the experiment. What are the proper positions for the Sun, Earth and Moon to obtain phases of the Moon? You may choose more than one option . **Q5a**: Did the experiment validate your hypothesis?	In this phase, students are invited to analyse the retrieved results and check if the acquired data is in accordance with their expectations. They have to evaluate the outcome of the experiment and conclude if they can successfully reproduce the phases of the Moon as expected. They have to reflect on the results and if necessary review their hypothesis, rebuild their experiment and try again to reach the desirable outcome. This activity aims to encourage students to think about the spatial relation between the three bodies that command our existence. **Problem-Solving Competencies Activated:** Students will be invited to synthesise their results and

	Monitoring and Reflecting	a) yes (proceed to the next question)b) no (rebuild your hypothesis and do the experiment again)	explore again their scientific reasoning. They are then invited to reflect on their results, compare them to their initial hypothesis, evaluate the success of the experience and advance in their understanding of the phenomenon explored.
		Q4b: After doing the experiment. Are you more confident in your understanding of the phases of the Moon? **Q5b**:Do you still think your initial answer was the adequate one? A. I think I need to review my understanding of the phases of the Moon. B. I want to redo my experiment. C. Go to the next question and see if you keep on the same path or if you prefer to change.	In Q4b, students are invited to reflect on the evolution of their understanding about the theme being explored and consider the importance of experiments to validate or correct ideas. In Q5b students are invited to review their initial ideas and compare with the results and insights obtained through the experimental phase. They are invited to either review and reassess their understanding, to experiment further or to move forward to new challenges. The sequence of questions is built not only to test the students' knowledge but also to foster their critical thinking, and to promote a deeper engagement in the learning of the scientific concepts presented. **Problem-Solving Competencies Activated:** Students will reflect on their learning and improve their confidence in their problem-solving skills. They will be further invited to reflect on their initial thoughts and make decisions about the next steps to further improve their results. Students at this stage are exercising their critical thinking, improving their competencies in applying knowledge in practical experiments and reflecting on their learning process.
		Experiment 4 - Using Miro to confirm the understanding of the concept and prepare for the next activity. **Q4c** Now that you understand the phases of the Moon choose the correct statement. (you can use Stellarium to help you answer this question): A. A new moon occurs when the Moon is not in the sky. B. A full moon can only occur when the Moon is between the Earth and the Sun. C. Full moon phase happens only when the Earth is between the Moon and the Sun.	Students are invited to put their new knowledge into practice by showing that they indeed understand the phases of the Moon. A new question is presented. Students answering A or B will be invited to go back to Miro and observe again the sequence of phases of the Moon. The activity and question aim to solidify the student's understanding of the spatial relationships between the Earth, Moon and Sun during the different phases of the Moon. The goal is to reinforce the correct conceptual model. **Problem-Solving Competencies Activated:** Students will improve their spatial reasoning, increase their scientific literacy, and improve their critical thinking. Through this experiment students are not just memorising facts; they are actively engaging with tools and materials which promotes a deeper learning and retention of the scientific concepts presented.
Reflection		**For students during Activity 1 and 2** **Q6**: After obtaining satisfactory results, what is causing the phases of the Moon?	Q6. Once again the students are challenged to answer a new question and invited to reflect on their results. The question presents several options that would validate if the students actually understood the phenomenon. Answer A presents again a common misconception, as the Earth's shadow is in fact causing a lunar eclipse and not causing its regular phases. Option B presents a partial understanding as indeed the Moon

		A. Because the Earth blocks the light from the Sun and that changes during the month. B. Because the Moon rotates on its axis. C. The orbit of the Moon around the Earth and its relative position to the Sun determines the phases of the Moon. **Q7**: Reflecting on the results of your experiment, can you identify when we can observe the full Moon? You can choose more than one answer. A. The full moon happens when the Moon is between the Earth and the Sun. B. The full moon can only be seen on Earth around sunset until sunrise. C. Once per moon cycle 100% of the face of the Moon facing Earth is illuminated.	rotates, at a rate that keeps the same side facing the Earth, but this is not the cause for the phases of the Moon. C presents a more complete understanding by adding the relative position of the Moon, Earth and the Sun. This question will be presented to students taking Path A and Path B. By choosing the correct explanation, students demonstrate their ability to reflect and apply the knowledge they have acquired. **Problem Solving Competences Activated:** Students are prompted again to reflect on their understanding and apply their knowledge reflecting on the phenomena from a different point of view. They will improve their conceptual understanding and analysis competencies. Q7. Is presented to students after they successfully finish Path A and or Path B. It is also a question that is presented to the students who in the initial phase presented a good understanding of the phenomenon. It serves as a confirmation of the student's knowledge and problem-solving competencies capability (at least for the students that navigated Path A and Path B). Students coming directly to Q7 and succeeding in the answer will have their problem-solving competencies assessed in the next activity. **Problem-Solving Competencies Activated:** Students will activate their observation and interpretation skills to validate their scientific understanding of the topic.
		Students who complete Experiments 3 and 4 **Q5c:** When can we see the Moon in the sky (you may choose more than one option) A. The Moon can only be observed during the night. B. The Moon can be observed sometimes during the day and sometimes during the night, regardless of the phase. C. The Moon can be seen in the sky both during the day and at night, depending on its phase.	This last question aims to assess the student's understanding of the phases of the Moon and invite them to reflect on what they have learned so far. Answers A and B are incorrect since the Moon can be seen during the day and sometimes during the night, depending on the phase. The new Moon is not visible at all as the position of the Moon in the sky is too close to the position of the Sun and our star brightness makes it impossible to see the Moon in the sky. As the orbit progresses we will slowly be able to observe the Moon in the sky, as its orbit takes it farther away from the Sun. The full Moon can be visible from sunset to sunrise. Stellarium is a very powerful simulation to help students explore this phenomenon. **Problem Solving Competences Activated:** Students will develop their observational skills, improve their critical thinking, and enhance their scientific literacy. The activity, as an overall will improve their spatial awareness related to the relationship between the Earth, Moon and Sun. It will also improve their digital literacy.

Provisory Link to the scenario: https://view.genial.ly/64abb2262442dc00195c5022/interactive-content-phases-of-the-moon-activity-1

The full explanation of the scenario can be found in Annex 5.4

3.6. Simple Machine: Pulley

This scenario intends to introduce students to the physics of the pulley as one out of the six simple machines. A table below explains how the whole cycle of Inquiry-Based Learning was implemented

Table 6 Phases of the Simple Machine: Pulley Scenario

Scenario Phase	Problem Solving Process	Questions of the Scenario	Educational Objective
Engagement	Exploring and understanding	**Q1.1:** Look the picture and choose the classical simple machines: A. b, d, e, f, h, I; B. a, b, d, f, g, h; C. b, d, e, f, g, h; D. None of them; E. All of them. **Q1.2:** Do you think basic simple machines help you accomplish job because A. they create all the force for you. B. they increase the force you apply. C. actually, they are not very helpful. D. all of them E. none of them **Q1.3:** We use the simple machines: A. because they change direction and magnitude of the force. B. because they decrease the amount of work. C. because they create energy which can move or stop the object. D. all of them E. none of them	Students are invited to explore one out of six simple machines – the pulley. The main misconceptions related to the topic are that (1) the terms energy and force are interchangeable (in reality, they are not); (2) efficiency and mechanical advantage are interchangeable (in reality, they are not); (3) machine makes less work for people (instead, a machine does not decrease the amount of work. A machine makes work easier by changing the size or direction of the force); and (4) pulleys always increase the amount of force (in fact, fixed pulleys do not increase, but redirect the effort force. Only moveable pulleys magnify the effort force). In this ELE (Effective Learning Environment), students will explore, formulate the hypothesis, manipulate the variables and use a virtual experiment to help them understand the topic. The video and set of questions aim to recognise the level of student understanding the topic. Students with less understanding will get guided explanations. Those with a better understanding will go directly to the second activity, where they will have more *practice to check their knowledge* in depth. Those with a good understanding will be directed to the Hypothesis scenario phase. The concept will be introduced with a short **video, pulley** definition, and assessment questions. **Problem Solving Competences Activated:** Scientific Understanding (students will check/reload their prior knowledge about the simple machine, force and its direction, as well as mechanical advantage); Critical thinking.

		Q1.4: What is the definition of mechanical advantage (MA) of a simple machine? : A. sum of the input and output forces. B. product of the input and output forces. C. ratio of the input and output forces. **Q1.5:** In your opinion, what is the units of the MA: A. newtons B. kilograms C. unitless, just ratio **Q1.7, Q1.8:** Select the examples of the pulley and diagram of a single fixed pulley	
Hypothesis	Representing and formulating	**Q2.1 - H1:** If we have a system with a single fixed pulley, then A. mechanical advantage (MA) will be greater than 1 B. mechanical advantage (MA) will be less than 1 C. the mechanical advantage will be 1, i.e. MA = 1.	The question aims to encourage students to think critically about the mechanical advantage of the single fixed pulley. Based on the video and previous activity, students may predict the qualitative answer for the MA of this type of pulley, i.e. greater than 1, less than 1 or equal 1. This question is designed to identify students who lack the understanding that a single fixed pulley does not increase the effort force and only redirect it. The experiment helps students understand this concept. **Problem Solving Competences Activated:** Students are thinking about the MA of the fixed pulley; critically evaluating suggested options, and building hypothesis structure (if..., then).
		Q2.1 - H2: If we have a system with a single fixed pulley, then the pulley A. changes direction, but not force B. changes both direction and force C. changes neither direction nor force.	Applying the previous activity, this question invites the students to reflect on their understanding of the forces and the direction for the single fixed pulley. The misinterpretation might cause the common misconceptions (pulleys always increase the amount of force). **Problem Solving Competences Activated:** Students are activating their analytical thinking and conceptual understanding during this phase. Additionally, they will critically evaluate suggested options, and build hypothesis questions. At this stage all students without any further explanation will progress to the next phase to explore whether their answers were correct or wrong.
Experiment	Planning	**Q3.1.1:** In the provided simulation the independent variables are: A. Pulley Diameter, High to Lift and Load;	Students are invited to get acquainted with the simulation. During this activity students should explore it (https://compassproject.net/html5sims/pulleysim/pulley_en.html) checking what variables are dependent and independent; what data should be collected, what data will be changeable or unchangeable, how data could be collected.

		B. Distance Pulled, Work Done and Potential Energy; C. Pulley Diameter, Height to Lift, Load and Applied Force **Q3.1.2:** In the provided simulation the dependent variables are: A. Pulley Diameter, High to Lift, and Load; B. Distance Pulled, Applied Force, and Potential Energy; C. Pulley Diameter, Load and Work Done	The guided questions aim to help students reflect on how they performed the experiment and invites them to understand that changing more than one variable at a time makes it difficult to isolate the element that is responsible for the observed changes. **Problem Solving Competences Activated**: Scientific method /culture and critical thinking skills will be activated by varying variables and observing the outcomes. The experimental design skills will be created. It also suggested to introduce the hands-on experiments for testing and better understanding of a scientific topic. At this stage all students will progress to the next phase to build and perform the next experiment.
	Executing	**Experiment - The single fixed pulley will be explored** **Q3.2:** While trying to confirm your hypothesis, create a chart to record the experimental data. Check whether in the chart you employ all required data and measurements: Load, Height Lifted, Applied Force, Distance Pulled, Input Work, Output Work, Actual MA, Ideal MA, Efficiency. Do not forget to provide the units for each measurement.	The virtual simulation provides an interactive means for the student to test their understanding and reinforce their knowledge on the topic. Q3.2 encourages students to think about the variables they need to prove (or not) their hypothesis. Which variables will be controlled? How does altering them affect the observed results? The chart will allow them to record and organize their measurements. This experience will help them develop a methodological approach to experimentation. Depending on the level of their understanding, students will build and perform the experiment without the support from a teacher or system, with guided system support or with direct system instruction. **Problem Solving Competences Activated:** During the experiment students will apply digital technology to improve their knowledge. Students will review their scientific methodology and model of investigation. They will reflect on the experimental process and reflect on how the variation of the different elements led to different results or different understanding of the phenomenon being observed. Students will activate their observation skills while improving their ability to observe and describe changes. Their science literacy will increase with the new understanding of how to build, perform and analyse the experiment and connect it to the studying concept. They will build on their critical thinking by evaluating the results and drawing conclusions.
Data Analysis	Monitoring and Reflecting	**Q4.1:** After performing the experiment. What relationship does the collected data show? **Q4.2:** Explain why your hypothesis was supported / not supported using actual data from the experiment.	In this phase students will analyse the received results and check if the acquired data aligns their hypothesis. With this activity they evaluate the outcome of the experiment and write the conclusion. If necessary they will rebuild, repeat their experiment and try again to reach the desirable outcome. This activity aims to encourage students to review the scientific data, determine the physical quantities such as work, actual and

		Q4.2.1: Did the experiment validate your hypothesis? A. YES (proceed to the next question) B. NO (teacher decide whether student should rebuild the hypothesis and do the experiment again) **Q4.2.2:** After conducting the experiment. Can you in own words explain the work of simple fixed pulley? A. YES B. NO C. I can with help of teacher or parents **Q4.2.3:** Do you still think your initial answer and experiment were reliable? A. I think I need to review my understanding of the fixed pulley. B. I want to redo my experiment in extracurricular time. C. Yes, I am fine with the results.	ideal MA, efficiency of fixed pulley, and understand the functional concept of this simple machine. **Problem Solving Competences Activated:** Students will be invited to synthesize their results and explore again their scientific reasoning. They are then invited to reflect on their results, compare to their initial hypothesis, evaluate the success of the experience and advance in their understanding of the phenomenon explored.
Reflection		**Q5.1:** The efficiency of a real simple machine is always less than 100 percent because some fraction of the input work is always converted to heat energy due to friction. A. True B. False **Q5.2:** Can you lessen/reduce the amount of force you must apply by attaching weights to the end of the rope that you pull? A. No, I cannot B. Yes, I can **Q5.2.1:** How can you explain your answer by considering an advantage of gravity?	The students are challenged to answer a new question and invited to reflect on their new knowledge. The question presents several options that would validate if the students actually understood the concept. At the same time students will demonstrate their competence to reflect and to apply the recently acquired knowledge to new real-life scenarios. **Problem Solving Competences Activated:** Students will reflect on their learning and improve their confidence in their problem-solving skills**.** Students showcase their understanding and apply their knowledge to real life scenario. They will improve their conceptual understanding and the analysis competencies. Students will activate the observation and interpretation skills to validate their scientific understanding of the topic.

Hypothesis	Representing and formulating	**Q6.1 – H1:** If we use an ideal single movable pulley system, then the force applied by the pulley to the Load will be A. greater than the force (Effort) you put in B. less than the force you put in C. equal to the force you put in	The students continue to study the simple ideal pulley systems. This question invites the students to reflect on their understanding of the forces and the direction for the single movable pulley. It encourages them to pay attention to the role of force in the functionality of the pulley. **Problem Solving Competences Activated:** Students will activate the observation, analytical thinking and interpretation skills to validate their scientific and conceptual understanding of the topic. Additionally, they will critically evaluate suggested options, and build hypothesis ((if…, then) questions.
		Q6.1 – H2: In a single movable pulley, if the load increases, then the required Effort/applied force to lift this load also increases. Is this a correct statement? YES / NO	The different presentation of the previous question will encourage students to review the previous answer. **Problem Solving Competences Activated:** Students will develop their observational skills, improve their critical thinking, enhance their scientific literacy. They will apply their knowledge reflecting on the concept from a different point of view
		Q6.1 – H3: If we use an ideal single movable pulley, then the mechanical advantage of this system is: A. MA = 1 B. MA = 2 C. MA = 4	The question aims to encourage students to think critically about the mechanical advantage of the single movable pulley. Based on the video and previous activity, students may predict the answer for the MA of this type of pulley. This question demonstrates that the single movable pulley increases the effort force in addition to redirecting it. The experiment helps students understand this concept. **Problem Solving Competences Activated:** Students are thinking about the MA of the movable pulley; critically evaluating suggested options. It may also improve their scientific culture and literacy. At this stage all students without any further explanation will progress to the next phase to explore whether their answers were correct or wrong.
Experiment	Planning and Executing	**Experiment - The single movable pulley will be explored** **Q7.1:** Repeat the same experiment for the movable pulley as was done for the fixed pulley. **Note for students:** Test a single variable by changing it while keeping all other variables constant without modification during the experiment. Think what variable you could keep unchangeable and which one you could test.	We assume that students are familiar with using the simulation. They can define the independent and dependent variables and build the experiment. If your students still face the issue, the previous activity could be repeated. The chart created in the previous experiment will allow them to record and organize their measurements. This experience will help them develop a methodological approach to experimentation. Depending on the level of their understanding, students can perform the experiment without the support from a teacher or system, with guided system support or with direct system instruction. **Problem Solving Competences Activated:** Students will activate the observation and interpretation skills to validate their scientific understanding of the topic. They will improve their scientific competence to design the experiment, collect data and

		Pay additional attention to the connection between Energy and Applied Force.	understand the reliability of the data during the experiment. It may also improve their digital literacy.
Data Analysis & Reflection	Monitoring and Reflecting	**Q8.1:** After performing the experiment. What relationship does the received data show? **Q8.2:** Explain why your hypothesis was supported / not supported using actual data from the experiment. **Q8.2.1:** Did the experiment validate your hypothesis? A. YES (proceed to the next question) B. NO (teacher decide whether student should rebuild the hypothesis and do the experiment again) **Q8.2.2:** After conducting the experiment. Can you in own words explain the work of simple movable pulley? A. YES B. NO C. I can with help of the teacher or parents. **Q8.2.3:** Does Energy depend on the applied Force? YES/NO Could you please justify your answer? **Q8.2.4:** Do you still think your initial answer and experiment were reliable? A. I think I need to review my understanding of the fixed pulley. B. I want to redo my experiment in extracurricular time. C. Yes, I am fine with the results.	In this phase students will analyse the received results and check if the acquired data aligns their hypothesis. With this activity they evaluate the outcome of the experiment and write the conclusion. If necessary they will rebuild, repeat their experiment and try again to reach the desirable outcome. This activity aims to encourage students to review the scientific data, determine the physical quantities such as a work, actual and ideal MA, efficiency of movable pulley, understand the functional concept of this simple machine. On this stage they can notice the difference between the *energy* and *force* (it is the first presentation that the terms *energy* and *force* are not interchangeable). **Problem Solving Competences Activated:** Students are prompted to reflect on their understanding, analyse the results and explore their scientific reasoning. They are also invited to compare the actual data from the experiment to their initial hypothesis, evaluate the success of the experience and advance in their understanding of the topic explored.

Hypothesis	Representing and formulating	**Q 9.1 – H1:** If we use an ideal *single* compound pulley system, then the mechanical advantage of this system is: A. MA = 1 B. MA = 2 C. MA = 3 **Q9.1 – H2:** If we use an ideal *double* compound pulley system, then the mechanical advantage of this system is **MA= (provide your answer)** **Q9.1 – H3:** If we use an ideal *triple* compound pulley system, then the mechanical advantage of this system is **MA= (provide your answer)**	The students continue to study the simple ideal pulley systems and its MA. They should build prediction statements about the MA for different types of the compound pulleys. The main idea is that they will check the pulley rule that “Calculating the IMA for pulleys is simple! Just count the ropes holding the movable load.” Students will check all three hypotheses in further activity (Experiment). At this stage all students will progress to the next phase to build and perform an experiment. **Problem Solving Competences Activated:** Students are invited to reflect on their understanding, and the previous knowledge and results to predict the behaviour of the simple machine: pulley as well as design the pulleys system based on the provided MA.
Experiment	Planning and Executing	**Experiment - The compound pulley will be explored** **Q10.1:** Repeat the experiment for the single, double and triple compound pulley similar to fixed and movable pulley. **Note for students:** Test whether energy and output work depend on the Load, High lifted, Applied Force; whether a difference exists between actual and ideal MA and Efficiency.	The chart built in previous two experiments will allow them to record and organize their measurements. This experience will help them develop a methodological approach to experimentation. Depending on the level of their understanding, students will build and perform experiments without the support from a teacher or system, with guided system support or with direct system instruction. **Problem Solving Competences Activated**: Students will develop their observational skills, improve their critical thinking, enhance their scientific literacy. They will improve their scientific competence to design the experiment, collect data and understand the reliability of the data during the experiment. It may also improve their digital literacy. Through this experiment students are not just memorising facts; they are actively engaging with tools and materials which promotes a deeper learning and retention of the scientific concepts presented.
Data Analysis	Monitoring and Reflecting	**Q11.1:** After doing the experiment. What relationship does the received data show? **Q11.2:** Explain why your hypothesis was supported / not supported using actual data from the experiment. **Q11.2.1:** Did the experiment validate your hypothesis?	This question invites the students to reflect on their understanding of the energy, work, efficiency, forces, as well as the direction for the compound pulley. It encourages them to pay attention to the role of force in the functionality of the pulley, difference in meaning of energy and force. The students will analyse the data received for the single, double and triple compound pulley. **Problem Solving Competences Activated:** Students will develop their observational skills, improve their critical thinking, enhance their scientific literacy.

		A. YES (proceed to the next question) B. NO (teacher decide whether student should rebuild the hypothesis and do the experiment again) **Q11.2.2:** After doing the experiment. Can you in own words explain the work of simple movable pulley? A. YES B. NO C. With help of the teacher or parents. **Q11.2.3:** Is the Energy depends on the applied Force? YES/NO **Q11.2.4:** Is the output Work depends on the Load? YES/NO **Q11.2.5:** Is the output Work depends on the Load? YES/NO Could you please justify your answers to *Q8.2.3-Q5.2.5*? **Q11.2.6:** Do you still think your initial answer and experiment were reliable? A. I think I need to review my understanding of the fixed pulley. B. I want to redo my experiment in extracurricular time. C. Yes, I am fine with the results.	
Reflection		**Q12.1:** If the type of the pulley system is changed, then the mechanical advantage it provides will also change. A. True B. False Please provide your reasoning.	This phase allows students to evaluate their experience in this activity. Students are challenged to answer a new question and invited to reflect on the experiment results. In the final Reflection activity, three common misconceptions will be discussed: (1) the terms energy and force are interchangeable (they are not); (2) efficiency and mechanical advantage are interchangeable (they are not, moreover, MA is unitless, while the efficiency unit is %); (3) machine makes less work for people (in reality, a

		Q12.2: Please elaborate your thoughts on the question: Based on the experiment, you've observed that the pulley systems multiply the force, do they multiply work or energy? What will your answer be? A. YES, they multiply work or energy. B. NO, they do not multiply work or energy.	machine does not decrease the amount of work. A machine makes work easier by changing the size or direction of the force). The simple rule of how to count the MA for pulley system will be figured out by students. **Problem Solving Competences Activated:** Students will improve their conceptual understanding and the analysis competencies by reflecting on the scientific process from a different point of view. Students will develop the interpretation skills to validate their scientific understanding of the topic. Moreover, students will reflect on their learning and refine their confidence in their problem-solving skills.
		Q (Bonus): Find at least one image of sport equipment applying the pulleys system and explain how it works.	This activity is designed for fast learners. It allows them to design engineering skills and see how physical concepts can be used in real-life approaches. **Problem Solving Competences Activated:** Students are engaged to reflect on their understanding of the topic and apply their knowledge in real-life context.

The full explanation of the scenario can be found in Annex 5.5

3.7. Ohm's Law

This scenario intends to introduce students to Ohm's law and some of its implications. The scenario starts with an invitation for students to explore an online virtual lab for circuit construction.

The learning goals of this activity are:

- Design electric circuit virtual lab experiments to explore different electric circuit components and the relationship between voltage (V), current (I) and resistance (R) for different types of materials and circuits.
- Design and test hypothesis concerning the relationship between V, I and R.
- Understand and state the Ohm's law.
- Learn about how this knowledge is relevant to our everyday lives.

Next, we present a table explaining how the whole cycle of Inquiry-Based Learning was implemented.

Table 7 Phases of the Ohm's Law Scenario

Scenario Phase	Problem Solving Process	Questions of the Scenario	Educational Objective
Engagement phase	Exploring and understanding	**Q1:** How does the steady flow of charge through a material depend on the voltage applied? A: Electric current depends only on the type of material and not significantly on the voltage applied. B: Electric current depends on the voltage and the type of material. C: The steady flow of charge through a material is the same for all materials independently of the voltage applied.	Students are encouraged to delve into Ohm's Law, a fundamental concept in electricity. Despite its importance, misconceptions about this law are not uncommon. Understanding Ohm's Law is crucial for grasping various electrical phenomena and applications. Therefore, students are invited to explore, experiment, and use virtual simulations to aid their comprehension. This question seeks to assess students' comprehension levels regarding the relationship between voltage and current. Those with limited or no understanding will engage in further simplified questions about the same topic and explore virtual experiments to help them improve their understanding. Those who answered correctly will proceed directly to the hypothesis phase. **B** is the correct answer. Electric current is defined as the amount of charge (in electrons) passing through a circuit,, which is proportional to the voltage applied across it. Electrons can move more easily through some material of higher conductivity, which in turn results in a higher current for the same voltage. Competences Activated: Scientific Understanding (students are invited to test their knowledge about circuits)
		Q2: Some materials allow charge to flow through them differently. Some materials do not allow charge to flow at all. What are the different categories of materials based on their ability to conduct electricity? A: Resistors, capacitors and batteries.	Students who arrive here do not understand how current depends on the type of material and voltage provided. The question provides basic information about the dependence on the type of material and aims to challenge students to research more about it and experiment more. Knowing the different categories of materials based on their ability to conduct electricity shows a basic understanding of how current depends on the type of material. C is the correct answer. Materials are classified as conductors, insulators or semiconductors based on their ability to carry electrical charge (electrons) through

		B: Only metals conduct electricity, and non-metals do not. C: Materials can be categorised into conductors, insulators, and semiconductors.	them. Conductors have a high enough free electron concentration to allow for easy transport of electric current and include metals such as copper or aluminium. Insulators, on the other hand, are materials that do not permit the flow of electrons under normal conditions and can be found in plastics, rubber or wood. Semiconductors lie somewhere in between these two extremes and can exhibit both conductive and insulating properties depending on external factors such as temperature, voltage or light exposure. **A** is incorrect because resistors, capacitors and batteries are not different types of materials, but different electronic components. **B** is incorrect because some non-metals (e.g., water) also conduct electricity. Competences Activated: In order to use the virtual lab correctly, students must activate basic digital skills. They are also introduced to experimentation and challenged to do a basic literature review in order to categorise the materials correctly.
		Q3: The current passing through a conductor varies with the applied voltage. What happens to the current when you increase the battery voltage? A: Its behaviour does not change.. B: It decreases. C: It increases.	Students who arrive here understand how current depends on the type of material but do not understand how current depends on the voltage provided. The question explains that the current varies with the voltage applied but asks to specify how. Students who fail this question are led back to the virtual lab to create a simple circuit to test the dependence of current on the voltage applied. After completing this challenge, students are assumed to understand how current depends on the voltage provided and the type of material. This basic understanding is essential to start generating reasonable hypotheses. **C** is the correct answer. Applying a voltage to a conductor (like a wire), creates an electric field inside the wire. The electric field is like a "push" or "pull" on the electrons. The current that passes through the wire increases when you increase the voltage because the electric field gets stronger. This means the electrons get pushed and pulled harder, so they move faster and more of them flow through the wire. Thus, **A** and **B** are incorrect. Competences Activated: In order to use the virtual lab correctly, students must activate basic digital skills. They are also introduced to experimentation through the use of different virtual lab tools (including electronic components and the voltmeter and ammeter), and have to think critically to use them correctly.

Hypothesis phase	Representing and formulating	**Q4:** How do a pencil and a paper clip differ in terms of the amount of charge passing through them over time when subjected to the same increase in applied voltage? A: They both experience an increase in current, but in different amounts due to properties inherent to the material. B: They both experience an increase in current, however not significant. C: They do not differ because they are both conductors, and, as such they have similar properties.	Students are invited to create an hypothesis on how voltage, current and resistance relate to each other. The challenge aims to encourage students to think critically about the relationship between voltage, current and resistance. Answering the question correctly means that their hypothesis, whatever it is, implies a correct understanding of the basic concepts. **A** is correct. They both experience an increase in current because of the applied voltage, but the amount differs due to their unique material properties. The pencil's poor conductivity and high resistance lead to smaller increase in current when compared with the paper clip, which has good conductivity and low resistance, leading to a larger increase in current. Due to these differences, **B** is incomplete and **C** is incorrect. **Competences Activated:** Students are thinking creatively about how voltage, current and resistance relate to each other. Students are activating their analytical thinking and conceptual understanding during this phase. They will improve their ability to make hypotheses and review their understanding of electricity principles.
Experiment phase	Planning and Executing	**E1** - build a simple circuit, for example to light up a lamp by connecting its terminals to the battery terminals but try different materials in between components, such as a pencil, a paper clip and an eraser. **E2 - Experiment to test hypothesis -** For each material you test, measure and register in a table the current passing through it every time you increase the battery voltage.	Students arriving **E1** did not get **Q4** completely correct. It is expected that students understood that current increases with the voltage provided. However, they are not yet aware that differences between materials are due to properties inherent to the material. Virtual simulations provide an interactive means for the students to test their understanding and reinforce their knowledge on the topic. During the experiment students have to explore, observe, measure and compare the electric current flow through the different materials. The aim of **E1** is to solidify their understanding of the basic concepts before reflecting on their hypothesis again and proceed to the **E2 experiment to test the hypothesis.** This basic understanding is essential to help them review their hypotheses before testing them. When on **E2** it is expected that students understand that current increases with the voltage provided and are aware that differences between materials are due to properties inherent to the material.

			These experiments will help students to develop a methodological approach to experimentation by encouraging them to reflect on their procedures and invite them to understand for example that changing more than one variable at a time makes it difficult to isolate the element that is responsible for the observed changes. It is also a way to assess their understanding of the scientific method and their critical thinking skills. They are invited to vary elements and observe the outcomes. **Competences Activated:** The experiments phase helps students activate their experimental design skills. Students are involved in hands-on experiments to help them test their understanding of a scientific topic. Students will activate their observation skills while improving their ability to observe and describe changes . By breaking down their results into smaller parts they are working on their analytical thinking. Their science literacy will increase, and they will build on their critical thinking by evaluating the results and drawing conclusions. Moreover, students will also learn to review their scientific methodology and model of investigation. They will reflect on the experimental process and reflect on how the variation of the different elements led to different results or different understanding of the phenomenon being observed.
Analysis phase	Monitoring and Reflecting	**Q5**: Given the plot of V versus I for each material considered, what do the results suggest about the relationship between voltage and current? A: Direct proportionality (y=kx) B: Inverse proportionality (y=x/k) C: Not proportional. **Q6**: Upon comparing the plots of V versus I for different materials in your experiment, if Material A's graph has a steeper slope than Material B's graph (k_A > k_B), what conclusion can be drawn about the materials' abilities to conduct electricity? A: Material A has a higher ability to conduct than Material B. B: Material B has a higher ability to conduct than Material A.	In this phase students are invited to analyse the retrieved results and check if the acquired data is in accordance with their expectations. The sequence of questions is built not only to test the students' knowledge but also to foster their critical thinking, to promote a deeper engagement in the learning of the scientific concepts presented. They have to evaluate the outcome of the experiment and conclude if their model is able to predict their results. According to the experiments, **A** is the correct answer in **Q5.** The plot of V versus I is represented as a straight line, which indicates that there is a direct proportional relationship between the two variables. Thus **B** and **C** are not correct. In **Q6**, if material A's graph has a steeper slope than material B's graph (k_A > k_B), for any V, I in A is less than I in B. That is, material B has a higher ability to conduct than material A. Thus **B** is correct, while others are incorrect.

		C: Both materials have the same ability to conduct. D: The ability to conduct cannot be determined from the slope.	In other words, when you double the voltage (V), the current (I) also doubles. This is because the electric field within the material increases linearly with the applied voltage, causing the charge carriers to move at a constant rate. **Competences Activated:** Through these questions students are encouraged to synthesise their results and explore their scientific reasoning by comparing their results with their initial hypothesis, so as to answer correctly.
		Q7: Look at your data table and check if changes in voltage consistently correspond with changes in electric current. If so, how can you model these changes mathematically? Are you able to predict these changes from your model? A: If so, you are on the right track to confirm your hypothesis. B: If not, you need to review your hypothesis and repeat the experiment and its analysis.	Students are invited to review their hypothesis/results if necessary and rebuild their experiment until they can confirm their hypothesis. **Competences Activated:** Students will reflect on their learning and improve their confidence in their problem solving skills. They will be further invited to reflect on their initial thoughts and make decisions about the next steps to further improve their hypothesis/results. Students at this stage are exercising their critical thinking, improving their competencies in applying knowledge in practical experiments and reflecting on their learning process.
		Q8: Based on the collected data, it seems that voltage (V) and current (I) are directly proportional (V=kI) in the materials you tested. The proportionality constant is k=V/I, the slope of the line. This slope indicates how much one variable change concerning the other, and it varies for each material. For the same voltage value, what happens to current when a low k material is replaced by a high k material? A: It increases. B: It decreases. C: It stays the same.	Here students are invited to reflect on their understanding about the implications of their results and the importance of experiments to validate results and make correct interpretations. If they answer correctly they proceed to the reflection phase. If not, they are given extra guidance through another lab activity that helps them understand Ohm's law better before they test their understanding of their results again. For the same reason that **B** is the correct answer in **Q6**, here, the correct answer is **A.** **Competences Activated:** Improve their critical thinking. Through the extra virtual lab students are not just memorising facts, they are actively engaging with tools and

			materials which promotes a deeper learning and retention of the scientific concepts presented.
Reflection phase		**Q9:** You measure the voltage across a resistor in a circuit as 24 volts, and the current through the resistor is 2 amperes. If you add an additional identical resistor in series, how would this change affect both the voltage and current in the circuit, according to Ohm's Law? A: Increasing the resistance may result in a change in the voltage and total current, but the exact effect depends on additional factors. B: The voltage will remain the same, but the total current will decrease. **Q10:** According to Ohm's law, describe the current in a circuit consisting solely of a battery connected directly by a highly conductive wire from its positive to its negative terminal? A: There is no current flow because nothing is connected to battery except the wire. B: The current is very high because the resistance is close to zero. C: It depends on the type of material that makes up the wire that connects the terminals together.	Students are challenged to answer new questions and invited to reflect on some of the implications of their results. Moreover, these questions present new concepts and numeric examples to exemplify how] Ohm's law can be used in practice. **Q10** is a more abstract question that requires a deeper understanding of mathematics. It challenges students to relate mathematical abstractions and physical phenomena. By adding an additional identical resistor in series, the resistance in the circuit will increase. Thus, according to Ohm's law, the current will decrease for the same voltage applied. Thus **B** is the correct answer in **Q9**. When a battery is connected directly by a wire from its positive to its negative terminal there is practically no resistance in the circuit. Therefore, according to law, I must be a very large number. Thus, **B** is the correct answer in **Q10**. **A** is incorrect because, when only the battery is connected without any other electronic components, connecting the positive and negative terminals directly completes the circuit, allowing current to flow. **C** is incomplete. Although different types of wires have in fact different inherent resistances, the resistance of highly conductive wires is negligible." **Competences Activated:** Students are prompted again to reflect on their understanding and apply their knowledge in more practical examples. This will not only improve their analytical, abstract and conceptual understanding but also their scientific numeracy through a practical example.
		Q11: All ohmic materials obey Ohm's law. Considering that the resistance in the circuit is approximately zero because there are no other components in the circuit and the resistance of the wires is almost negligible (R is approximately zero), what	This question challenges students to think more critically and in an abstract mathematical perspective. Students failing to understand the basic idea behind this question are challenged with a virtual lab activity to measure the current in a circuit consisting solely of a battery with its terminals connected together through wires with no other components.

		happens to I when R becomes a very small number (holding V constant)? A. I becomes a very large number. B. I does not change.	By the same reason that **B** is the correct answer in **Q10**, here, the correct answer is A. **Competences Activated:** Through this question and the virtual lab, students will improve their ability to interpret mathematical results physically, thus enhancing their capacity for creative critical and abstract thinking about real-world phenomena.

Provisory Link to the scenario:
https://view.genially.com/6645e599b3e3a900158b4b64/interactive-content-robot-horizontal-info

The full explanation of the scenario can be found in Annex 5.6

3.8. Population Genetics

This scenario intends to introduce students to the topic of population genetics, while encouraging them to develop their scientific reasoning and knowledge about the scientific method. The scenario starts with the question "Why does a population evolve over time?" that invites students to reflect on their perception of evolution and its mechanisms and the reason why evolution needs to happen. Below we present the summary table of the whole journey to allow a more fluid navigation through the scenario.

Here we present a table explaining how the whole cycle of Inquiry-Based Learning was implemented:

Table 8 Phases of the Population Genetics Scenario

Scenario Phase	Problem Solving Process	Questions of the Scenario	Educational Objective
Engagement	Exploring and understanding	**Q:** Why does a population evolve over time?	Students are invited to discuss their perceptions of why evolution occurs. Although this question might seem simple at first glance, it is sometimes a question that is overlooked. We know that populations evolve, but why do they need to do so? The first question aims to recognize the level of understanding a student has on the topic, while also serving as a stepping stone to introduce the fundamental principles of evolution and the mechanisms through which populations change over time. This

			question is made at the start and the end of the scenario, so students can confront their perceptions at the beginning of the class with the insights they gained by performing the virtual experiment. After discussing this question the first time, students will be able to perform the virtual lab simulation “Evolutionary Arms Race”, which depicts the effects of a prey’s toxin on its predator. They will later proceed to a second activity, using a virtual experiment. The experiment has two parts, each of them featuring questions that will guide students through their experimental process. Each question has usually three choices, one that reveals that the student lacks knowledge on the subject (usually c); one that reveals an intermediate understanding (usually b), and a fully correct answer that reveals the student’s good understanding (a). When students answer b or c, they will be invited to reflect a bit more on the topic asked and given the chance to answer correctly again, while students that answer a will proceed to the next question.
Hypothesis	Representing and formulating	**Virtual Lab Simulation “Evolutionary Arms Race”** **Part I:** What is the effect of the toxin on predator speed? **Part II:** How does the percentage of toxic prey in the predator’s diet affect predator toxin resistance over time?	The virtual experiment is divided into two parts. Part I focuses on individual predators, while Part II presents population averages. In the first part, a predator makes four runs through a path: the first run without toxin exposure and three runs after being injected with increasing "units" of the toxin. For this simulation, students are invited to examine how the toxin affects the predator's speed. The more resistant the predator, the less its speed is reduced by the toxin. Students will formulate a hypothesis to answer the question “What is the effect of the toxin on predator speed?”. In the second part, students are able to control the percentage of toxic prey in the predator's diet to try to understand the difference in control speed (0 units of toxin) and toxin speed at the beginning of the study (generation 0) and after 10 generations. During the experiment, students will analyse how varying percentages of toxic prey in the diet affect the level of resistance in the predator population over time, once again formulating an hypothesis that will describe how the percentage of toxic prey in the predator’s diet will affect predator toxin resistance over time.
		Part I: **Q1a:** In order to get valid results, how many predators (how many times) should you test? **Q1b:** Which number of repetitions will make your results the most robust?	Question Q1a (and Q1b) aim is to guide students in understanding the importance of multiple trials in scientific experiments in order to ensure the validity and robustness of results. The question allows students to reflect that testing multiple predators and increasing the number of repetitions can reduce variability and random errors, leading to more accurate and reliable findings. Through this question, students are encouraged to design their own experiment with sufficient repetitions to get more reliable results.

Experiment	Planning and Executing	**Part I:** **Q2a:** Should you include the first test (with zero toxin) in your data analysis? **Q2b:** Why should you include a control group?	These questions aim to foster students' critical thinking skills and deepen their understanding of experimental design principles in scientific inquiry, by guiding them to reflect on the critical role control groups in to validate results and encouraging them to question and explore the necessity of baseline measurements and control groups in scientific experiments. Students will understand that including initial measurements (Q2a) provides a reference point for comparison, allowing them to assess the impact of toxin exposure accurately. Additionally, they will comprehend their importance in isolating the effect of the variable being tested (Q2b), thus validating experimental results and ensuring that the observed changes are attributable to the experimental treatment. These questions aim to foster students' critical thinking skills and deepen their understanding of experimental design principles in scientific inquiry.
		Part II: **Q3:** What was your reasoning for choosing the toxin percentages to test?	This question aims to cultivate students' ability to select their experimental design (in this case, the toxin percentages) critically and meaningfully. By prompting students to articulate their reasoning, the question encourages them to engage in critical thinking and consider various factors influencing their choices. Through this process, students develop a deeper understanding of experimental design principles and learn to approach scientific inquiry with thoughtful consideration. Ultimately, the objective is to encourage students to make informed decisions in their experimental designs, ensuring that their choices are grounded in logic and align with the goals of their scientific investigation.
Data Analysis	Monitoring and Reflecting	“Now that you have the data in your hands, discuss it with your colleagues. Did they obtain the data the same way as you?” “What is the effect of the toxin on predator speed? Create a graph with your data and analyse your results.” “Did your colleagues calculate the results in the same way as you? What do their graphs look like?”	Throughout the scenario, students are presented with several questions to guide them through their data analysis and reflection on the results and methodologies used. These questions aim to encourage collaborative discussion and comparison of methodologies among peers, fostering communication skills and promoting learning through their peers. By prompting students to create a graph with their data and analyse the effect of the toxin on predator speed, students will apply data visualization techniques and critical analysis, broadening their understanding of the experimental outcomes. Students will also develop their problem-solving skills when considering alternative approaches to the ones they chose, to fix mistakes or understand their peers’ reasoning behind their choices, promoting active engagement and reflection throughout the data analysis process.

		"Did the randomised % of toxin provide you with a good curve for you to analyse your data? What would you change?"	
Reflection		Was your initial hypothesis proven? If not, why?	At the end of each part of the experiment, students are prompted to reflect on whether their initial predictions were supported by the evidence obtained through the virtual simulation. This question aims to highlight the importance of empirical evidence in hypothesis testing. This type of questioning fosters students' critical thinking skills, allowing students to analyse their results thoughtfully and refine their hypotheses based on evidence-based reasoning. It also encourages students to consider alternative explanations for their observations, promoting a better grasp of the scientific way of thinking.
		Q: So, why do you think a population evolves over time? Is it necessary? Why do you think both the prey and the predator of the previous experiment need to survive?	At the end of the scenario, students are revisited with the question, "So, why do you think a population evolves over time". This question is meant to compare the students' initial understanding and assumptions with their newfound knowledge gained through the experimental activity. By revisiting the question, students are encouraged to reflect on their new knowledge of the topic and confront their previous assumptions with their more informed ones. This question also ultimately aims to highlight the significance of species adaptation and evolution, while encouraging students to critically evaluate their assumptions, and synthesize their learning to construct a more comprehensive understanding of the topic.

The full explanation of the scenario can be found in Annex 5.7

Provisory Link to the scenario:

https://view.genially.com/664c64113d58dc0015ac475e/presentation-population-genetics-scenario-i

3.9. Newton's 3rd Law

This scenario is designed to introduce students to the concept of action and reaction. Below we present a summary of the scenario implementation across the inquiry phases.

Table 9 Phases of the Newton 3rd Law Scenario

Scenario Phase	Problem Solving Process	Questions of the Scenario	Educational Objective
Engagement	Exploring and understanding	**Q1**. When you push a wall, what do you feel in your hand? What forces are exerted on the bodies here and where is each one exerted from? **Q2**. Why did the child lose the balance and end up on the ground?	At this stage we aim to start introducing students to the concept of action and reaction. Thus, we ask them what they feel in their hand when they are pushing a wall. The idea that every action has a reaction is presented through a very common example from everyday experience. Moreover, we aim to test if students can identify at which body each force is exerted. Accordingly, we present a more complicated example where a child wants to use a hose to water a plant and ask why the child lost his balance.
Hypothesis	Representing and formulating	**Q3**. In the picture the man is pushing the trash bin with a constant force, without any movement. What forces are exerted on each of these two bodies (man - M, trash bin - B)? **Q4**. Among the forces exerted on the two bodies (man, bin), which ones do you consider are mutual actions between them and what relationship connects them as vector quantities?	Moving to the hypothesis phase, we want to make sure that students can clearly identify all the forces that are applied on a system- the man-bin system in the specific case. We want to make sure that students can identify the vertical force N from the ground to the man. In addition, students should understand that even though there is no movement, the man exerts a force on the bin and the bin exerts a force on the man. Then we ask students to identify the different pairs of action and reaction from the different forces in the system. Moreover, we want to emphasize the vector character of the force. Students should be able to describe that action and reaction have the same magnitude but opposite directions and are exerted to different bodies.

Experiment	Planning and Executing	**Experiment** Open the "Friction" simulation, replace the box with the bin, check all the boxes as in the table at the top right of the bin, leave the friction indicator as it is. Gradually increase the value of the force F_{MB} exerted by the man on the bucket as F_{MB} = 250 N and observe the value of Friction (static) variation. **Q5**. The man exerts a varying force on the bucket F_{MB} and $F_{TOTAL}=0$ (Sum of Forces = 0 for each value of F_{MB}). The man and the trash bin are in a state of equilibrium. Why is the man in balance? **Q6**. Which pairs of opposite forces (action-reaction) do you think are exerted during the interaction of the bodies with the bin when the man pushes the bin with a varying force and the bucket balances?	At this phase students are called to perform experimental work in order to test the hypotheses made on the previous phase. The way that students are performing the experiment is of crucial importance, so that they can see the impact that the different parameters have on the system. Accordingly, we ask them to answer two questions based on their experimental findings. In Q5, students should be able to describe why the man is balancing. From their measurements they should be able to describe now all the forces that are exerted on the man, and which are the pairs that cancel out. It is important to stress at this point that we focus only on the forces on one body, in this case the man. Students reaching at this point of the scenario should also have a good understanding of Newton's first law. The latter will be reminded and explained to moderate and low performers. Accordingly, in Q6 we focus on the pairs of opposing forces. Here students are asked to identify the different forces acting on the different bodies and recognize that they have the same magnitude, but opposite directions.
Data Analysis		**Q7**. According to Newton's 3rd law, when a body A exerts force F on a body B and B exerts force -F on A. Therefore:	In the analysis phase we want to make sure that students after performing an experimental work can clearly say which force is exerted by each body and avoid a common misconception which has to do with the net force between action and reaction. Since these forces are exerted to different bodies there is no net force. At this point some students are expected to create a wrong picture that the net force is zero. Accordingly, we present

Reflection	Monitoring and Reflecting	**Q8**. When F_{MB} = 258 N and F_B = 188 N, what is the force F_{BM} exerted by the bin on the man? **Q9**. An egg accidentally falls to the floor. Why does it break? **Q10**. A runner starts: What forces are exerted on her body and by which body(s)? **Q11**. The force moving her body is a reaction to which force, if the effect of air is considered negligible? **Q12**. Why do apples fall to the Earth while the moon orbits around the Earth? Can the same laws apply on the earth and in the sky?	a picture to the students and ask them what is the force exerted by the bin on the man. For one more time, the reason is to emphasize that action and reaction have the exact same magnitude and that all the other information is just to create confusion. In this way we test that students are confident into the knowledge that they have acquired so far and are not confused by other information. Moving to the final phase, the reflection, we are about to ask students more demanding questions. First we ask why an egg breaks when falling on the floor. At this point again some students might consider that the floor is exerting a greater force on the egg, and this is the reason that the egg breaks. Then we give the example of a runner and ask the students first to identify the different forces and accordingly why she is moving. Several examples have been presented to the students so far, where there is a clearly visible force applied on a body and causing it to accelerate. At this point this is not so obvious. Students should clearly describe in this case the forces causing the motion of the athlete; thus the athlete is exerting a force on the ground and the ground exerts friction to her. Students should understand that the vertical forces applied on the athlete cancel out. Finally, Q13 aims to challenge students even more. We ask why apples fall to Earth, but the Moon is orbiting, thus whether the physical laws are not the same on the earth and sky. High performers at this point will understand that the physical laws cannot be different on Earth and the sky, thus they are the same everywhere. Then they should also understand that an apple contrary to the Moon does not have initial velocity. The Moon has a horizontal velocity (considered as initial velocity) and moves roughly in a circular orbit. The same will hold for an apple if it is thrown with a horizontal velocity of 8 km/s.

The full explanation of the scenario can be found in Annex 5.8

3.10. Seasons Explored: Embarking on Earth's Annual Journey

This scenario aims to help students recall basic knowledge about the season and get a more in depth understanding of this phenomenon

Scenario Phase	Problem-Solving Process	Questions of the Scenario	Educational Objective
Engagement	Exploring and understanding	**Q1**: What do you think this picture is representing? **Q'1a:** Look more carefully to the picture. Although it seems to be a nice park, the picture is trying to illustrate something else. See how the weather and the trees change sequentially. **Q'1b:** Look more carefully to the picture. Yes, the weather changes in each image, but the picture is trying to illustrate something more. See how the weather and the trees change sequentially.	Students are oriented to recall basic knowledge about the seasons, as they know them in Europe, by interpreting pictures. The 1st picture asks them to identify the annual cycle of the seasons through its weather characteristics. If they can't do so in the first question (Q1), the following questions will guide them there (Q'1a, Q'1b). **Competencies Activated:** Critical Thinking is involved when interpreting pictures.
		Q2: This picture represents the apparent sun path across the sky at different times of the year and each path corresponds to the first day of a season. Paths A, B and C correspond to the first day of which season? **Q'2 ac:** Path A takes the sun higher in the sky and it is a longer path, meaning that there are more daylight hours. In contrast, path C is shorter and consequently days are shorter. With this in mind, paths A, B and C correspond to the first day of which season?	The 2nd picture is about how the sun's path in the sky changes throughout the year. Students are asked to identify the sun's path with the first day of a season (Q2). They have already learnt at school, but they also have the knowledge from their daily experience. If they don't remember immediately with the 1st question (Q2), they can relate summer to having the Sun higher in the sky and more daylight hours, so the following question will guide them (Q'2ac). Students that paired the paths with the seasons in the 1st question will have a more challenging question related to being able to deduce that the picture depicted the situation at the northern hemisphere (Q'2b). **Competencies Activated:** Critical Thinking is involved when students make connections between their knowledge and their interpretation of the pictures.

		Q'2b: Knowing that this picture is from a south-facing perspective, do you think it is illustrating the situation in...	
		Q3: Let's look again at the picture. Now consider the shadows at noon - which position do you think is responsible for shadow D? **Q'3bc:** Picture **A** shows how the angle of light incident on an object changes the length of its shadow. Now, look again at picture (**B**) - which season do you think is responsible for shadow D? **Q'3a**: Yes! During the first day of Summer, which is Path A, the Sun is higher in the sky at noon, and so the shadow is shorter. What would happen if you were in a place with a higher latitude, i.e., nearer the North pole? Would the shadow be longer or shorter? Use the picture to help you figure it out.	Students are given the same picture as before, but now they are asked to relate the size of a stick's shadow to the height of the sun (Q3). Students that are confused will be guided to deduce correctly by the next question (Q'3bc). Students who didn't have doubts will have a more challenging question regarding what would happen if the picture were depicting a place with higher latitude. **Competencies Activated:** Critical Thinking is involved when students make connections between their knowledge and their interpretation of the pictures. Also, students have to reason deductively.
Hypothesis	Representing and formulating	**Q4**: Do you think that the fact that the sun is higher in the sky in summer makes this season warmer than others? To answer this question, you are going to do an experiment. Look at the picture illustrating the light rays hitting the ground at different angles. What do you think happens?	Students are given 3 hypotheses to choose one: Students who understand the seasons will choose the first one, but all hypotheses can be tested with the experiment so they will work with their chosen hypothesis. **Competencies Activated:** Critical Thinking is involved on the choice of the hypothesis.

Experiment	Planning and executing	**Q5:** It's lab time! You will design an experiment to test your hypothesis with the equipment you see in the picture. The independent variables of your experiment are the height of the lamp, the angle of incidence of the light, the intensity of the lamp, the time the light was hitting the thermometer. And you have one independent variable, the temperature of the surface stroke by the light, which you measure. How will you handle the variables when conducting the experiment? **Q5'c**: You are planning to change the height of the lamp, the intensity and the angle of incidence of the light at each experiment. If the temperature changes from one experiment to another, which variable will be responsible for the effect?	Students arrive at the Experiment phase. They will need to plan and execute the experiment. To do so, the first step is to make sure students know with which variables they will work with, and that information is given. The first question is there to test the plan that students have come up with (Q5). There are three plans, and they will choose one. The first one is the best plan, but the second one is also acceptable. The last one isn't a good plan, so students have some guidance (Q'5c) and are asked to choose another plan Students are ready to execute their experiment and gather their data. Students can form small groups. Teachers won't interfere too much but can help when needed. **Competences Activated:** This phase involves critical thinking and creativity to plan and execute the experiment. Working in group will favour collaboration and communication competencies.

Data Analysis	Monitoring and reflecting	**Q6:** Well done! You've completed the first experiment and obtained your own data. Now comes a very important part: analysing the data and checking whether your initial hypothesis has been verified or not. Recall your hypothesis – you should have written it down in your notebook. Do you verify your hypothesis? **Q'6a:** So, your hypothesis has been verified? **Q'6b:** So, your hypothesis hasn't been verified? **Q'6c:** So, you can't conclude if your hypothesis has been verified or not.	After finishing executing the experiment, students are asked if their hypothesis was verified, if their hypothesis isn't verified or if their experiment and data analysis was unconclusive (Q6). The next set of questions sorts out if the experiment gave the expected result (Q'6a, Q'6b, Q'6c). If it was unconclusive, or the 1st hypothesis wasn't verified, or if the 2nd and 3rd hypotheses were verified, then students will analyse thoroughly their work to see if they understand why it didn't work (maybe with the help of the teacher) and will perform the experiment again. The conclusion of the experiment is that if the light strikes the ground more directly (closer to perpendicular), it will heat up the area more than if the light strikes at more glancing angles. That is because the energy is concentrated in a smaller area and consequently, the amount of energy per area is greater than for glancing angles. **Competencies Activated:** This phase involves critical thinking and creativity to analyse the data. Working in group will favour collaboration and communication competencies.
Reflection		**Q7:** Now we can go back to our initial question: do you think that the fact that the sun is higher in the sky in summer makes this season warmer than others?	Students will relate the conclusion of their experiment to the initial question (Q7). This will be the kick-off to the next activity, that restart the engagement. **Competencies Activated:** Students will need critical thinking, creativity and reasoning skills to relate their experiment to the initial question.

Engagement	Exploring and understanding	**Q8:** And speaking of seasons, can you explain what causes the different seasons on Earth? **Q8'c:** The Earth's rotation is responsible for day and night on Earth. Between day and night, are there different seasons? No, so the Earth's rotation doesn't cause seasons. Then, what causes? **Q'8b**: In fact, the distance between the Earth and the Sun changes throughout the year. But is that the cause for the seasons? Look at these two pictures taken in December, near Christmas time. Think about the seasons represented in these two images. Do you still think that it is the change of the distance between the Earth and the Sun that causes seasons?	Students are oriented to reflect on the reason why there are seasons (Q8). Main misconceptions are addressed at this stage - seasons aren't caused by the Earth's rotation nor by the changing distance Sun-Earth throughout the year – with questions Q'8c and Q'8b giving clues to students. **Competencies Activated:** Critical Thinking and deductive reasoning skills are involved in this phase.
Hypothesis	Representing and formulating	**Q9:** We shall now investigate how the tilt of the Earth's axis might cause the seasons. What do you think?	Students are given 3 hypotheses on how the tilt of the Earth's axis might cause the seasons (Q9). They will choose one. Students who understand the seasons will choose the 1st one. The 2nd and the 3rd hypotheses address misconceptions, in this case, related to the Earth's tilt. Students will be guided to understand why these are not reasonable. **Competencies Activated:** Critical Thinking is involved on the choice of the hypothesis.

Experiment	Planning and executing	**Q10**: Your variables are: **Q10'bc**: An independent variable is the cause of a phenomenon; its value is independent of other variables – you can control. A dependent variable is the effect, and its value depends on changes in the independent variable(s). Now that you know better the difference between independent and dependent variable, what are the variables in the simulator?	Students will investigate the hypothesis: The tilt of the Earth's axis causes different parts of the Earth to receive sunlight at different angles throughout the year, leading to the changing seasons. They will use an online simulator, *Seasons and Ecliptic Simulator*, developed by the University of Nebraska-Lincoln. Students start by playing with the simulator to get to know how it works. Before designing their experiment, they are questioned about the variables that are in use by the simulator (Q10). If there are misunderstandings, the students will be guided to understand which are the independent and the dependent variables used in the simulator (Q'10bc). Once it is understood, students will design their experiment, execute it and acquire their data. Students can form small groups. Teachers won't interfere too much but can help when needed. **Competences Activated:** This phase involves critical thinking and creativity to plan and execute the experiment. Working in group will favour collaboration and communication competencies.
Data Analysis	Monitoring and reflecting	**Q11**: Which of the following are true from your data analysis? For a fixed location in the Northern Hemisphere, a) the sunlight angle is more horizontal in December and more vertical in June b) the sunbeam spreads more in December and less in June	After finishing executing the experiment, students are asked questions to see if their experiment gave the expected results. All options should be verified by their experiment. The teacher can promote a discussion of each of these statements. **Competencies Activated:** This phase involves critical thinking and creativity to analyse the data. Working in group and discussing results will favour collaboration and communication competencies.

		c) in September, there is a day when the night line is parallel to the Earth's axis.	
Reflection		**Q12**: Students prepared a model to study the Earth's movement around the Sun and the seasons: a lamp was the Sun, and 4 Earths, at different locations around the Sun, simulated its orbital movement. The students set up the model as you see in the image. But then someone said: we aren't going to be able to understand the seasons with the model as it is. What did they do wrong? **Q'12b:** All axes should have the same inclination since the Earth's tilt doesn't change throughout the year. But should all axes point to the same location? If you are in the northern hemisphere, you must have heard of the Polar Star. Why is this star so famous? **Q'12a:** Exactly, all axes should have the same inclination since the Earth's tilt doesn't change throughout the year and should point to the same location in the sky. Where should it point to?	A problem is posed to the students: a hands-on model that should help explain the seasons and the Earth's movement around the Sun is shown on a picture. They are told that there is a problem with model and students have to find out what is wrong (Q12). Students, with guidance if needed (Q'12b), must conclude that throughout the year, the Earth's axis is always pointing to the same point (the Polar Star) (Q'12a). To finalize, the teachers can: - promote a discussion of the findings, - ask for a report on the activity - have students prepare a hands-on activity **Competencies Activated**: This phase involves critical thinking and creativity to analyse the data. Working in group and discussing results will favour collaboration and communication competencies.

The full explanation of the scenario can be found in Annex 5.9

4. Conclusion

The collection of scenarios presented in this document represent a consolidated start to the creation of differentiated solutions to reinforce students' learning experiences. By guiding students to solve problems by designing and conducting experiments, then reflecting on their findings, these scenarios foster a deeper understanding of the presented concepts while at the same time providing opportunities to improve the student's problem solving competencies. The opportunity to monitor the progress of the students and to provide guidance provide a strong support to facilitate the students' learning experience. It also empowers educators to assess the progress of the students in a dynamic manner.

The presented scenarios incorporate valuable tools to enrich students' STEM education by offering various opportunities to explore scientific concepts in a hands-on approach. The scenarios will cultivate in students a sense of curiosity and a taste for discoveries. The different paths taken by the students will ensure that their different tracks will bring all of them to the same level of understanding of the concepts and development of their competence profile.

In all scenarios students are invited to reflect on their work, discuss their results and rethink their findings and strategies.

These starting scenarios are setting the ground for a fruitful co-creation and localisation of learning in different settings, for various purposes and audiences, facilitating diverse educational needs and promoting enriched learning experiences.

These scenarios will be the trigger for the creation of more complex AI enhanced scenarios, leading educators and learners to a new model of teaching and learning experiences.

5. Annex

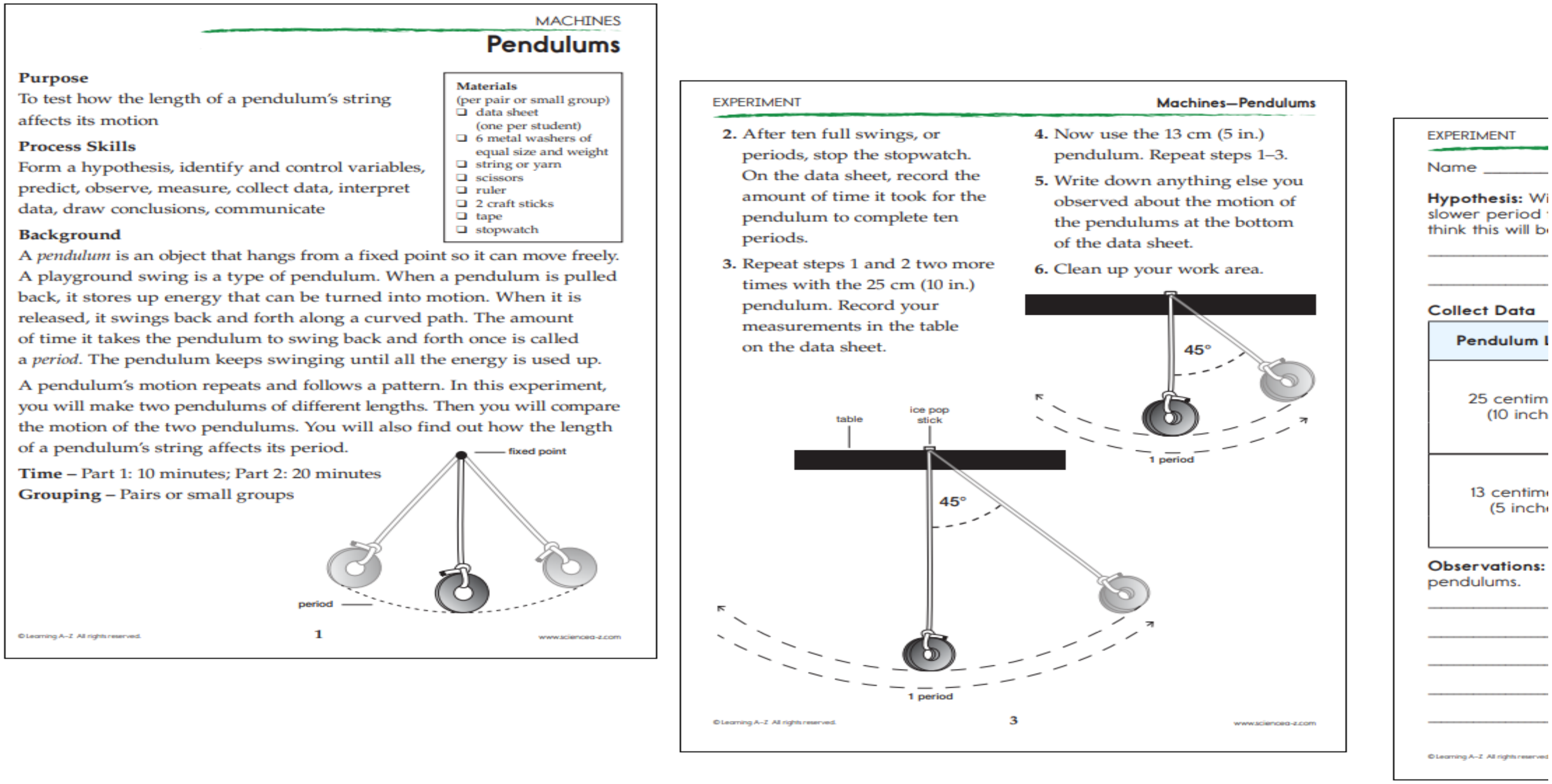
This section presents the various scenarios in more detail. The reading of this part should be accompanied by the summary tables presented in chapter 3.

5.1. Simple Pendulum Scenario

This scenario was presented in D2.2, but for the completeness of the Discovery Space scenarios we repeat its explanation in this annex.

This subsection is an illustrative example on how the AI learning companion could facilitate the inquiry process. The scenario concerns the case of the simple pendulum, a common topic in the introductory lessons in the lower secondary school Physics curricula. At this level the pendulum is used as a device for measuring time. The accuracy of the measurements and the definition of the parameters that could affect the results of measurements are the focus points of the intervention. The aim of the experiment is the measurement of the Period of the pendulum and the identification of its dependence (or not) on a number of parameters (mass of the pendulum, length of the pendulum). The pendulum is introduced with a simple demonstration, and accordingly students are asked to define the optimal (most accurate) process (experiment) to measure the period T of the pendulum.

The Figure 3 presents indicative pages of school textbooks that include worksheets to document the students' findings. The study of the Pendulum is used to introduce the concept of time and the periodic phenomena. Students will need to perform several measurements and to assess their accuracy. Furthermore, through the realization of the measurements, students will need to explore the dependence of their period of the pendulum's motion on its mass and on its length. The overall duration of this activity varies from 3 to 5 didactical hours. In Discovery Space we will enrich this common educational activity with a number of challenges where the students will interact with the AI learning companion. Based on the students' reactions and responses the AI learning companion will guide the students during the inquiry process. Students who demonstrate deeper understanding of the phenomena under study will follow a different learning path, that will include more complex tasks. Students who demonstrate moderate understanding will follow different learning paths with scaffolds to improve their understanding. Students who are demonstrating lower levels of understanding of the phenomenon under study will need to get involved in additional activities (learning cycle) – including simulations and augmentations – that could possibly facilitate their conceptual change.


MACHINES
Pendulums

Purpose
To test how the length of a pendulum's string affects its motion

Process Skills
Form a hypothesis, identify and control variables, predict, observe, measure, collect data, interpret data, draw conclusions, communicate

Materials
(per pair or small group)
❑ data sheet (one per student)
❑ 6 metal washers of equal size and weight
❑ string or yarn
❑ scissors
❑ ruler
❑ 2 craft sticks
❑ tape
❑ stopwatch

Background
A *pendulum* is an object that hangs from a fixed point so it can move freely. A playground swing is a type of pendulum. When a pendulum is pulled back, it stores up energy that can be turned into motion. When it is released, it swings back and forth along a curved path. The amount of time it takes the pendulum to swing back and forth once is called a *period*. The pendulum keeps swinging until all the energy is used up.

A pendulum's motion repeats and follows a pattern. In this experiment, you will make two pendulums of different lengths. Then you will compare the motion of the two pendulums. You will also find out how the length of a pendulum's string affects its period.

Time – Part 1: 10 minutes; Part 2: 20 minutes
Grouping – Pairs or small groups

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EXPERIMENT Machines—Pendulums

2. After ten full swings, or periods, stop the stopwatch. On the data sheet, record the amount of time it took for the pendulum to complete ten periods.
3. Repeat steps 1 and 2 two more times with the 25 cm (10 in.) pendulum. Record your measurements in the table on the data sheet.
4. Now use the 13 cm (5 in.) pendulum. Repeat steps 1–3.
5. Write down anything else you observed about the motion of the pendulums at the bottom of the data sheet.
6. Clean up your work area.

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EXPERIMENT
Name ______
Hypothesis: Wi
slower period
think this will b

Collect Data

Pendulum l
25 centim (10 inch
13 centim (5 inch

Observations:
pendulums.

Figure 3: The study of the simple Pendulum is a very common topic in the Physics curricula.

Exploring and understanding

The challenge is presented in the following way:

Q1: To achieve the most accurate measurement of the period of the pendulum:

A. **I must measure the total time (t) of many oscillations (N) and then calculate the average time (period) for one oscillation T=t/N. (3p)**
B. **I must measure the period Ti of each of many oscillations (N) and then calculate the average time $T = (T_1 + \cdots + T_N)/N$. (2p)**
C. **One measurement is enough. (1p)**

The challenge for the students here is to identify the physical meaning behind mathematical operations and be able to understand the differences behind options A and B. The source of errors, which are introduced in the measurements, should be identified by the students. According to the given answers, different learning paths can be drawn. Students choosing the option A are identified as (potential) high performing students, since they can understand that the error source is on the reflexes of the experimenter as he/she performs the measurement. Students that give as answers options B and C above are identified as (potential) moderate and low performers, respectively, and further actions are required, so they can understand why their options will not minimize the error in the measurement of the period. The final decision for the level of the student will be made at the end of each phase, as it must be based to a series of responses to the challenges set by the AI learning companion. Students who demonstrate moderate and low levels of understanding will be asked to use the virtual lab (https://phet.colorado.edu/sims/html/pendulum-lab/latest/pendulum-lab_all.html) [70] and they will be involved in a number of experiments with it. This will offer them further time for experimentation in a controlled environment and will provide evidence of their exact level of understanding the key concepts.

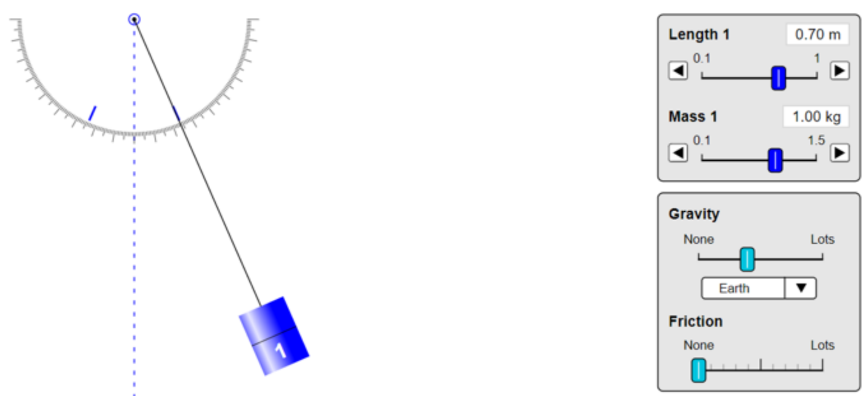


Figure 4: A virtual lab (see Ref. [70]) used for the students to measure the period T and perform experiments to identify the main parameters determining the pendulum's period.

After they become familiar with the lab, they must perform the following actions (the orange color indicates that these actions are addressing low and moderate performers) and then react to a set of challenges:

- **For a rope length of L= 0.70 m and a mass of 1 kg try to measure the period of a complete oscillation.**
- **Repeat the above process but this time try to measure the period of a complete oscillation four times.**
- **Compare your results with those of your classmates. Which is the source of deviations?**

By comparing their results and discussing the different values of the measured period, students are engaging in a process where they share understanding and effort to solve a problem. Moreover, as they start conducting experimental work, students start to develop an academic mindset, dictating to put any hypotheses they make into the test. Once they have performed the actions mentioned above, low and moderate performers in Q1 will need to react to a new series of challenges:

Q1a: During the experiment, what causes the inaccuracy in the measurement of the period of the pendulum?

A. **Your reflexes when operating the stopwatch, mainly when starting the clock.**
B. **Your reflexes when operating the stopwatch, both when starting the clock and when you stop it.**
C. **You should be more careful with your measurements next time.**

Q1b: We propose you to count the total time of more pendulum oscillations and divide it by the number of oscillations. Which measurement is going to be the most accurate one?

A. **By measuring the time of 1 oscillation.**
B. **By measuring the time of 50 oscillations.**
C. **By measuring the time of 5 oscillations.**

Students choosing options A or C in questions Q1a and Q1b will need to repeat their measurements and if they still have difficulties, then the learning companion will explain to them the process of getting the most accurate result (see Figure 5).

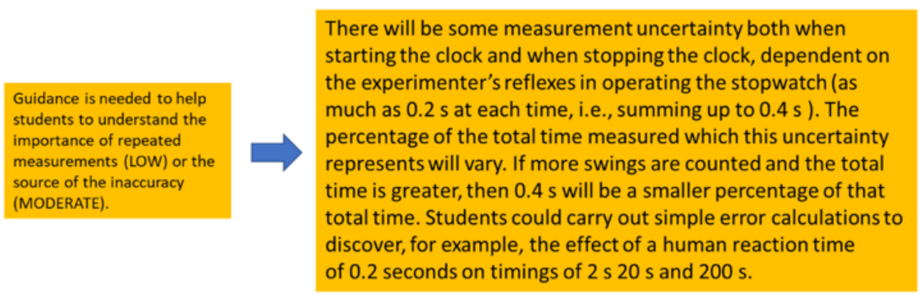


Figure 5: The AI learning companion will provide the necessary explanation at the end of the learning cycle to facilitate the continuation of the inquiry process.

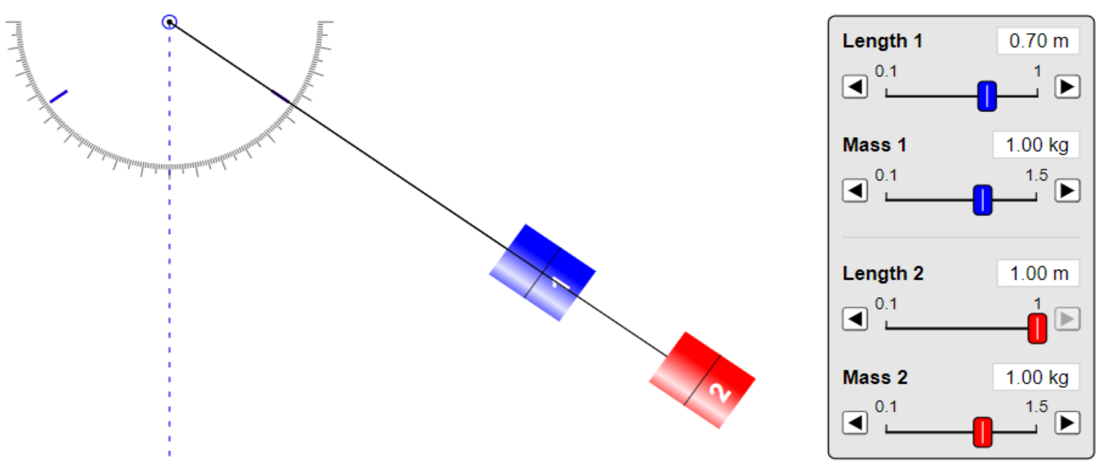


Figure 6: Two pendula with different rope lengths and same mass [65]. Students will need to answer which one swings faster. In this way reasoning skills are employed during the problem-solving process, while they start decomposing the problem to its parameters.

Accordingly, all students are presented with two different cases where there are two pendula. In the first case they have the same mass but different lengths and in the second case the same length but different masses. The former case is shown in Figure 6, followed by Q2 and the latter in Figure 7, followed by Q3.

Q2: Which pendulum swings faster if there is no friction?

A. They go the same speed. (1p)
B. 1 is faster. (3p)
C. 2 is faster. (1p)

The main goal of Q2 and Q3 is for the students to start identifying the main parameters from which the problem consists of. In addition, these questions are preparing the students for the following phase of the scenario (hypothesis), where they will have to use their inductive skills to reply on questions which are linking directly the different parameters (length, mass) with the pendulum's period. Furthermore, the answers given by the students at this phase will be used by the AI learning companion, in combination with the answers that will be provided in phase 2, to (re)design the optimal learning path for each student.

Representing and formulating

Moving on to the hypothesis phase, students will need to represent and formulate. The relative parameters should have been identified, yet their effect on the period is not fully clarified to this point, thus the following questions are testing the student's skills towards this direction. The first (Q4) concerns the length of the pendulum and the second (Q5) is about the effect of the bob mass.

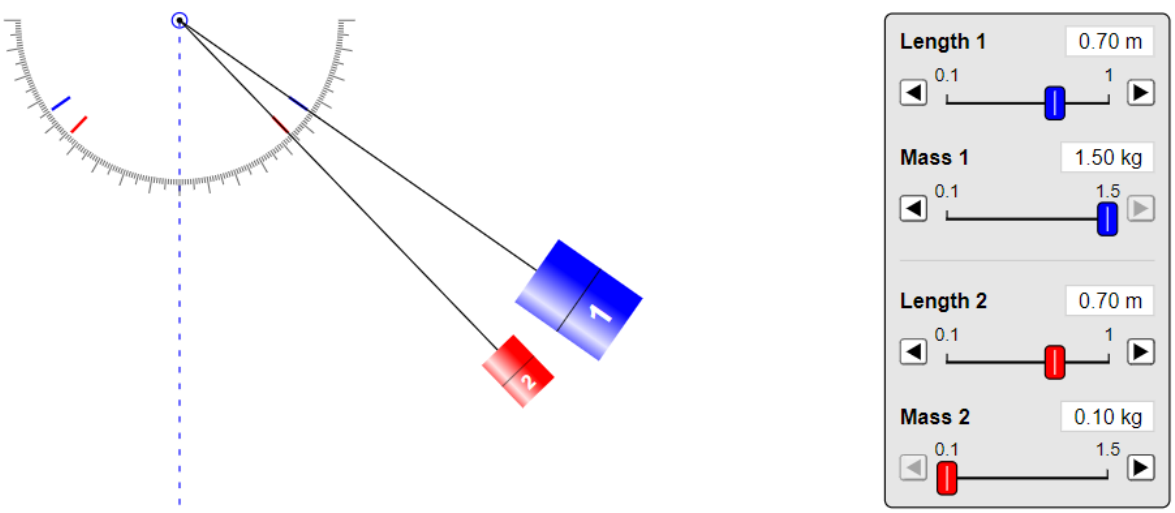


Figure 7: Two pendula with the same rope length and different masses [65]. Students will need to identify whether the mass has any effect on the period of the pendulum.

Q3: Which one swings faster if there is no friction?

A. They go the same speed. (3p)
B. 1 is faster. (1p)
C. 2 is faster. (1p)

Q4: What can you say about the length of the rope?

A. Does not affect the speed of the pendulum. (1p)

B. **Shorter length means higher speed. (3p)**
C. **Shorter length means lower speed. (1p)**

Q5: What can you say about the bob-mass?

A. **It does not affect the speed of the pendulum. (3p)**
B. **Smaller mass means higher speed. (1p)**
C. **Smaller mass means lower speed. (1p)**

Representation skills should be employed here, and the students start creating rough models connecting the length and mass with the period. High achievers should identify that the mass has no effect on the period of the pendulum. It is worth noting that both questions ask about the speed of the pendulum not the period, thus the connection between the two needs to be clearly understood. Such a process is developing students' critical thinking as they must make a hypothesis based on the two parameters that they can vary. Returning to the discussion of the pendulum scenario, students with low performance are going to perform a series of measurements and answer questions, as presented below (the red color refers to low performers).

Measure the period for three different pendula, using the virtual lab, and complete the table.

L (m)	m (kg)	T (s)
1	0.5	
0.7	0.5	
0.7	1	

At this point the students are expected to be familiar with measuring the period of the pendulum. The teacher can validate that students who cannot create the appropriate model for the pendulum's period are now learning through the experiment. Whether or not students have reach to the right conclusions is tested with the following questions:

Q_{L1}: Compare the values of T1 and T2 (different length, same mass), what do you observe?

A. **L1>L2 and T1>T2**
B. **L1>L2 and T1=T2**
C. **L1>L2 and T1<T2**

Q_{L2}: Compare the values of T2 and T3 (same length, different mass), what do you observe?

A. **m2<m3 and T3>T2**
B. **m2<m3 and T2=T3**
C. **m2<m3 and T3<T2**

In the process described above, students follow a deductive path [71] to reject their mistaken hypothesis on the relationship between T, L, and m, after they have collected and analyzed data, while on the same time they need to follow an inductive pathway [71], where from their given observations they need to recognize patterns and consequently draw general conclusions. Guidance will be provided to moderate performers concerning the relationship between the pendulum's period, the frequency of the pendulum and its speed. Accordingly, they move to the next phase of the scenario, the experiment, in which high performers already are. By this point low and moderate achievers should already know that the period increases as the length increases. The characterization of the student as low, moderate or high performer is not based on a single response to a challenge but is progressively constructed based on a series of reactions to different challenges that the student is facing in his or her educational path. For example, students who were not able to realize which option is minimizing the error in the estimation of the pendulum's period are only considered low performers only later in the process based on their reactions in the four challenges which follow the initial response.

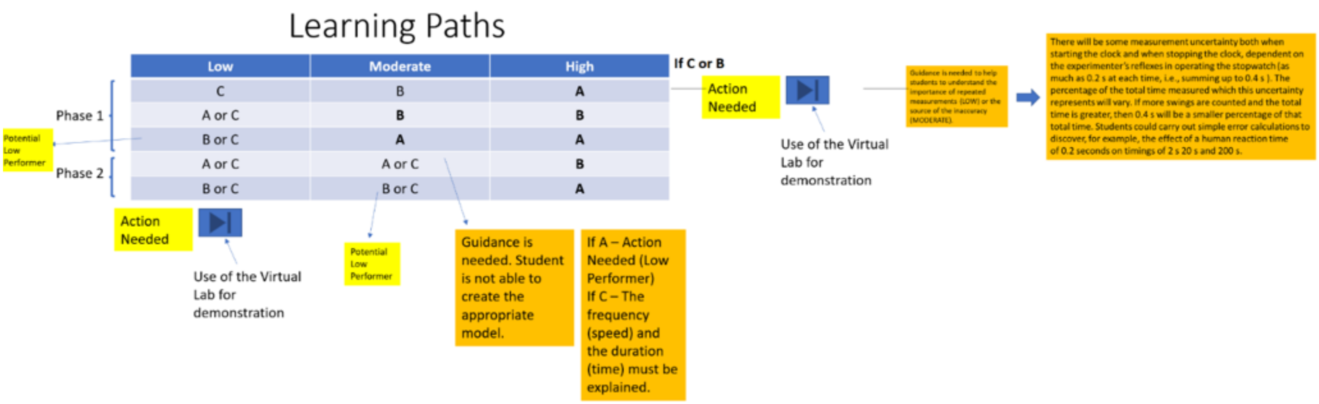


Figure 8: Based on the reactions of students a different educational path is assigned to them.

Planning and executing

In this phase students are called to perform their own experiments. As mentioned earlier, some students (low performers) have already performed experimental work, thus, given the time constraints, this might be the end of the learning pathway for those students. According to the assessment model presented in the previous section, they will receive 1p for the questions in the phases that they did not perform. At this stage students are planning and executing experiments which should in principle validate their hypotheses from the previous phases. Deductive and quantitative reasoning skills are employed in this phase, while the way that students are performing the measurements is also important, as development of critical thinking is necessary to get the most accurate experimental results. Students should perform the experiment by *varying a single parameter each time*, thus they can clearly understand its effect on the pendulum's period. Small groups of students can be formed favoring collaborative problem-solving once again. Two different experiments are expected to take place, the first investigating the relationship between the period of the pendulum and its length and the second the relationship between the period of the pendulum and its mass.

Experiment 1: Design an experiment to check your hypothesis on the relationship between the pendulum's period and length. Could you reach to a reasonable conclusion if you vary both the length and the mass simultaneously.

Use the virtual lab for your experiment and fill the following table:

m	L	t (30 oscillations)	T

It must be noted that the AI learning companion will continuously monitor the students work. For example, in this experiment the learning companion will check if the students are performing the measurement of the period with the higher accuracy (measuring the total time of a number of oscillations and then divide by the number of oscillations as it was indicated in the first phase). In case that the students are not following the correct procedure a tip could be offered: *Think about how you would measure the period to achieve greater accuracy.*

After the students have completed the experimental procedure, once more they will need to answer a question and accordingly specific tasks will be given to them in case, they have not provided the correct answer. This is shown below:

Q6: Which one of the following do you observe according to your measurements?

A. **If the mass of the pendulum remains constant and its length increases, then its period decreases. (1p)**
B. **If the mass of the pendulum increases and its length increases, then its period decreases. (2p)**
C. **If the mass of the pendulum remains constant and its length decreases, then its period decreases. (3p)**

Results and actions:

- **If B then low performer: Repeat the experiment and keep the mass constant.**
- **If A then moderate performer: Repeat the experiment more carefully this time.**
- **If C then high performer: Move on to the next experiment.**

The second experiment is more demanding as students need to identify that the mass of the pendulum does not affect its period.

Experiment 2: Design an experiment to check your hypothesis about the relationship between the mass of the pendulum and its period.
Use the virtual lab to conduct your experiment and fill in the same table as in Experiment 1.

The learning companion will check again if the students are performing the measurement of the period with the higher accuracy (measuring the total time of a few oscillations and then divide by the number of oscillations as it was indicated in the first phase). In case that the students are not following the correct procedure a tip could be offered: *Think about how you would measure the period to achieve greater accuracy.* The learning companion could also highlight the importance of changing one parameter at the time while performing the experiment in case that the students are changing at the same time both with the following tip: *If we want to find the relation between two variables, we need to keep all the other variables constant. Which are the variables in this experiment?*

Monitoring and reflecting

As was the case before, a question about the outcome of the experiment is following, and accordingly there is a classification and actions to be performed at each level, as follows:

Q7: According to your measurements, which of the following statements is correct, about the relation between the mass of the pendulum and its period?

A. **If the mass of the pendulum increases and its length remains constant, then its period remains constant. (3p)**
B. **If the mass of the pendulum increases and its length increase, then its period increases. (2p)**
C. **If the mass of the pendulum and its length increase, then its period remains constant. (1p)**

Students who will select the options B or C will receive further guidance and support to realize the process of performing the experiment while modifying only one variable at the time. The provision of scaffolds at this point is based on the functionalities of the virtual lab that allows for such interventions. In a more advanced learning environment, the AI learning companion could be informed for the students' actions directly from the lab interface.

Encountering a cognitive conflict

For most of the students, the above-mentioned phases are expected to absorb all the available time allocated to the scenario. Nevertheless, very competent students are also expected to go relatively fast through phases 1-4 of the scenario and for that reason we are introducing a fifth phase (reflection), to challenge them more. In more detail, at this last phase the goal is to check how confident the students are in the knowledge that they have acquired so far and further clarify meanings that might still be unclear for them. At first, we revisit the mass of the pendulum.

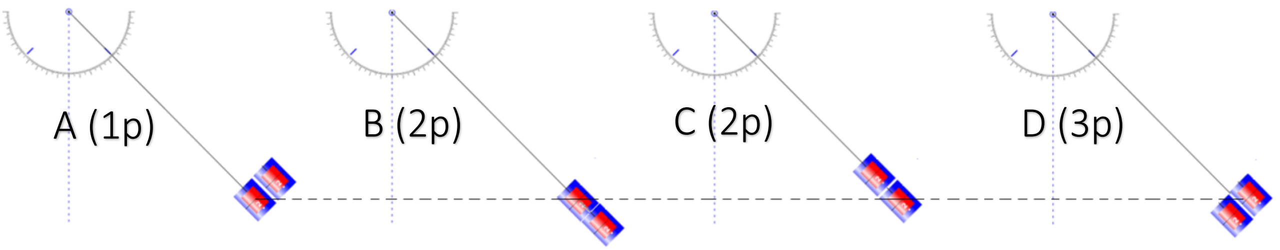
We want to assess students' critical thinking and deeper understanding on the influence of the mass on the pendulum's period, by leading them in purpose towards results which contradict their previous observations. Accordingly, students will need to identify subtle differences between the problem situation presented to them at this phase and the ones in the previous. In the following we discuss the specific example from the scenario.

Figure 9: The pendulum (remote lab) of LabsLand. It will be used by students who make it to the last phase of the scenario.

We use of the LabsLand pendulum [72] (remote lab, shown in Figure 11) for this purpose. Students have the option to increase the mass of the pendulum by adding mass on the top of the mass that is adopted to the pendulum. This is not the correct way to increase the mas of the pendulum as now the center of mass is displaced, and it is located higher.

We will take advantage of this mistake and we will support students to identify that by attaching the additional mass, the position of the center of mass is changing, which is equivalent to a change in the length of the rope, thus the period is affected.

Q8: So far, we have established that the mass of the pendulum does not affect its period. Suppose now that you need to hang a second mass from the pendulum. In your opinion, which is the best way to do that, out of the four shown in the image?



After the students have provided an answer, they are called to perform an experiment again, this time using the remote lab shown in Figure 11. The LabsLand pendulum [72] allows them to select how the second mass will be attached and then they can start timing the period of the "new" pendulum and test again if there is any dependence on the mass. A set of detailed instructions is also provided to the students, as described below:

Q9: Does the period of the pendulum depend on the suspended mass?
Instructions: Swing the pendulum at an angle of oscillation of 25˚ and determine the period of oscillation for the different masses selected. Measure the time corresponding to a total of 10 oscillations. Repeat this process twice and determine the average time. Then divide the total time by the number of oscillations and calculate the oscillation period. Present your results on a table.
Note: The results may vary depending on the angle of oscillation chosen and on the average time calculated.

Once the students have completed their measurements, they should obtain a table like the following one and then they will be provided with two answers for the question above (Q9):

	Mass	t (s) (10 oscillations)	T (s)
Experiment 1	**M (initial value)**	**13,87**	**1,387**
Experiment 2	**M+m (m is placed on the top of M)**	**12,70**	**1,270**
Experiment 3	**M+m (m is placed under M)**	**14,74**	**1,474**

A. **Oh! I made a mistake. The period depends on the mass. (1p)**
B. **My assumption was correct. The way that I am attaching the additional weight is crucial. The center of mass must remain to the same point. (3p)**

According to the answers given in the two questions of the reflection phase, the students are classified as follows:

LOW PERFORMER	MODERATE PERFORMER	HIGH PERFORMER
A	B or C	D
A	A	B

The reflection phase is indicative of the students deeper understanding as students are called to support the model that they have already created against actual experimental data which are indicating otherwise. Such an approach is in the core of the Discovery Space project, as it favors exploratory learning supported by remote and virtual labs, while students are mastering the academic content taught to them and are developing an academic mindset. The latter phase of the scenario is also indicative of the development of critical thinking, since the students are supporting their opinion with an argument rather than quit and admit they were mistaken without any further thought. Concluding the discussion about the pendulum scenario, a classification of the different learning paths, for the low, moderate and high performers is collated on Table 6.

The crucial role that the AI learning companion plays becomes obvious by looking on Table 6. It would have been impractical to write down all the possible outcomes of the multiple-choice questions and design a learning path for each one, yet by not doing so it means that the above classification is not including a vast number of combinations. For example, in which of the three categories a student who gave the following combinations of answers (A, C, C, B, A, C, C, C, B) belongs to? The learning companion though can be trained to recognize different learning patterns by accumulating more and more data and design a learning path accordingly, thus the above classification serves as a guide to the AI learning companion. It is worth noting again that the teacher can watch the students as they are going through the learning path, as the AI learning companion provides feedback at every time.

Table 10: An overall description of the paths of the low, moderate and high performers, according to their reactions to the challenges posed by the AI learning companion. In fact, here we are presenting the three reference paths. In the real classroom setting numerous paths will emerge as the reactions of the students will vary from the reference paths, moving from one level to the other.

<table>
<tr><th>Question</th><th>LOW PERFORMER</th><th colspan="2">MODERATE PERFORMER</th><th>HIGH PERFORMER</th></tr>
<tr><td>1</td><td>C</td><td colspan="2">B</td><td>A</td></tr>
<tr><td>2</td><td>A or C</td><td colspan="2">B</td><td>B</td></tr>
<tr><td>3</td><td>B or C</td><td colspan="2">A</td><td>A</td></tr>
<tr><td>4</td><td>A or C</td><td>A or C</td><td>B</td><td>B</td></tr>
<tr><td>5</td><td>B or C</td><td>A</td><td>B or C</td><td>A</td></tr>
<tr><td>6</td><td>B</td><td colspan="2">A</td><td>C</td></tr>
<tr><td>7</td><td>B</td><td colspan="2">A</td><td>C</td></tr>
<tr><td>8</td><td>A</td><td colspan="2">B or C</td><td>D</td></tr>
<tr><td>9</td><td>A</td><td colspan="2">A</td><td>B</td></tr>
</table>

Our goal is the simultaneous development of deeper learning and the development of 21st century skills on one hand, with mastery of academic knowledge on the other. A crucial role towards the achievement of this goal play both the structure of the scenario, which should be built in a way that allows students to create new knowledge based on what they have been taught so far, as well as the AI learning companion. The latter will guide the student through the different phases of the scenario and provide targeted feedback addressing his/her specific misconceptions.

The scenario in a compact form, along with the different educational goals of each phase is shown on **Error! Reference source not found.**.

The learning paths for the high, moderate and low performers are shown in Error! Reference source not found., Error! Reference source not found. and in Figure 14, respectively. A more complicated scenario, dealing with a phenomenon from Quantum Physics, the photoelectric effect, has also been prepared for the purposes of the project. This scenario is addressing to senior year students, while the contradictions between classical and quantum physics offer an ideal situation for practicing critical thinking and understand how to use experimental data as a guide for creating new knowledge and eventually master academic content.

5.2. Photoelectric Effect

This scenario is currently built on a power point but for harmonisation purposes, in this deliverable, the content is migrated to this annex.

The overall goals of the scenario are:
Describe the photoelectric effect and the setup necessary for its observation
Use the PhET platform to perform virtual experiments
Spot the weaknesses of classical Physics in the description of the photoelectric effect
Understand the photoelectric equation and the relative graphs
Learn about different applications of the photoelectric effect

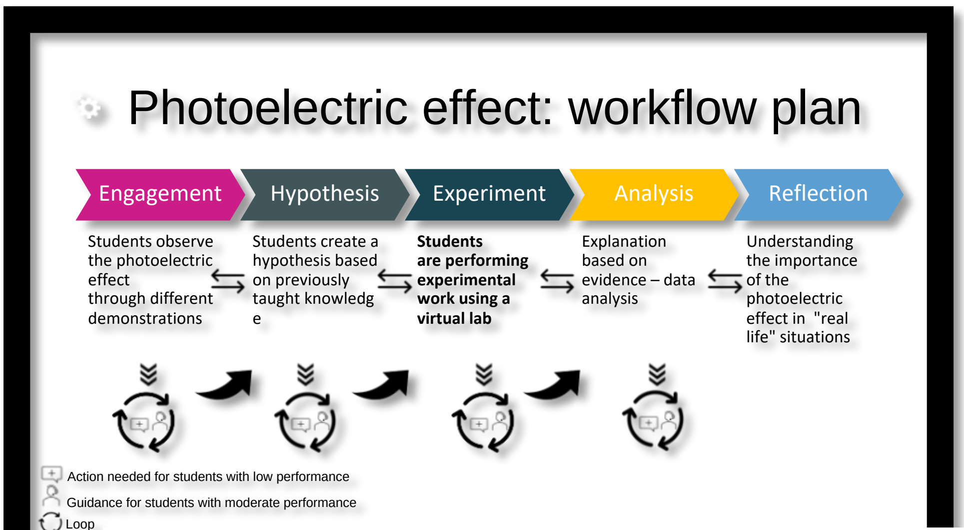


Figure 10 Photoelectric effect scenario workflow plan.

The work plan is presented to the teachers highlighting the expected workflow for each of the students according to their competence profile

Phase 1: Engagement of the students

The photoelectric effect is introduced to the students through one of its applications. A circuit consisting of a photocell and an amperometer is presented to the students. Then the students are asked to shine light (sunlight for example) onto the surface of the cell and observe the indication on the amperometer. Accordingly, the surface of the cell is covered and the indication on the amperometer is recorded again by the students. Why do you think there is current (flow of electrons) in the circuit?

Another demonstration in order to intrigue the students and try to make them get an experiential understanding of the photoelectric effect through a classical analogue is the following: An object weighting around 2.5 Kg is placed onto a table. The teacher is distributing very light ping-pong balls to the students and asks them to throw them *simultaneously* to the object in order to make it fall from the table. Then a basketball is thrown by the teacher to the object and the object falls off the table. The object falling from the table symbolizes the release of an electron.

To be noted Previous knowledge of wave theory and Planck's hypothesis for the black body radiation is assumed

Two questions are presented to the students:
Q1. Assume that the Sun is behaving like a black body, then according to Planck's hypothesis:
The Sun emits radiation continuously
Radiation gets emitted by the Sun only in discrete packets

A. Both can happen

Q2. What do you think happens so that the amperometer records current? :

A. Some emitted packets by the Sun have enough energy to release electrons from an atom of the cell
B. No matter what the energy of the packet is, if we wait for a long time electrons will flow on the circuit anyway, since several packets would have been absorbed
C. Both can happen

The path for the different students is presented in the following table:

Table 11 Table indicating the students' different paths.

	Low	Moderate	High
1	A or C	B	B
2	B	C	A
Actions	Repeat and exaplain black body radiation emission-Planck hypothesis – **slide 7**	Provide guidance in conjuction with demonstration 2 – **slide 7**	Move to the next phase

Students are provided the necessary guidance depending on their answer.

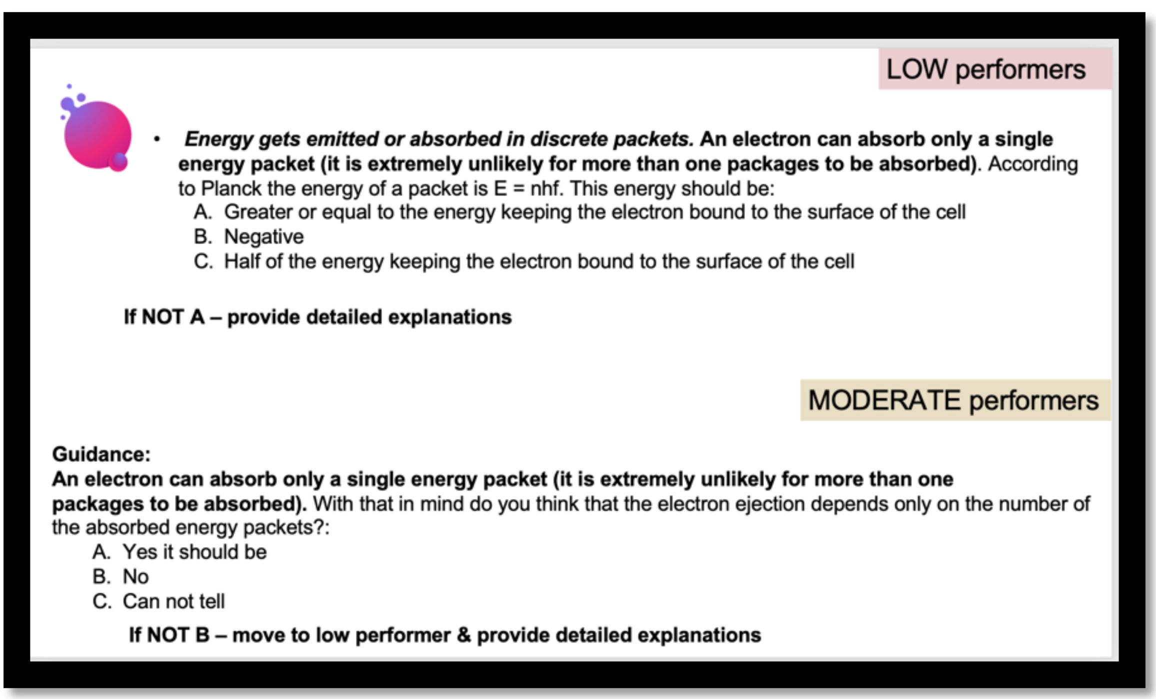


Figure 11 Guidance to students

Phase 2: Hypothesis

In this phase students are called to create and test a hypothesis. The critical parameters for the understanding of the photoelectric effect have to be defined, namely:

- The frequency (wavelength) of the light and accordingly its connection to the photon energy
- The intensity of the light and how its previously given definition should be modified in order to interpret the observations

A new set of questions are presented to the students:

Q3. Consider the demonstration with the ping-pong balls and the basketball in the previous section. The object falling of the table symbolizes the release of electrons. Then:

A. The number of balls is important for the release of electrons – with each hit the object is slightly moving till it falls off
B. The kind of ball that we are throwing is the crucial parameter – no matter how many ping pong balls we are going to throw the object will never fall
C. Both the number of balls and the kind of ball can release electrons

Q4. With Planck's hypothesis in mind, which of the following you think is correct:

D. The mass of the ball should correspond to the frequency of a packet and the number of balls to the intensity of a beam of such packets
E. The exact opposite from what is mentioned above is correct
F. Neither of the previous is correct

Depending on the answer students are again directed to more guidance:

Table 12 Paths definition for the hypothesis phase according to the answer to questions Q3 and Q4

	Low	Moderate	High
1	A	C	B
2	B or C	B or C	A
Actions	Provide explanations and guidance -actions in phase 1 **slide 7 & slide 11**	Provide guidance – **slide 11** - Move to the next phase	Move to the next phase

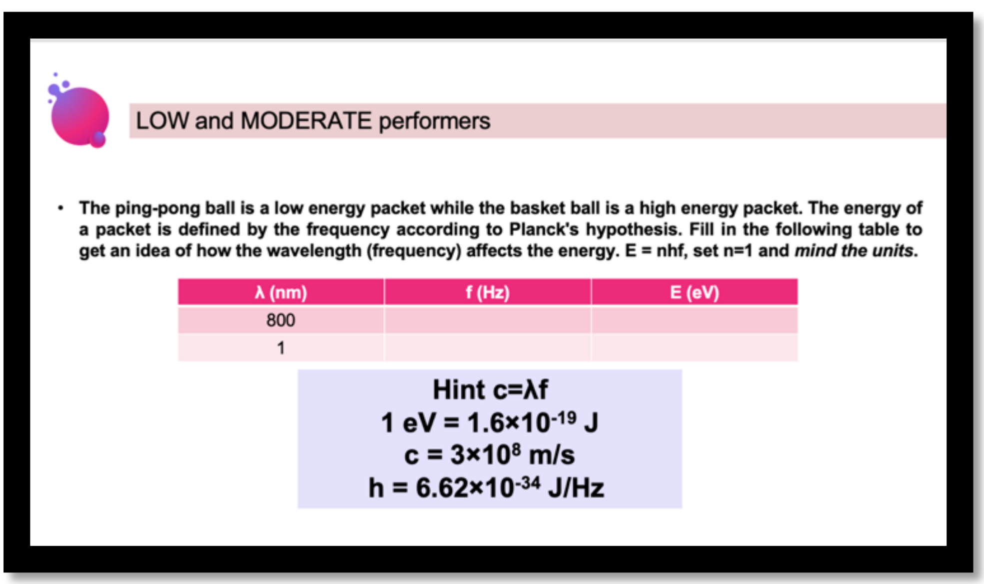


Figure 12 Guidance provided to students during the hypothesis generation phase.

A summary for the actions during phase 1 and phase 2 is presented below

Table 13 Summary of Phase 1 and Phase 2 student's trajectories.

		Low	Moderate	High
Phase 1	Q1	A or C	B	B
	Q2	B	C	A
Phase 2	Q3	B	A	A
	Q4	B or C	B or C	A
Action		Extended use of the PhET platform – provide guidance and explanations at all phases	Extended use of the PhET platform – provide guidance	Use the PhET platform - advanced questions – applications of the photoelectric effect in the reflection phase

Phase 3: Experiment - Gather evidence from observations

Students are then invited to start the experimental phase

- ❑ Use the virtual lab https://phet.colorado.edu/sims/cheerpj/photoelectric/latest/photoelectric.html?simulation=photoelectric to test the hypotheses made in the previous phase and either validate them or reject them.
    - ❑ Which is the crucial parameter for the ejection of electrons?
    - ❑ What happens as the intensity of the light is changing?
    - ❑ What is the impact of the applied voltage on the recorded current?
    - ❑ What do you observe as the frequency of the light increases?

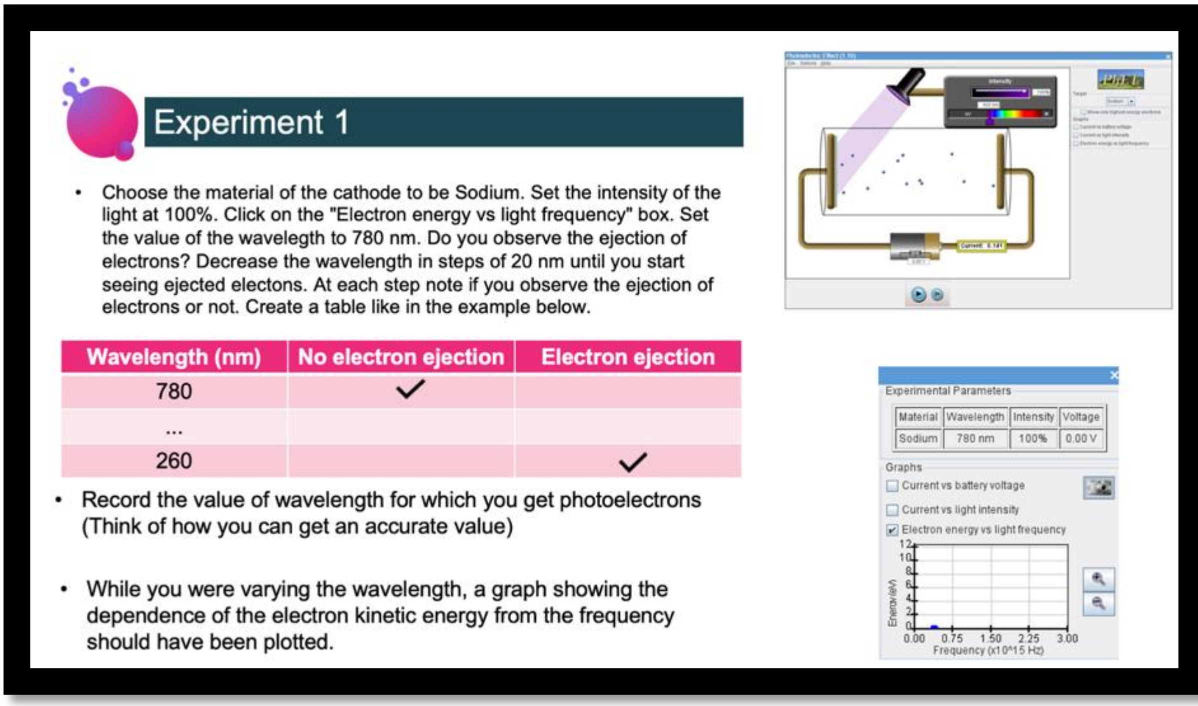


Figure 13 Experiment 1 instructions.

Experiment 1 - Results

Q5. According to your measurements:

A. The ejection of electrons depends on the frequency and there is a critical value
B. The ejection of electrons depends on the frequency and the intensity
C. The ejection of electrons depends only on the intensity

Q6. As you decrease the wavelength the energy of the light beam is:

A. Decreasing
B. Increasing
C. Remaining the same

Q7. As the wavelength decreases, the number of ejected electrons:

A. Increases
B. Decreases
C. I can't tell while the intensity is set at 100%

Q8. The value for which you observe the ejection of electrons in the plot and the one obtained from your table:

A. Are very close to each other
B. Are completely different
C. Are the same if one of them is multiplied by ten

Table 14 Different path for the students according to their options.

Experiment 1 - Results

	Low	Moderate	High
1	C	B	A
2	A or C	B	B
3	B or C	A	A
	B or C	A	A
Actions	Provide detailed explanations – **slide 17**	Provide guidance – **slide 17** – move to experiment 2	Move to experiment 2

Different guidance is provided for each group of students

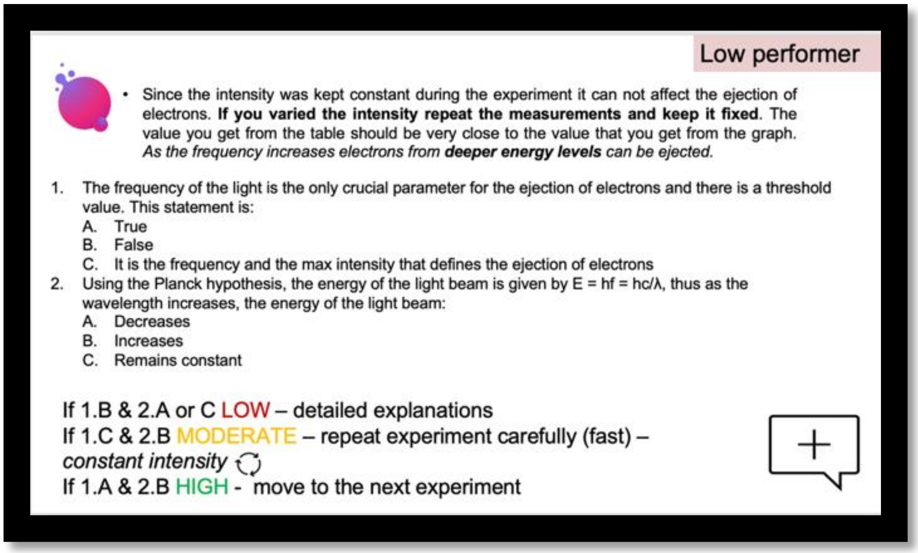


Figure 14 Guidance for students depending on their choices.

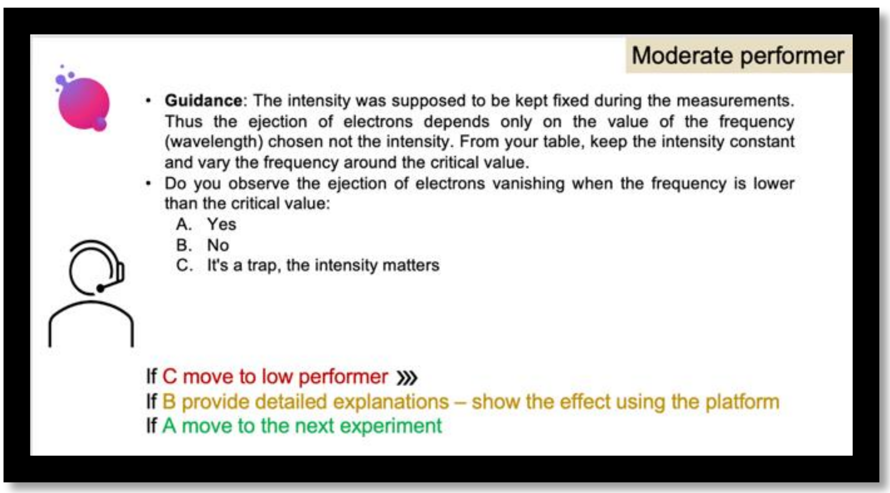


Figure 15 Guidance to the other group of students.

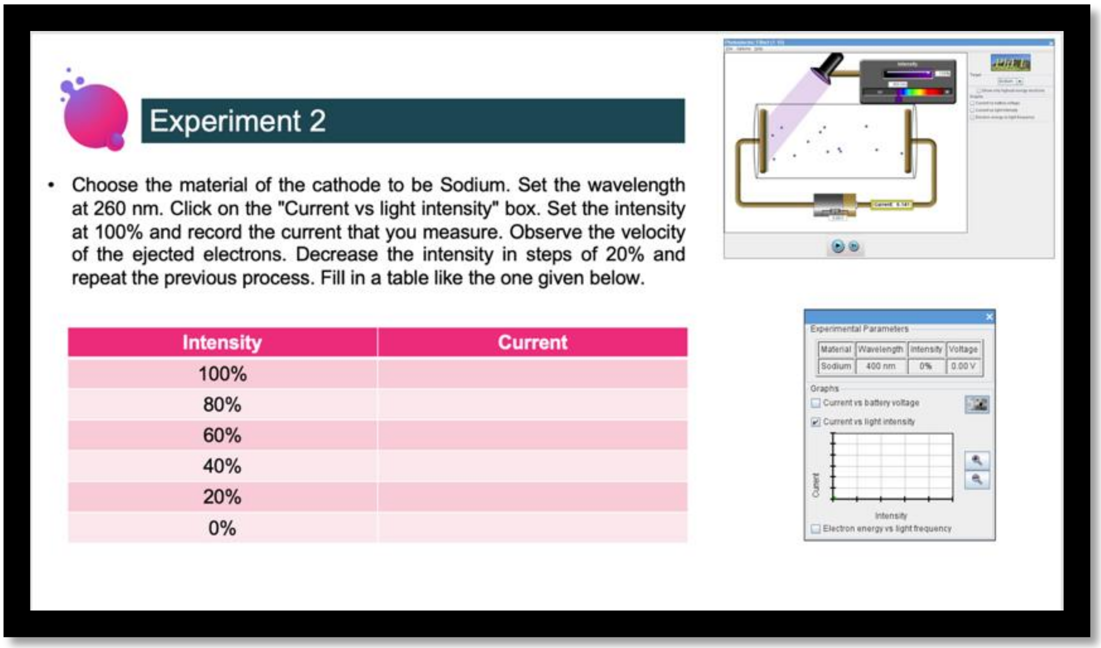


Figure 16 Instructions for Experiment 2.

Experiment 2 - Results

Q9. According to your measurements:

A. As the intensity decreases the number of the ejected electrons increases
B. As the intensity decreases the number of the ejected electrons decreases
C. Nothing is changing

Q10. As the intensity decreases, the ejected electrons become:

A. Faster
B. Slower
C. Their kinetic energy remains the same

Q11. The plot that you obtained:

A. Contradicts the values recorded on your table
B. Is in line with the values on your table
C. I can't tell unless I vary the wavelength as well

Table 15 Different path for the students according to their options.

Experiment 2 - Results

	Low	Moderate	High
1	C	B	B
2	A or B	B	C
3	A or C	B	B
Actions	**Slide 22** – provide detailed explanations	**Slide 23** - Provide guidance – move to experiment 3	Move to experiment 3

Different guidance is provided for each group of students

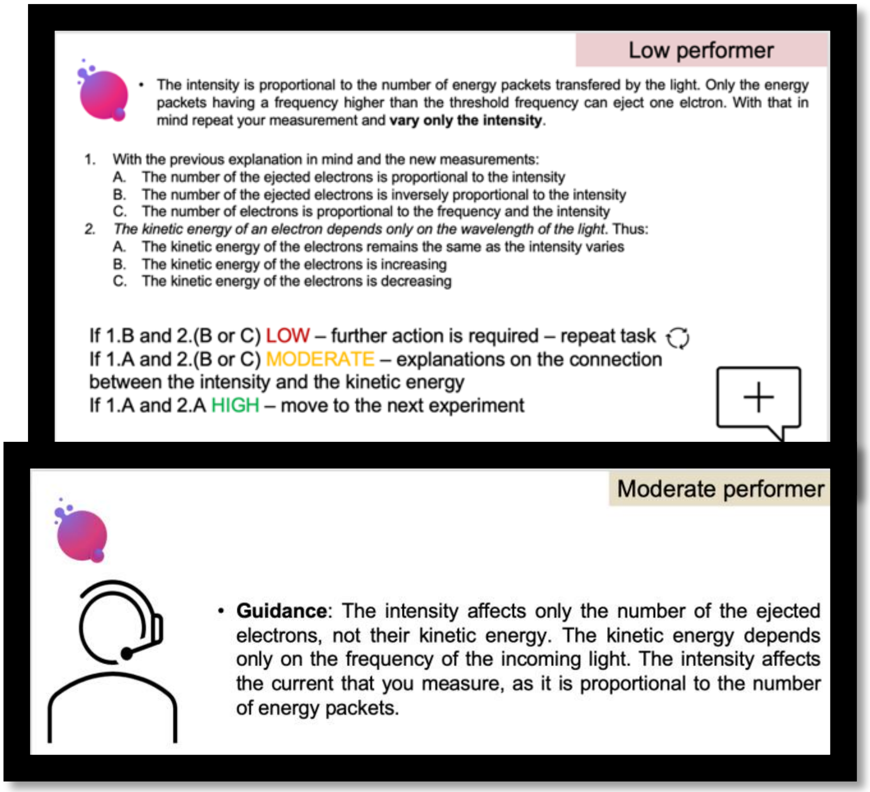


Figure 17 Guidance for the students depending on their choices on Experiment 2

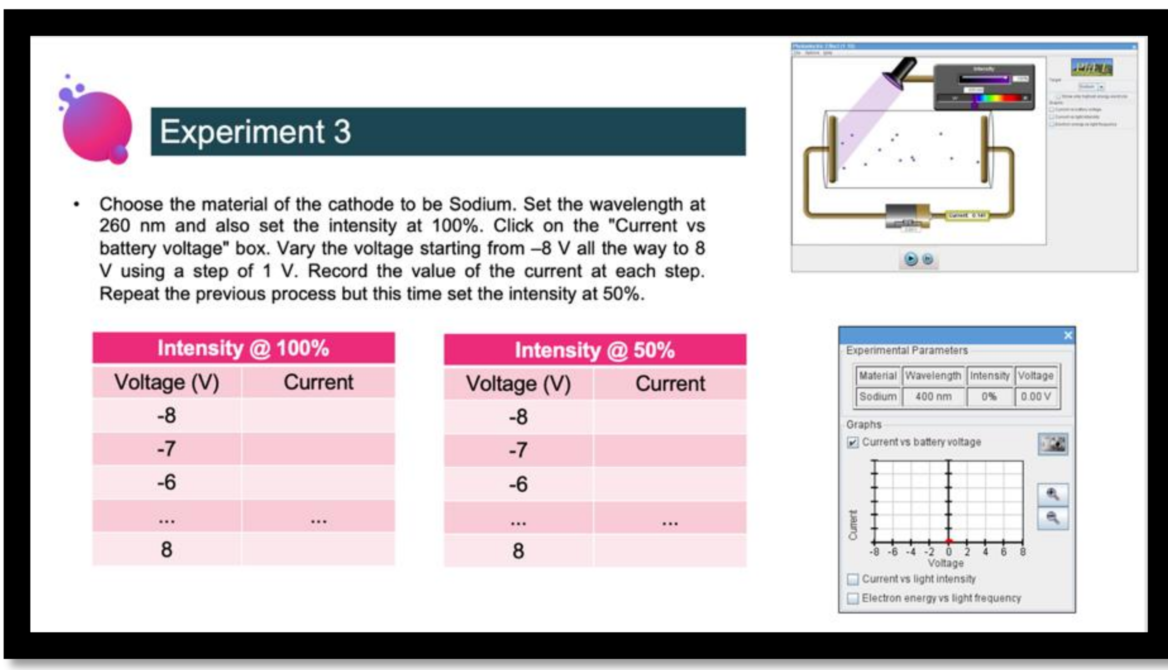


Figure 18 Instructions for Experiment 3

Experiment 3 - Results

Q12. When the value of the voltage is negative:
- A. The cathode is positively charged
- B. The cathode is negatively charged
- C. The cathode is neutral

Q13. From the plot you get with the intensity at 50%, what do you observe:
- A. The current drops at half
- B. The current remains the same
- C. The current gets doubled

Q14. From your measurements:
- A. There is cut-off voltage ($-V_0$) after which no electrons can make it to the anode
- B. Electrons can make it to the anode only when the voltage is positive
- C. There is electron ejection only when the applied voltage is positive

Table 16 Different path for the students according to their options on Experiment 3

Experiment 3 - Results

	Low	Moderate	High
1	B or C	A	A
2	B or C	A	A
3	C	B	A
Actions	Provide detailed explanations – **slide 27**	Provide guidance – **slide 28** – move to the next phase	Move to the next phase

Guidance is provided to the students according to their choices:

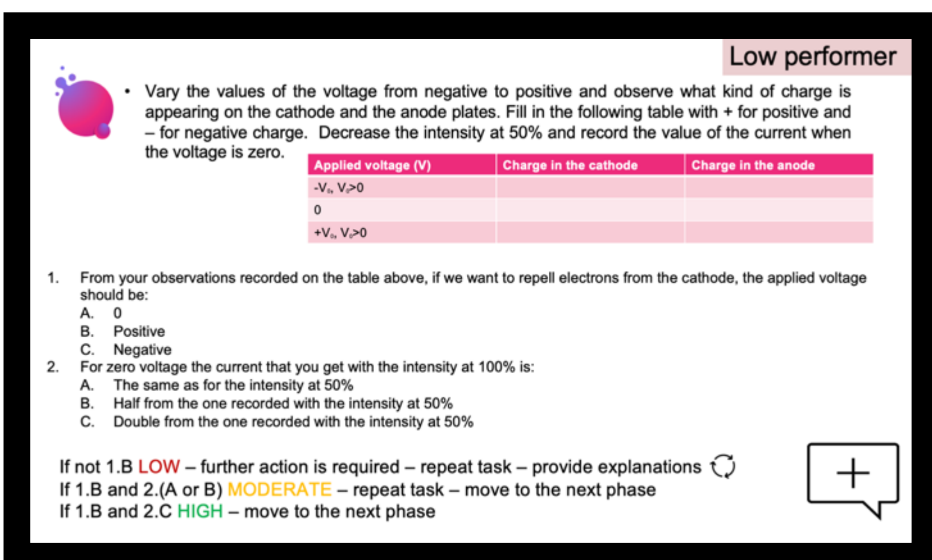


Figure 19 Guidance provided to students in need of more in-depth support.

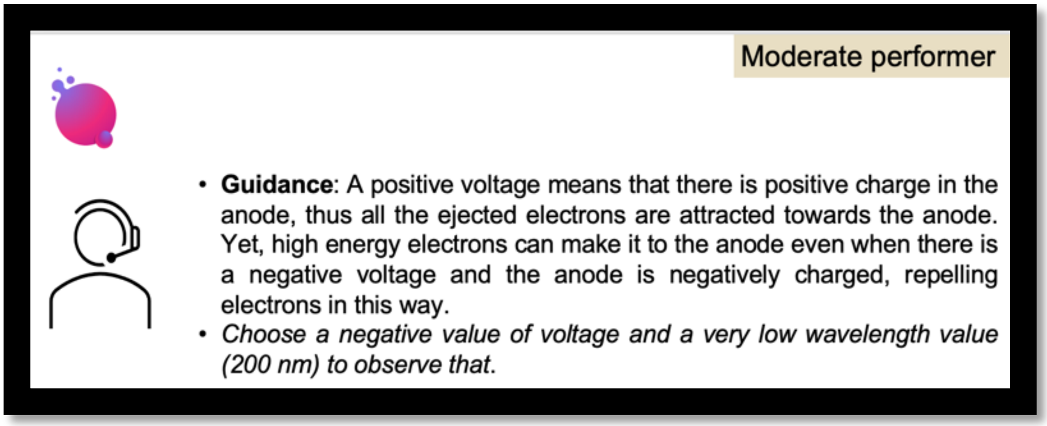


Figure 20 Guidance to support students with a need for moderate support

In the next phase students will start to prepare their explanations based on the evidence collected:

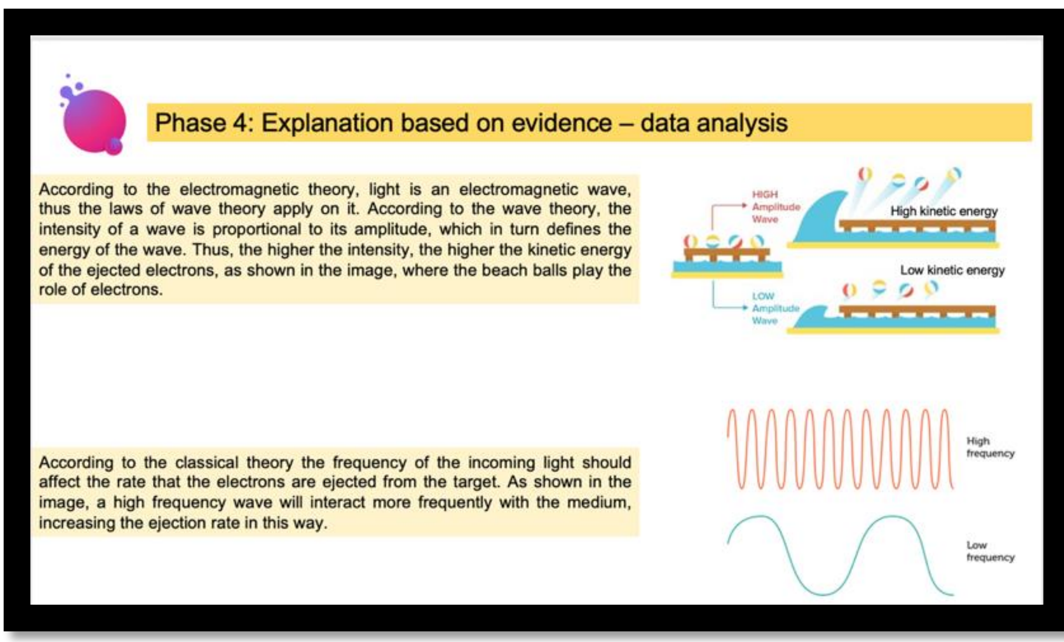


Figure 21 Information provided to start Phase 4 (Images @Khan Academy).

A new set of questions is presented

According to the wave theory, if an electron absorbs cumulatively the amount of energy needed it will be eventually ejected. In other words, no matter what the frequency of the light is, an electron can in principle be ejected. According to your findings from Phase 3, this statement is:

A. True
B. False
C. The ejection should depend both on the frequency and the intensity

According to the arguments given above, the maximum kinetic energy of the ejected electron will be defined by the intensity of the incoming light. Your findings are:

A. Validating this statement
B. Contradicting this statement
C. Showing that both the frequency and the intensity define the maximum kinetic energy

Finally, the current that you are recording should depend on the selected frequency, according to the previous. From your findings:

A. The current depends on the intensity
B. The current depends on both the frequency and the intensity
C. My findings are in line with wave theory

Table 17 Next set of actions depending on the students' answers.

	Low	Moderate	High
1	A	C	B
2	A	C	B
3	C	C	A
Actions	Repeat experiments 1,2 – **slide 14 & slide 24**	Provide explanations - **slide 18 & slide 23**	Move to the next phase

A new explanation is presented, and students are asked again to answer a set of questions:

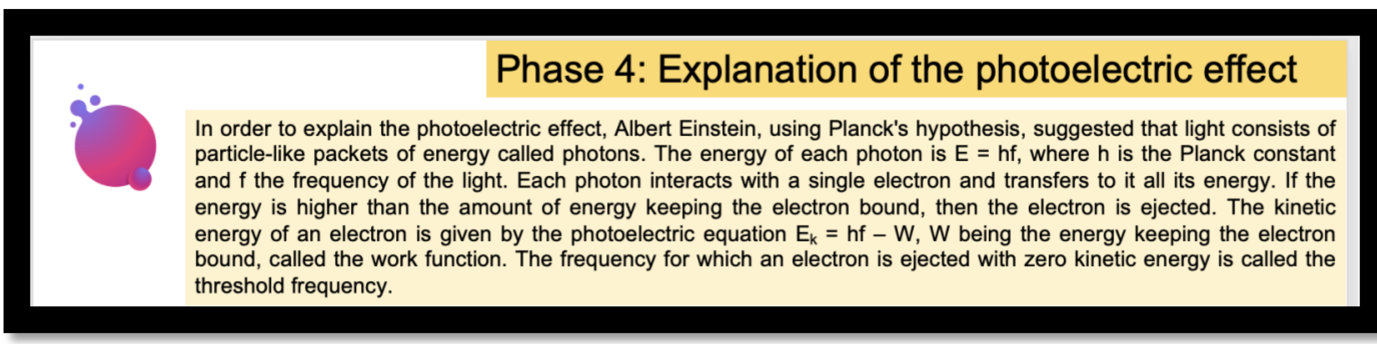


Figure 22 Initial explanation for phase 4

Q15. According to the above explanation and your findings from phase 3:

A. Electron ejection takes place when $f>f_0$, f_0 being the threshold frequency
B. Electron ejection takes place when $f<f_0$, f_0 being the threshold frequency
C. I cannot tell

Q16. From the graph you obtained and the photoelectric equation, the value of the threshold frequency should be:

A. f0=W/h
B. f0 = hW
C. f0 = W

Q17. According to the above explanation, light in the photoelectric effect behaves like:

A. Wave
B. Particle
C. Both

Table 18 New actions related to the previous questions

	Low	Moderate	High
1	B or C	A	A
2	B or C	A	A
3	A or C	C	B
Actions	Repeat experiments 1,2 – provide detailed explanations – **slide 33**	Provide explanations – **slide 33**	Move to the next phase if high performer so far

Further guidance is provided to the students depending on their answers.

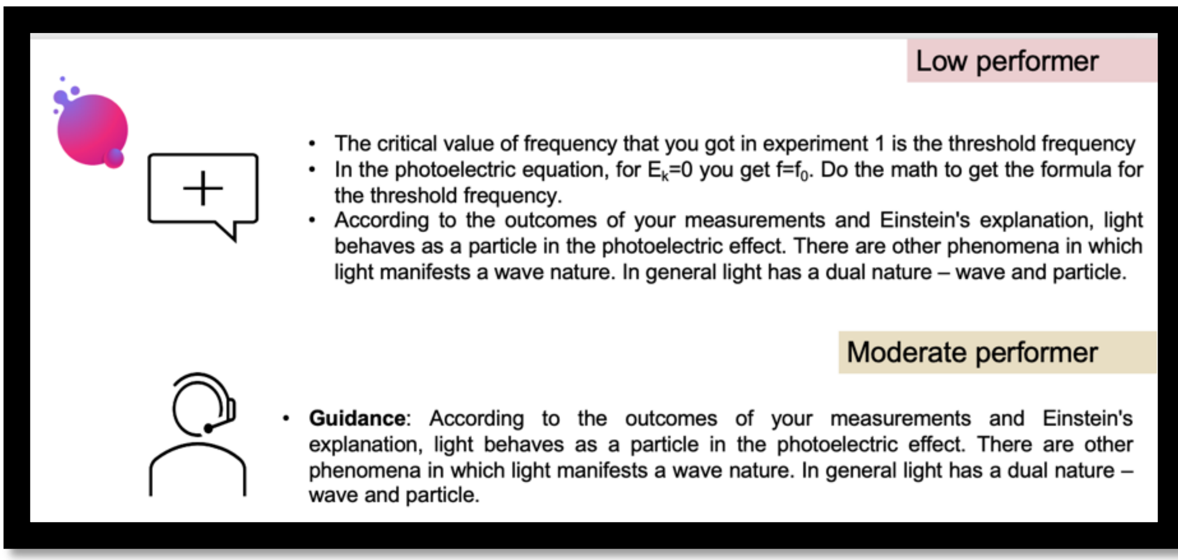


Figure 23 Guidance for the students during Phase 4

Phase 5 – Reflection - ***Maximum kinetic energy – cutoff voltage***

Some questions are presented to provoke students' reflection on what they have learned so far:

Q18. What should be the maximum kinetic energy of an electron, assuming a cut-off voltage V_0:

A. hV_0
B. hV_0/e
C. eV_0

Q19. From the photoelectric equation, the formula giving the threshold frequency and your answer in the previous question, the cut-off voltage should be equal to:

A. V0 = hf0/2
B. V0 = h(f-f0)/e
C. V0 = hf

Q20. The applied voltage helps us:

A. To measure a (critical) kinetic energy value
B. To eject electrons from the target
C. Because it is equal to the photon energy

Phase 5 – Reflection - *Use the photoelectric effect to identify unknown substances*

Q21.You have a piece of metal of an unknown element, and you would like to figure out from which element it consists of. You irradiate it with light, the frequency of which is 6.2 × 1014 Hz. The kinetic energy of the ejected electrons is measured at 3.28 × 10-20 J. Using the table given below, which is the element of the metal:

Metal	Work function Φ (Joules, J)
Calcium, Ca	4.60×10^{-19}
Tin, Sn	7.08×10^{-19}
Sodium, Na	3.78×10^{-19}
Hafnium, Hf	6.25×10^{-19}
Samarium, Sm	4.33×10^{-19}

A. Calcium
B. Sodium
C. Samarium

Q22. If the piece of the metal is an alloy, consisting of several elements, is the frequency selected above suitable in order to identify other metals listed on the table:

A. Yes
B. No, we need a lower frequency
C. No, we need a higher frequency

Table 19 Final activity actions

Reflection phase		Low	Moderate	High
Max kinetic energy – cutoff voltage	1	A or B	C	C
	2	A or C	B	B
	3	B or C	B	A
Use the photoelectric effect to identify an unknown sub stance	1	A or C	B	B
	2	B	A	C
Actions		Provide the correct answers and explanations – repeat a phase if there is still time for low performers		No further tasks

5.3. Newton's 1st and 2nd Laws

This scenario is currently built on a power point but for harmonisation purposes, in this deliverable, the content is migrated to this annex.

The overall goals of the scenario are:

1. Understand the meaning of force – vector character
2. Become familiar with mathematical operations of vectors.
3. Understand the importance of Newton's laws and the equations describing them.
4. Be able to describe free fall.

Phase 1: Engagement of the students

Two questions are introduced to ignite the engagement of the students to the topic:

Q1. Imagine that you would like to guide a robot to push a very heavy box. Which info you need to pass to the robot?

A. How hard it should push.
B. In which direction it should push.
C. Both how hard it should push and in which direction.

Q2. You want to calculate the net force of several co-axial forces. You get the result ΣF=-10 N. What does this mean?

A. My calculation is wrong.
B. The direction of the net force is opposite to the direction defined as positive.
C. The net force is not a vector anymore.

The path for the different students is presented in the following table:

Table 20 Table indicating students different paths related to their answers to Q1 and Q2.

Question	LOW	MODERATE	HIGH
1	A or B	C	C
2	C	A	B
Actions	Provide explanations & simple questions. Go to slide 5	Provide explanations. Go to slide 6	Move on

Students are provided the necessary guidance depending on their answer.

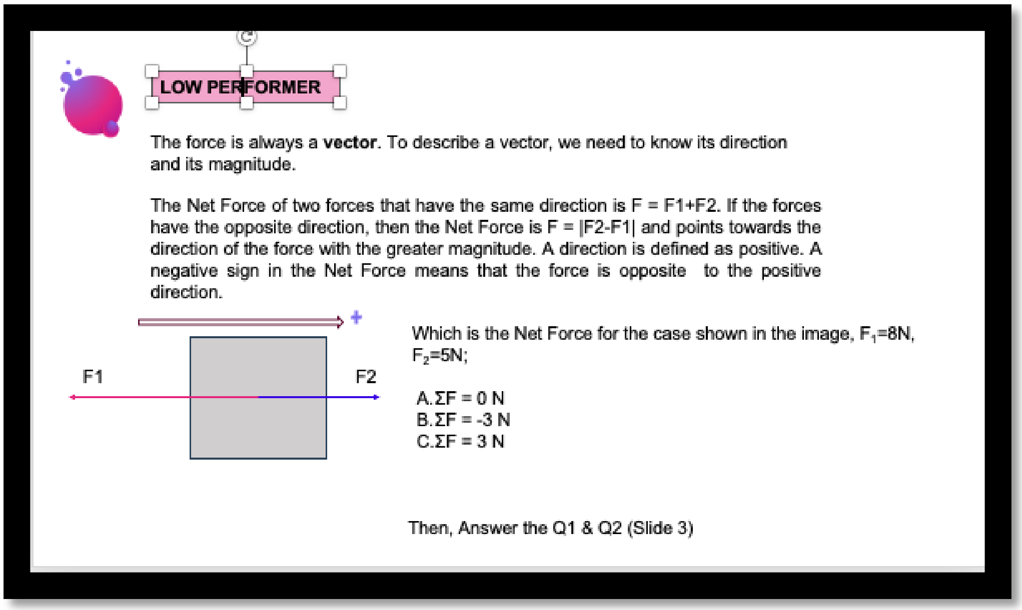


Figure 24 Guidance to students needing more in-depth support.

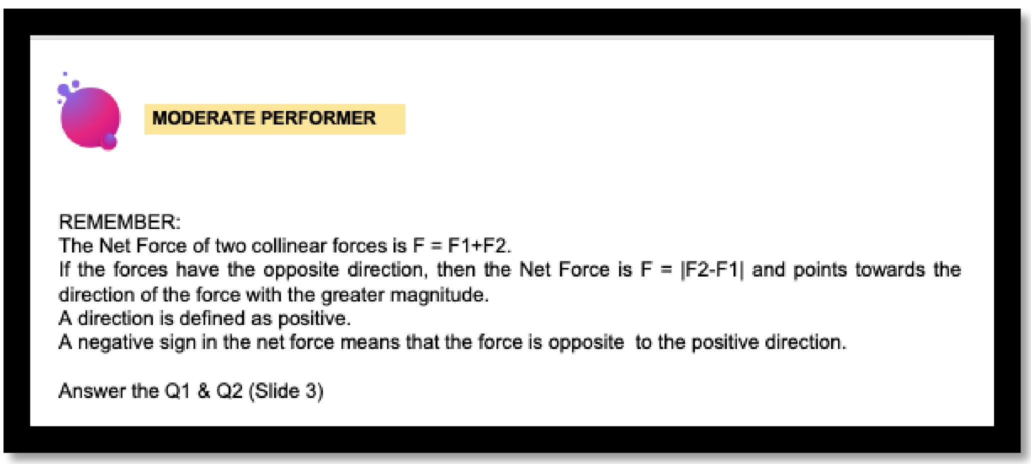


Figure 25 Students in need of moderate support.

Phase 2a: Hypothesis – 1st Newton's Law

In this phase students are called to create and test a hypothesis. They then have to answer a couple of questions that will support them during this phase.

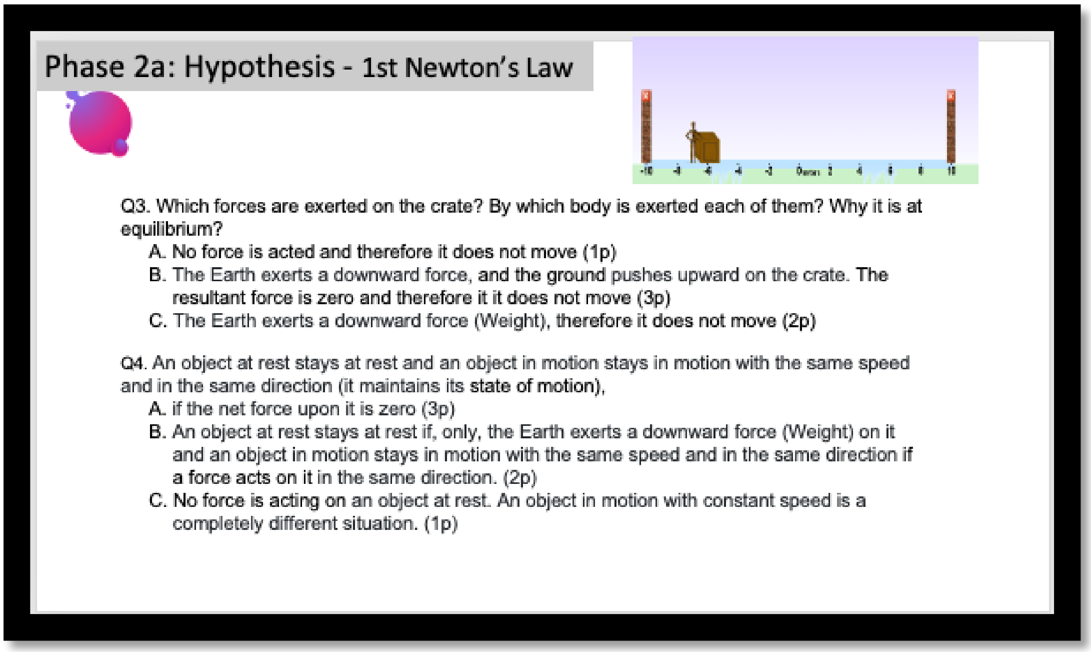


Figure 26 Questions to support students during the creation of their hypothesis.

The path for the different students is presented in the following table:

Table 21 Paths definition for the hypothesis phase according to the answers to Q3 and Q4.

Question	LOW	MODERATE	HIGH
1	A	C	B
2	C	B	A
Action	Provide explanation / Action. Go to slide 9.	Provide explanations. Go to slide 10.	Move on

Students are provided the necessary guidance depending on their answer.

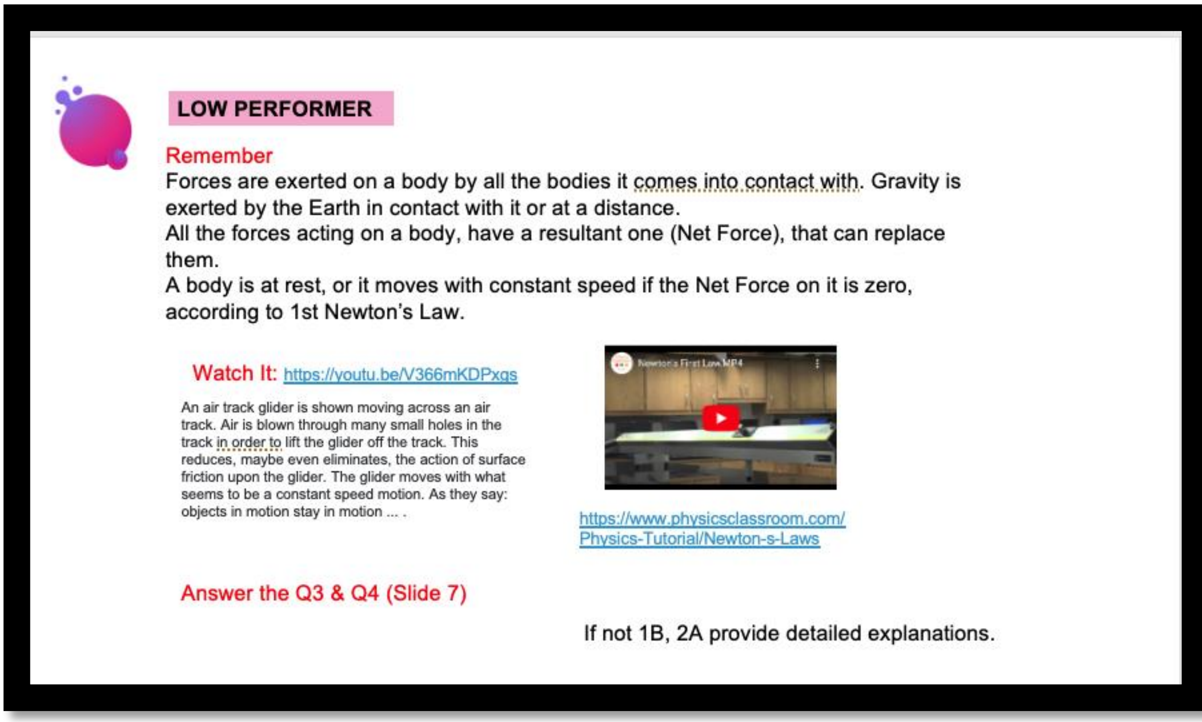


Figure 27 Guidance given to students needing more support to move forward.

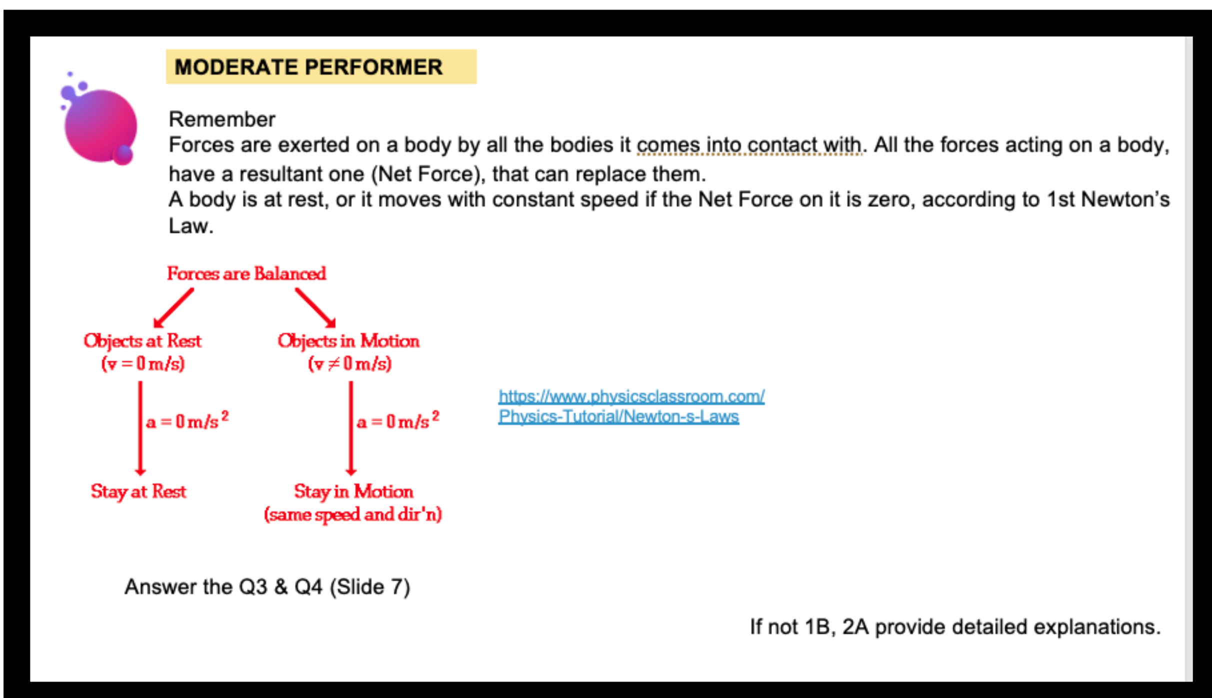


Figure 28 Guidance provided to students in need of more moderate support.

Phase 2b: Hypothesis – 2nd Newton's Law

Students are now invited to dive into Newton's second law

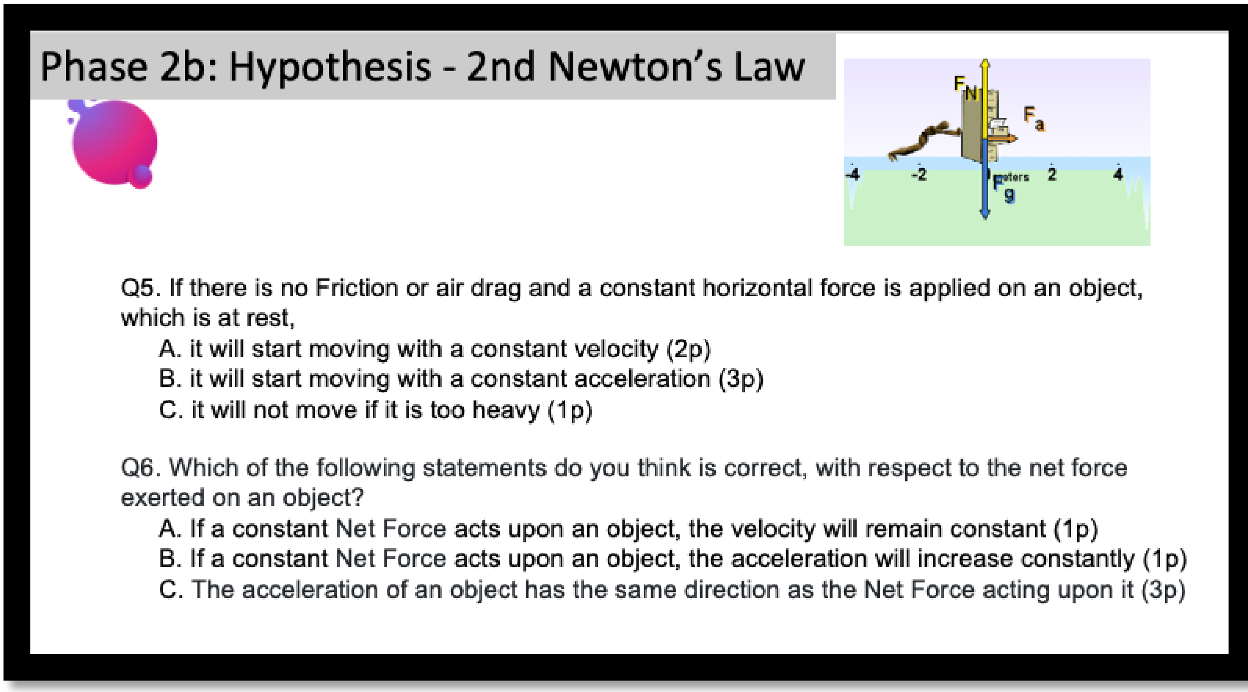


Figure 29 Questions inviting students to reflect on Newton's second law.

The path for the different students is presented in the following table:

Table 22 Paths definition for the hypothesis phase according to the answers to Q5 and Q6..

	LOW	MODERATE	HIGH
1	C	A	B
2	A	B	C
Action	Provide explanation / Action	Provide explanations	Move on

Student are presented guidance according to their needs:

LOW & MODERATE PERFORMER

Remember
Newton's second law of motion states that the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.
This verbal statement can be expressed in equation form as follows: $\Sigma F = ma$
(https://www.physicsclassroom.com/Physics-Tutorial/Newton-s-Laws)

Answer the Q5 & Q6 (Slide 11)

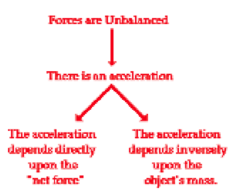
If not 1B, 2C provide detailed explanations.

Figure 30 Guidance to the students for the study of the 2nd Newton's Law.

LOW & MODERATE PERFORMER

Remember
Newton's second law of motion states that the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.
This verbal statement can be expressed in equation form as follows: $F_{net} = m \times a$

If a constant force acts upon an object, which is at rest, it will start moving with constant acceleration.



https://www.physicsclassroom.com/Physics-Tutorial/Newton-s-Laws

Answer the Q5 & Q6 (Slide 11)

If not 1B, 2C provide detailed explanations

Figure 31 Further support to the students.

After finalising their hypothesis phase students are now invited to commence the experimental phase:

Phase 3a: Experiment - 1st Newton's Law

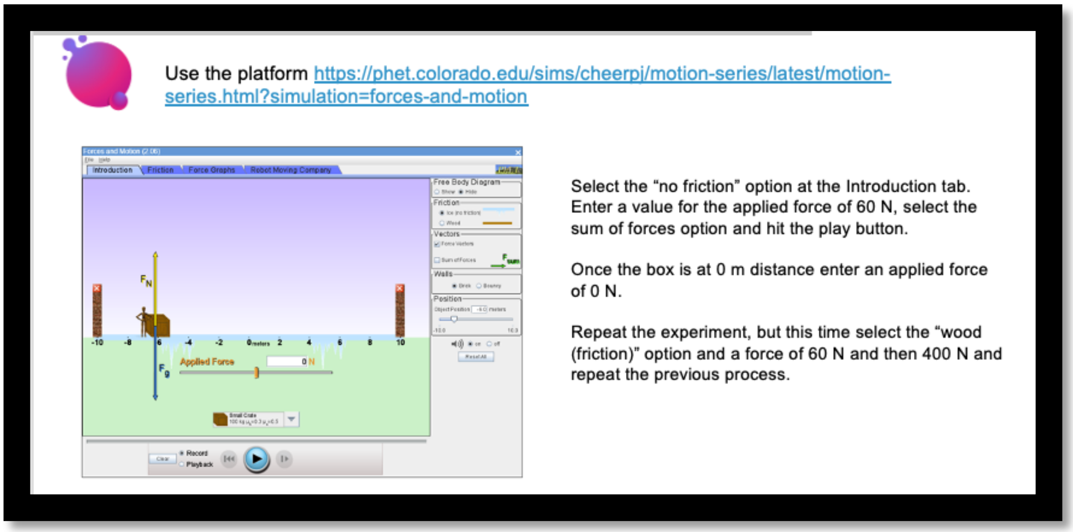


Figure 32 Instructions for the students on the use of the virtual lab.

A series of questions are now presented to verify if the students can properly interpret the acquired results:

Q7. What do you observe when you select the “friction” option.

A. The box is not moving.
B. The box is either moving slower until it stops or not moving at all.
C. The box is moving faster.

Q8. When you select the “no friction” option and the net force is zero:

A. The box will never stop moving.
B. The box will stop moving at some point because it is not possible to move forever.
C. It depends on the forces which are perpendicular to its direction of motion.

Q9. Which conclusion you draw from your experiment:

A. When the sum of forces exerted in a body is zero it takes a long time for it to stop moving
B. When the sum of forces exerted in a body is zero, the body is not moving.
C. When the sum of forces exerted in a body is zero the body is either not moving or if it moves then it will never stop moving

A new path is then designed for the students according to their choices:

Table 23 Paths definition for the hypothesis phase according to the answers to Q7, Q8 and Q9.

	LOW	MODERATE	HIGH
1	C	A	B
2	C	B	A
3	A	B	C

Actions	Repeat experiment – provide explanations	Provide guidance	Move on

Support is provided during this phase according to the student's needs:

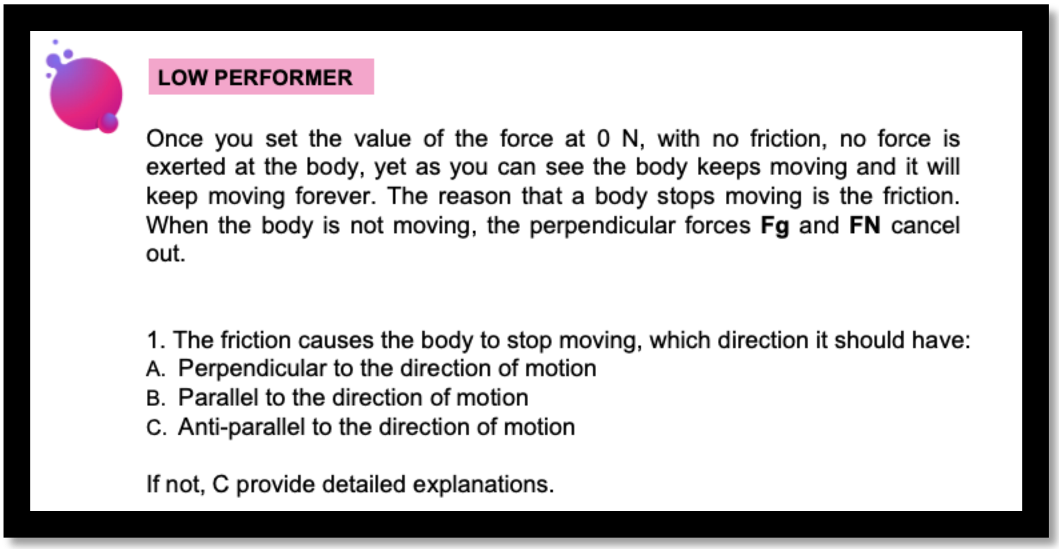


Figure 33 Support given to students in need of more support.

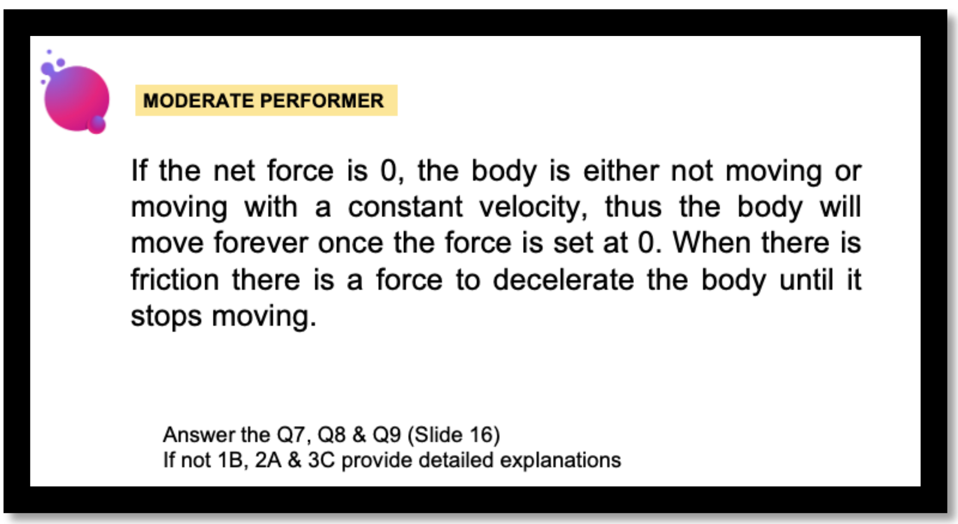


Figure 34 Support given to students in need of moderate support.

Phase 3b: Experiment – 2nd Newton's Law

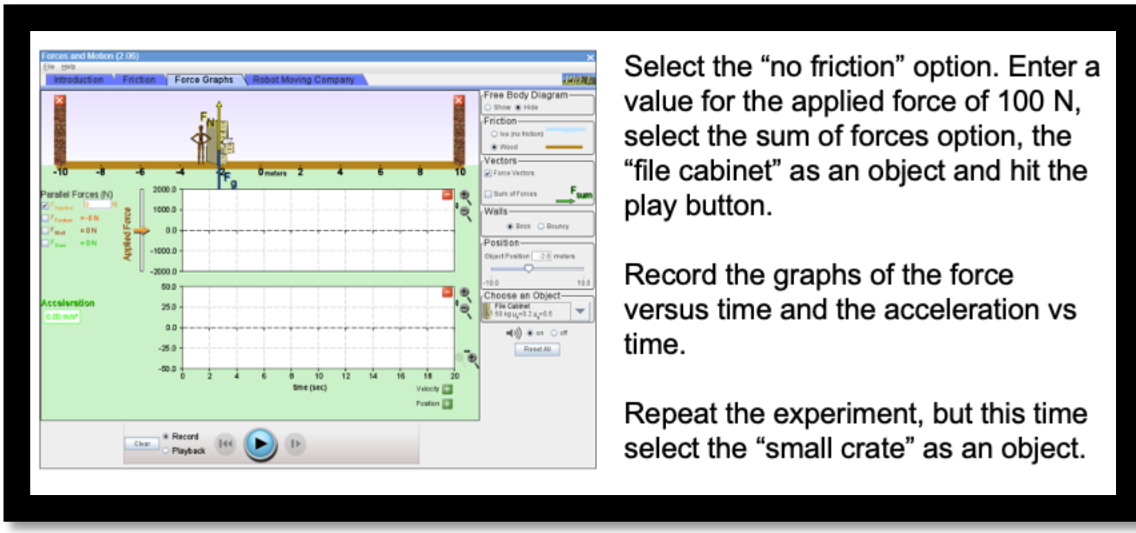


Figure 35 A new experiment is introduced related to Newton's second law.

A series of questions are now presented to verify if the students can properly interpret the acquired results:
Q10. In the two experiments, which parameters do you control?

A. The force and the acceleration.
B. The force only.
C. The force and the mass of the object.

Q11. Which one of the following can you say:

A. The object is accelerating with a constant acceleration when a constant force is applied to it.
B. The acceleration depends on the mass of the object not the applied force.
C. The object is moving with a constant velocity when a constant force is applied.

Q12. From the two experiments what do you observe, for the relation between the mass and the acceleration, when the force is constant:

A. When the mass doubles the acceleration remains the same.
B. When the mass doubles the acceleration doubles.
C. When the mass doubles the acceleration drops at half.

A new path is then designed for the students according to their choices:

Table 24 Paths definition for the hypothesis phase according to the answers to Q10, Q11 and Q12.

	LOW	MODERATE	HIGH
1	A	B	C
2	C	B	A
3	B	A	C
Actions	Repeat the experiments carefully	The AI agent provides explanations	Move on

Support is provided during this phase according to the student's needs:

LOW PERFORMER

The force and the acceleration are connected through the equation **F** = m**a**. A constant force will result in a constant acceleration and the mass is the proportionality constant. Repeat the experiment and set different values of force for a *constant mass* to see the relation between the force and the acceleration.

Repeat the experiments carefully

Figure 36 Guidance to students in need of more in depth support.

MODERATE PERFORMER

The force and the acceleration are connected through the equation **F** = m**a**. A constant force will result in a constant acceleration and the mass is the proportionality constant. For example, if you apply a force of 200 N in a 100 Kg object the acceleration that you will get is 2 m/s^2. If the mass becomes 200 Kg the acceleration will become 1 m/s^2, thus it drops at half.

Repeat the experiments carefully

Figure 37 Guidance to students in need of moderate support.

Newton's laws and free fall are then presented to the students:

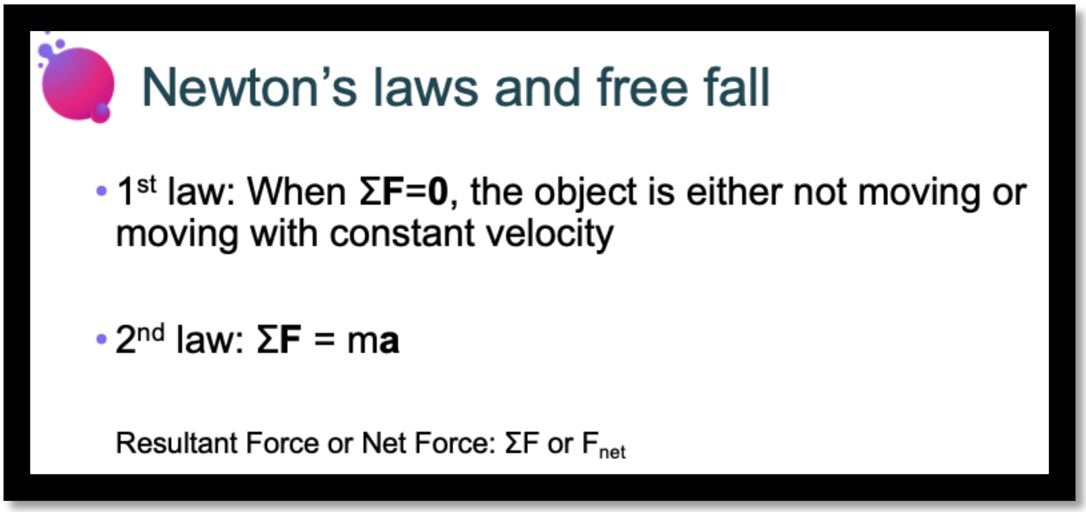


Figure 38 Newton's laws are presented to the students.

Students are now invited to perform some mathematical operations in support of their data analysis:

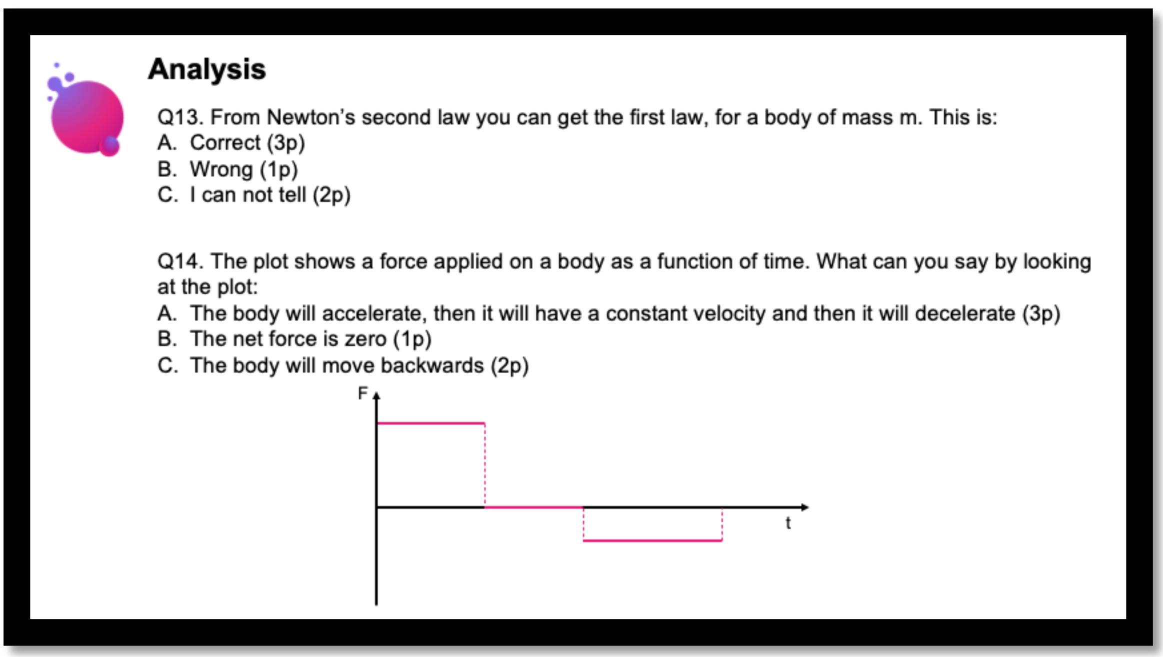


Figure 39 Questions presenting new challenges for the students related to Newton's laws.

A new path is then designed for the students according to their choices:

Table 25 Paths definition for the hypothesis phase according to the answers to Q13 and Q14.

	LOW	MODERATE	HIGH
1	B	C	A
2	B	C	A
Actions	Provide detailed explanations	Provide guidance	Move on

Support is provided during this phase according to the student's needs:

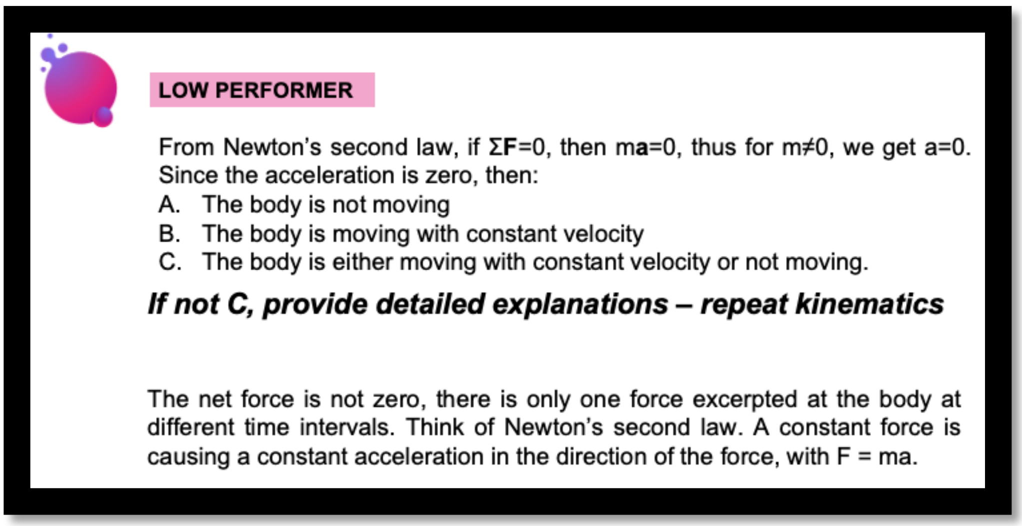


Figure 40 Guidance provided to students in need of more support.

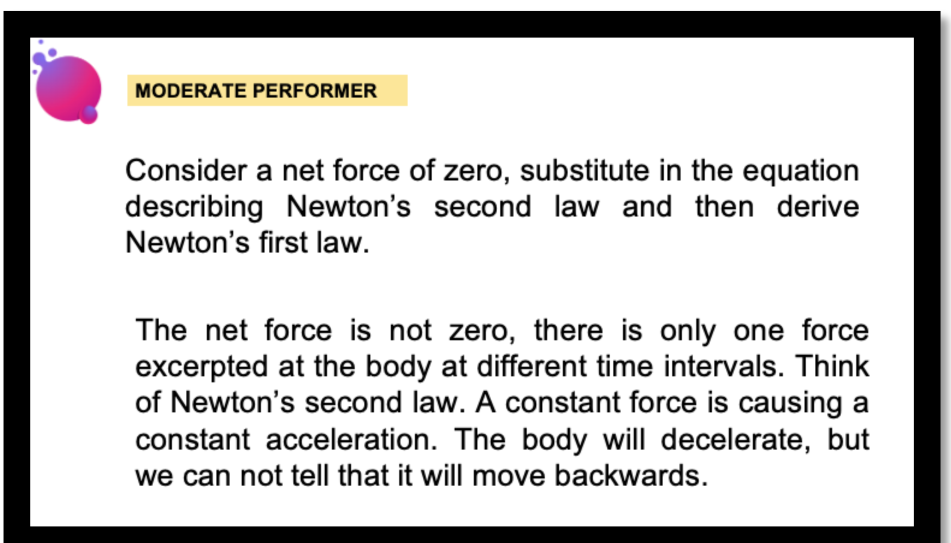


Figure 41 Guidance provided to students in need of moderate support..

Reflections

Students are now invited to reflect on their results. New questions are presented in order to support them in this task:

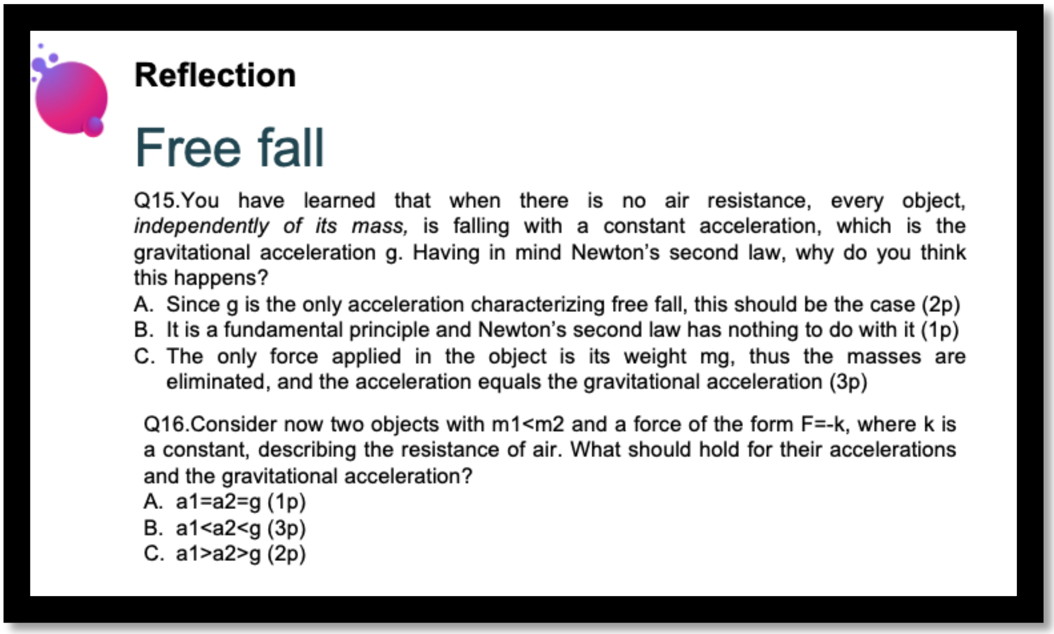


Figure 42 Prompt for students reflection on their results.

Table 26 Paths definition for the hypothesis phase according to the answers to Q15 and Q16.

	LOW	MODERATE	HIGH
1	B	A	C
2	A	C	B
Actions	The AI agent provides explanations		Move on

Support to students to finalise the activity:

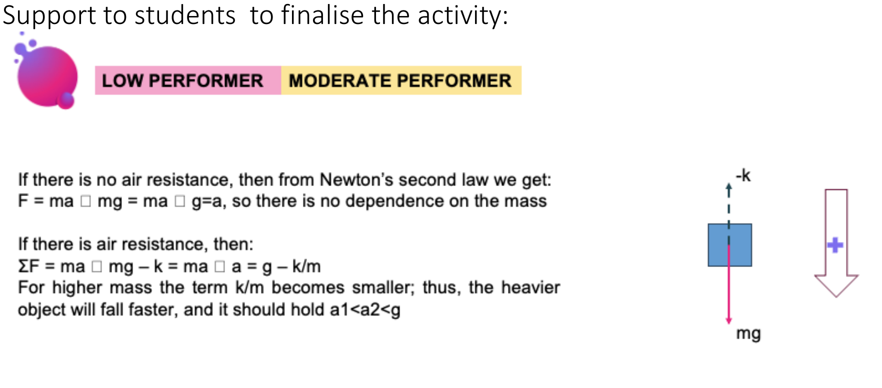


Figure 43 Support to finalise the activity.

5.4. Phases of the Moon

The first phase of the scenario is devoted to awakening the curiosity of the student about the topic:

Figure 44 Exploring the Phases of the Moon Scenario

Students are invited to observe the Moon as a way to ignite their curiosity. They are invited to observe the Moon for a month and register what they see. Students receive a template with the necessary instructions.

Figure 45 Observing the Moon Phases preparation activity

Message for the teacher:

Invite your students to compare their observations and discuss their findings. If possible, collaborate with schools in other parts of the world for a richer experience since the phases of the Moon will appear differently in different parts of the world (a topic for one of the future scenarios).

https://portaldoastronomo.org/wp-content/uploads/sites/3/2020/04/MoonDiary_en.pdf

Figure 46 Template for the phases of the Moon observation

Students are then invited to compare and discuss their results with their colleagues. This stage intends to increase their curiosity and spark their creativity. If the students cannot acquire their own data the calendar can be produced by using this online app: https://starwalk.space/en/moon-calendar

Figure 47 Invitation for group discussion and reflection.

Message for the teacher:

Divide your students into groups or conduct a whole class discussion on the results of their observations. You might invite them to have their observations distributed across the classroom wall to make it easier for them to understand if everyone observed the same thing and which conclusion they have reached.

After observing a complete cycle of phases of the Moon, students are now invited to reflect on this natural phenomenon considering the possible reasons for its occurrence. There are several misconceptions related to the Moon. Many people think that the Moon can only be seen at night, that the Moon produces its own light instead of reflecting the sunlight, that the phases of the Moon are caused by the Earth's shadow produced on its surface, that is related to the rotation of the Moon on its own axis, that the Moon takes only one day to orbit the Earth, that the Moon orbits the Sun and so much more[1].
Students are now ready to go more in-depth on the topic. Students are invited to answer the first question:

Figure 48 The first question where the knowledge of the students will be assessed.

Q1: What is the primary reason for the occurrence of Moon phases?
A. It is due to changes in the Earth's shadow cast on the Moon.
B. It is a consequence of the orbit of the Moon around the Earth.
C. It is the relative positions of the Sun, Earth, and Moon and the orbit of the Moon around the Earth.

Three options will be presented. Students selecting answer A will probably have little knowledge about the topic, those selecting answer B have some understanding but don't fully understand the whole phenomenon yet, and answer C. is the most complete.

[1] Lunar and Planetary Institute: (https://www.lpi.usra.edu/education/pre_service_edu/PhasesMisconceptions.shtml)

Message for the teacher:

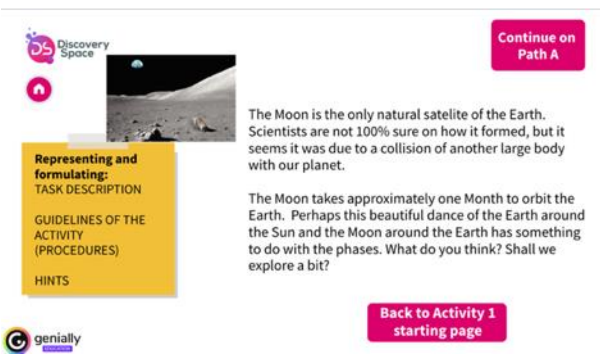
Answer A is incorrect. The orbit of the Moon and the Earth are not aligned. There is an angle between them of approximately 5 degrees. When the Moon's and Earth's orbit cross, we can have what we call Solar or Lunar eclipses, depending on the alignment. To understand solar eclipses, you can find a nice explanation here: https://www.exploratorium.edu/eclipse/why-dont-we-have-an-eclipse-every-month . The same explanation holds for Lunar eclipses. (This will be a topic for a future scenario).

Answer B is correct but incomplete. It is because of the tilt of its orbit and also the relative position of the 3 objects.

Answer C is the most complete answer.

There are 3 paths designed related to each specific answer. Students choosing A will have more information provided and invited to reflect more in depth on the topic starting from the position of the objects and the reason for the existence of phases. Students choosing B will be invited to go more in-depth on the phases and consider their timings and differences. Those that choose C will be invited to move forward to a second question that will add one more evidence that they possess the necessary knowledge to move forward in their exploration.

Path A This part explains the trajectory of the students who selected the answer A



Students who choose the first answer will receive further guidance from the conversational agent, and more information to help them acquire the necessary understanding of the topic. They will be invited to build a physical model of the Earth, Moon and Sun and then try to reproduce with their model the phases of the Moon. Their path will take them in one or more cycles supported by several questions (Q2a, Q3a, Q4a and Q5a) and necessary guidance and explanations. After the first cycle, they are invited to repeat the cycle or move forward with the Act. 2.

Figure 49 Conversational agent provides guidance to the students.

The conversational agent will then invite the students to think critically about the relationship between the 3 celestial bodies and their spatial relationship.

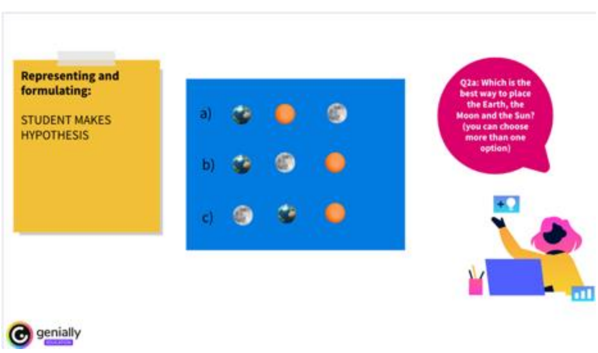


Figure 50 Possible answer to the relative position of the Earth, Moon and Sun.

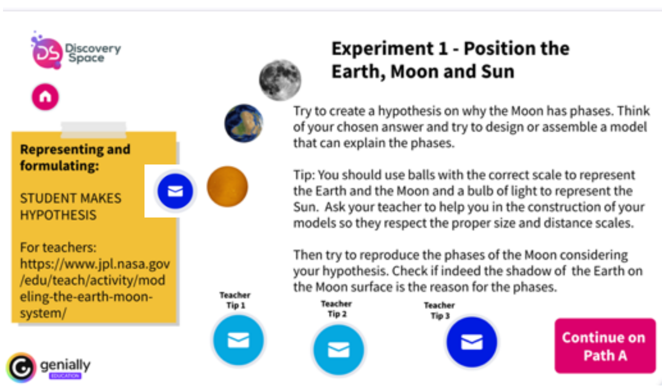
Q2a: What are the possible solutions to place the Earth, the Moon and the Sun? (you can choose more than one option)

Earth – Sun – Moon
Earth – Moon – Sun
Moon – Earth – Sun

Only the first choice is incorrect as the Moon is not orbiting the Sun. Students are then invited to use the material, according to their answer, and try to reproduce the phases of the Moon with the chosen position Earth, Moon and Sun. This activity will invite them to review their reasoning and rethink possible misconceptions. Students are encouraged to create a table to take notes of their results.

Message for the teacher:

How to position the Earth, Moon and Sun: The Moon will be located between the Earth and the Sun during part of its orbit and the Earth or on the opposite side of the Earth during the other parts of its orbit. So, answers B and C are both correct. Answer A is incorrect since the Moon doesn't orbit the Sun.



The next moment is to make students reflect on their procedures. The aim is to guide them to perceive that in an experiment they should vary only one element at a time.

Figure 51 Instructions for the first experiment.

Teachers are instructed on how to support students in the process of building their hypotheses.

Helping your students build a hypothesis

Start by suggesting that they identify the variables. Explain the importance of changing only one variable at a time. Suggest that they pick the variable that they believe is the cause for the change in the moon's phases (e.g., the position of the Earth, moon, or Sun). Help them think about what changes will affect the results (e.g., the appearance of the moon's phases). Now suggest the construction of the predictions about what will happen when the variable changes (e.g., if the Earth is between the moon and the Sun, then a certain phase will be observed). Example Hypotheses: "If the Earth is positioned _______________ the moon and the Sun, then we will observe _______________."When the moon is ___________Earth and the Sun, we will see __________".Encourage students to avoid vague statements and ensure their hypotheses are clear and measurable. Relate to the experiment they will perform. Help students connect their hypotheses to the material they will use. Guide them to think about how they can manipulate the positions of the Earth, moon, and Sun in order to test their hypotheses.

Message for the teacher: Find here the necessary instructions to help students build a model with the proper size and distance scale: Use the formula below to choose the correct size of balls of the Earth and the Moon. You can use this model as inspiration https://www.wikihow.life/Create-an-Earth-and-Moon-Model.

$$\frac{\text{actual Earth diameter } 12{,}742\text{ km}}{\text{scale Earth diameter}} = \frac{\text{actual Moon diameter } 3{,}475\text{ km}}{\text{scale Moon diameter}}$$

Figure 52 Physical model for the Path A

Teachers receive a link and the necessary information about the calculation of the size of the objects for the activity and a link with the full information to support the student's experience. Students are then invited to use the material and choose what is the best composition to support their ideas. A new question is presented to help the conversational agent perceive if the student is competently preparing their experiment. There are 2 challenges at hand, the relative position of the Earth, Moon and Sun and also the inclination between the orbit of the Earth around the Sun and the orbit of the Moon around the Earth. For now, we are just teasing the students to understand the relative position. Once this is understood we will move to another scenario where they are invited to understand why we don't see Solar and Lunar eclipses every month.

Message for the teacher: It is not just the orbit there is another very important element, the inclination. The orbit of the Moon around the Earth is 5º inclined in relation to the orbit of the Earth around the Sun. As a result, we see a complete series of phases every ~29 days but we only see eclipses when the orbits intersect (https://www.jpl.nasa.gov/edu/teach/activity/when-do-lunar-eclipses-happen/) .

Conversational agent supports the start of the experiment and suggests the creation of a table to collect the experimental data:

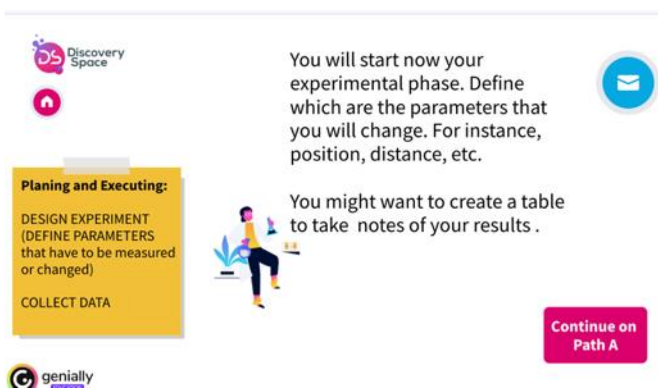
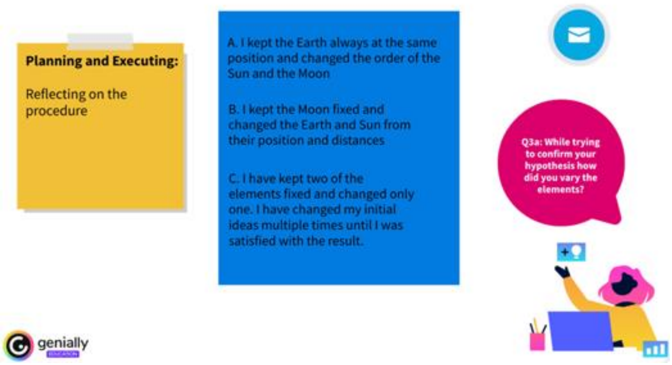


Figure 53 Students are invited to initiate the experiment and collect data.

Message for the teacher: Students exploring the phases of the Moon
In this phase, students should build their proposed model and try to analyse the obtained data. Suggest that they create a table with the sizes and distances of the Earth, Moon and Sun and log all the data as they progress with the experiment.

To help your students understand you can use the following activity.



Q3a: While trying to confirm your hypothesis how did you vary the elements?
A. I kept the Earth always in the same position and changed the order of the Sun and the Moon.
B. I kept the Moon fixed and changed the Earth and Sun from their position and distances.
C. I have kept two of the elements fixed and changed only one. I have changed my initial ideas multiple times until I was satisfied with the result.

Figure 54 Students are invited to reflect on their experiment.

Message for the teacher:

At this stage, the important part is to verify if the students understood how to design their experiments and collect the data. It is possible that they will reach inconclusive results due to the change of multiple variables at the same time. It is important to guide them on this reflection moment until they understand that the only way to collect the necessary evidence is to change one variable at a time.

Finally, students are invited to present their conclusion, but the elements are presented in a slightly different manner, to ensure that they really understood what the cause of the phases of the Moon is:

Q4a: What are the possible solutions to place the Earth, the Moon and the Sun? (you can choose more than one option)

- **A. Sun – Earth - Moon**
- **B. Earth – Sun - Moon**
- **C. Sun – Moon – Earth**

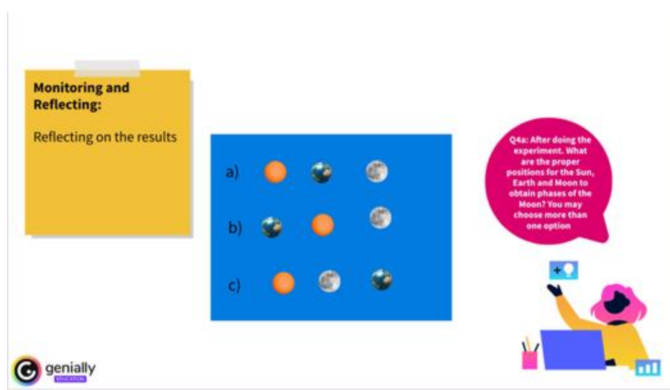
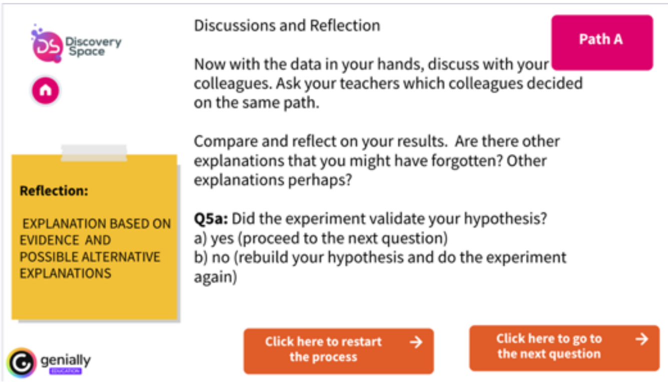


Figure 55 Students are teased to review their choice.

The only incorrect choice is B, for the same reason already presented above. Students are then invited to discuss with their colleagues and reflect on the results. A final question is presented.



Q5a: Did the experiment validate your hypothesis?

a) yes (proceed to the next question)

b) no (rebuild your hypothesis and do the experiment again)

Figure 56 Students are invited to discuss and either repeat the experiment or continue to the next question.

If the experiment was successful, students are invited to proceed to the next question. If not, they are invited to repeat the experiment. A new question is presented to ensure that the students have acquired the necessary knowledge.

Figure 57 A new question is presented to validate the student's knowledge of the topic.

Q6: After obtaining satisfactory results, which in your opinion is causing the phases of the Moon?

A. Because the Earth blocks the light from the Sun and that changes during the month.

B. Because the Moon rotates on its axis.

C. The orbit of the Moon around the Earth and its relative position to the Sun determines the phases of the Moon.

Message for the teacher:

A is the wrong answer as it is once more presenting what happens during an eclipse.
B. is also incorrect as the rotation of the Moon around itself is not related to the phases of the Moon. Actually, the Moon presents a synchronous rotation, in other words, it takes the same time for the Moon to make a full rotation around its axis as it takes to complete one orbit around the Earth. The consequence of this phenomenon is that, from Earth, we only see one side of the Moon. (A topic for another Scenario). **C.** is the correct answer.

Students choosing A are invited to go to a slide where more guidance is provided and then proceed to repeat the experiment.

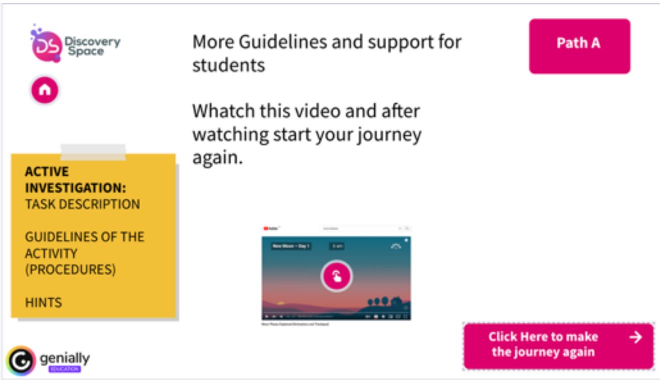


Figure 58 More guidance is provided to students who yet didn't fully understood the topic.

Students who choose B are invited now to take Path B and continue exploring the phases of the Moon using a virtual simulation. (This path is presented next).

Students who choose C are directed to a new question that will confirm their progress and guide them to the next activity.

Students selecting B, are invited to take Path B. Students selecting C are invited to go to the final validation question.

Q7: Reflecting on the results of your experiment can you identify when can we observe the full Moon? You can choose more than one answer.

A. The full moon happens when the Moon is between the Earth and the Sun.
B. The full moon can only be seen on Earth around sunset until sunrise.
C. When 100% of the face of the Moon facing Earth is illuminated, it happens once every moon cycle.

Figure 59 A final question to confirm that the student is now more prepared to continue the exploration of the phases of the Moon.

Message for the teacher:

A. When the Moon is between the Earth and the Sun is when we call it the new Moon, the brightness of the Sun makes it impossible to observe the Moon during the day sky.

B. The answer is correct.

C. Is also correct.

The objective of this question is to verify if the student is now prepared to move to the next activity.

Students who choose A are invited to take Path B again. Those who choose B or C are invited to go to the next activity.

Path B This part explains the trajectory of the students who selected the answer B

Students who chose option B in the first question, who in principle have a bit more understanding of the theme, will take Path B. We will now invite them to reflect on their answer and present a new question where teachers will be able to better understand if the students really understand the concept or if it was just a lucky guess.

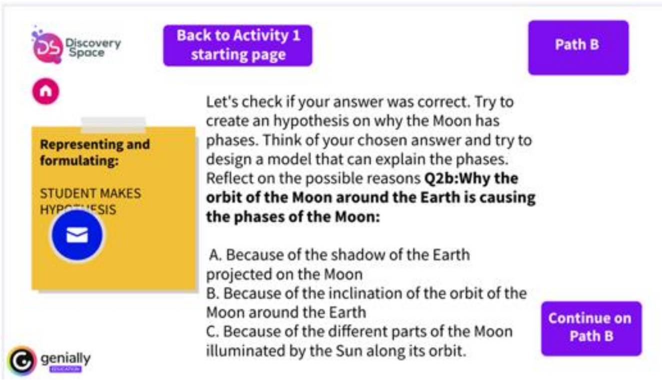


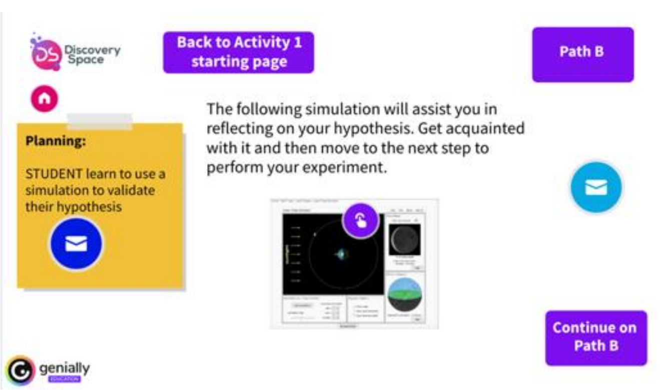
Figure 60 Reflecting on the orbit of the Moon around the Earth.

Q2b: Why the orbit of the Moon around the Earth is causing the phases of the Moon:
A. Because of the shadow of the Earth projected on the Moon.
B. Because of the inclination of the orbit of the Moon around the Earth, in relation to the orbit of the Earth around the Sun.
C. Because of the different parts of the Moon illuminated by the Sun along its orbit.

Teachers are instructed on how to support students in the process of building their hypotheses.

Helping your students build a hypothesis

Start by suggesting that they identify the variables. Explain the importance of changing only one variable at a time. Suggest that they pick the variable that they believe is the cause for the change in the moon's phases (e.g., the position of the Earth, moon, or Sun). Help them think about what changes will affect the results (e.g., the appearance of the moon's phases). Now suggest the construction of the predictions about what will happen when the variable changes (e.g., if the Earth is between the moon and the Sun, then a certain phase will be observed). Example Hypotheses: "If the Earth is positioned _______________ the moon and the Sun, then we will observe _______________."When the moon is ___________Earth and the Sun, we will see __________". Encourage students to avoid vague statements and ensure their hypotheses are clear and measurable. Relate to the App Experimentation. Help students connect their hypotheses to the interactive app. Guide them to think about how they can manipulate the positions of the Earth, moon, and Sun within the app to test their hypotheses.

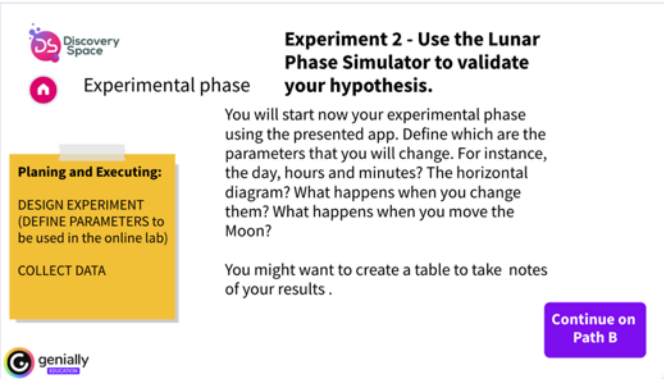


Students are then introduced to the virtual simulation they will use to support their investigation. They are invited to get acquainted with the different possibilities of the app:
(https://astro.unl.edu/naap/lps/animations/lps.html)

Figure 61 Students taking Path B will be introduced to the virtual simulation.

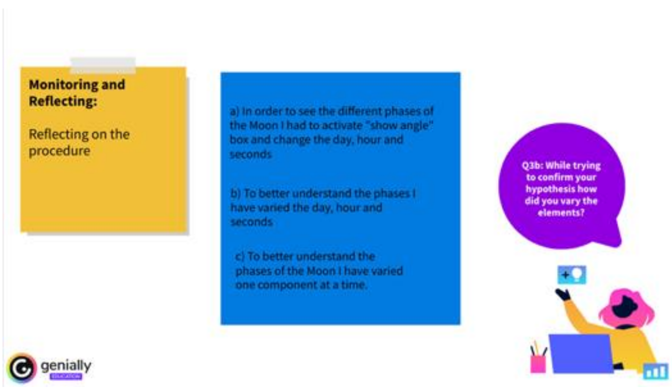
Message for the teacher:

This virtual simulation allows students to simultaneously see the part of the Earth illuminated by the sun (part of the planet where it is daytime) and the part where it is night-time. It is possible to change the phase of the Moon and see its position related to the Earth and the Sun, it is possible to change days, hours and minutes. The student will immediately see the effect of changing any of the variables.



Students receive further information on how to design their experiment and a subsequent question is presented inviting students to share with the conversational agent what their options were. This will give some indication about the understanding of the student on how to properly perform an experiment.

Figure 62 Tips to students for the design of their experiment.

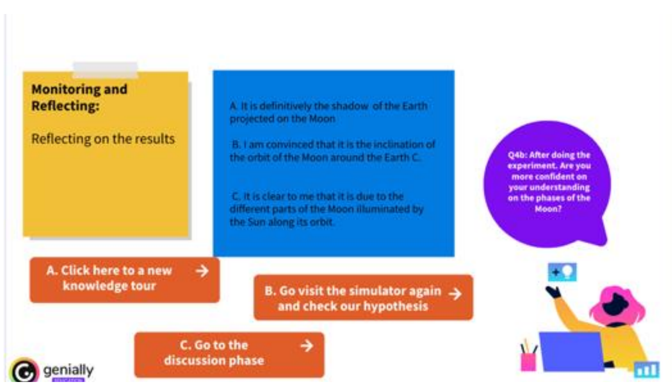


Q3b: While trying to confirm your hypothesis how did you vary the elements?
A. In order to see the different phases of the Moon I had to activate the "show angle" box and change the day, hour or seconds
B. To better understand the phases I have varied the day, hour and seconds
C. To better understand the phases of the Moon I have varied one component at a time.

Figure 63 Students are invited to reflect on their experimental choices

Message for the teacher:

At this stage, the important part is to verify if the students understood how to design their experiments and collect the data. It is possible that they will reach inconclusive results due to the change of multiple variables at the same time. It is important to guide them on this reflection moment until they understand that the only way to collect the necessary evidence is to change one variable at a time.
Students are then invited to reflect on the results of their experiments. A new question is presented helping the conversational agent determine the best course of action for the student.



Q4b: After doing the experiment. Are you more confident in your understanding of the phases of the Moon?
A. It is definitively the shadow of the Earth projected on the Moon
B. I am convinced that it is the movement of the Earth around the Sun.
C. It is clear to me that it is due to the different parts of the Moon illuminated by the Sun along its orbit.

Figure 64 Student reflect on their understanding.

Message for the teacher:

A is definitively the wrong answer as we have seen before. Students choosing this answer should go back to Path A to have the opportunity to go more in-depth into the topic and review their understanding with more support. Students choosing option B should experiment on Path B again. They are not wrong but some more information is missing in their understanding. Students choosing the C option are now ready to go ahead and discuss with their colleagues their findings.

Students proceed then to discuss their findings with their colleagues and finally reflect on their journeys. They are allowed to repeat the experience if they wish.

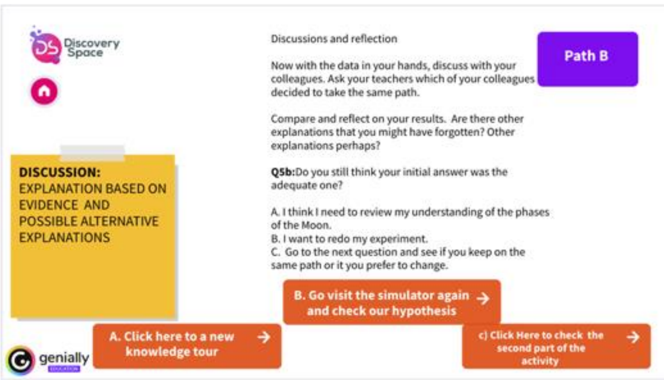


Figure 65 Discussion and Reflection phase.

Q5b: Do you still think your initial answer was the adequate one?

A. I think I need to review my understanding of the phases of the Moon.

B. I want to redo my experiment.

C. Go to the next question and see if you keep on the same path or if you prefer to change.

Students will again be invited to review the topic, to make the virtual experiment of proceed to the final phase.

The final phase is a new question that will confirm that the student acquired the necessary knowledge and desired competencies.

Figure 66 Final activity question to confirm students successfully finalised the new learning.

Q7: Reflecting on the results of your experiment can you identify when can we observe the full Moon?

A. The full moon happens when the Moon is between the Earth and the Sun.

B. The full moon can only be seen on Earth around sunset until sunrise.

C. Is when 100% of the face of the Moon facing Earth is illuminated, it happens once every moon cycle.

Students choosing answer A will be directed to repeat the path B, and students answering B or C will proceed to the new Experiment.

Message for the teacher:

A. When the Moon is between the Earth and the Sun is when we call it the new Moon, the brightness of the Sun makes it impossible to observe the Moon during the day sky.

B. The answer is correct.

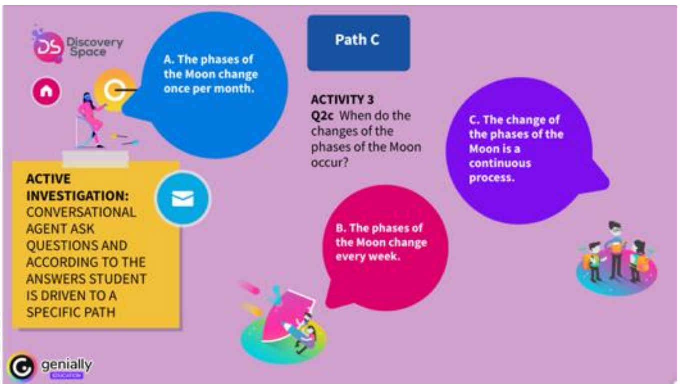
C. It is also correct.

The questions, answers and the path to be taken are defined by the interactions of the students with the conversational agent. The different paths are summarised in the following table.

Path C

This part explains the trajectory of the students who selected the answer C in all verification questions (Q1, Q6 and Q7). Or the students who successfully finalised Path A and or Path B.

Students who already have a good understanding of the spatial relation between the Sun, Earth and Moon are now ready to explore the phenomenon further, adding one more degree of complexity, and a deeper understanding of the reason for the changes in the phases of the Moon. This new activity starts with a teasing question:



Q2c When do the changes of the phases of the Moon occur?
A. The phases of the Moon change once per month.
B. The phases of the Moon change every week
C. The change of the phases of the Moon is a continuous process.

Figure 67 Beginning of Activity 3

Message for the teacher:

Answer A is not correct.
Answer B. This answer is also wrong
Answer C. This is the correct answer as the phases of the Moon are continuously changing across its orbit around the Earth.

All students reaching this phase are invited to continue and explore the presented experiments.

Students are invited to get acquainted with the virtual simulation, Stellarium[2], adopted for the Experiment 3.

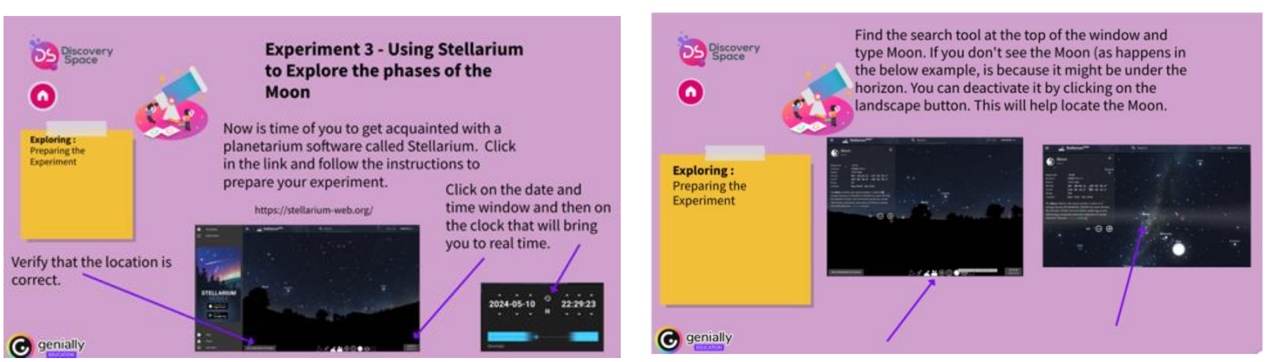


Figure 68 Students get familiarised with Stellarium

Students are supported by their teachers to create a hypothesis and proceed with the data collection.

[2] https://stellarium-web.org/

After successfully collecting the data, students are invited to answer a new question posed by the conversational agent.

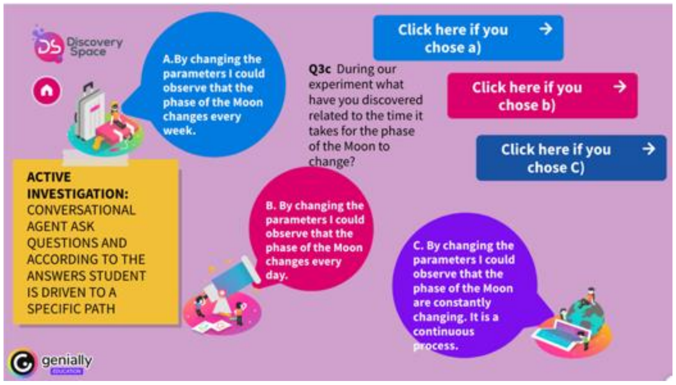


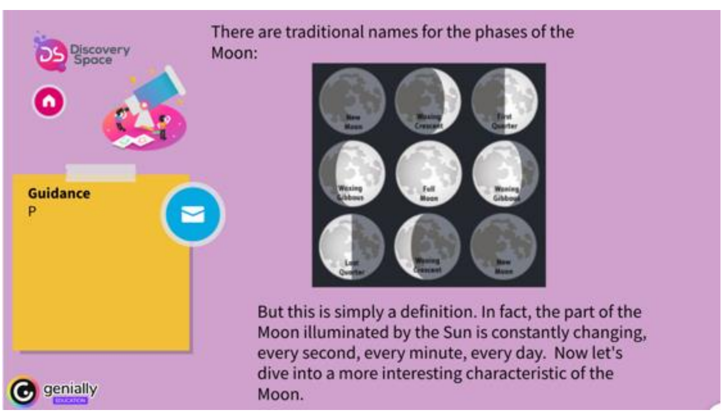
Figure 69 Students are invited to reflect on the results acquired.

Q3c During our experiment what have you discovered related to the time it takes for the phase of the Moon to change?
A. By changing the parameters I could observe that the phase of the Moon changes every week.
B. By changing the parameters I could observe that the phase of the Moon changes every day.
C. By changing the parameters I could observe that the phase of the Moon is constantly changing. It is a continuous process.

Students are invited to reflect on their results and discuss in groups what should be the correct answer to the question. Students choosing the wrong option are invited to repeat the experiment. Teachers might also decide to invite some students to take Path A or Path B to ensure that the phenomenon is properly understood.

Message for the teacher:

Again, the correct answer is C. Invite your students to discuss in groups and reflect on their results. Maybe some students should be invited to go back to the activity and perform the experiments presented in Path A and or Path B.



Some more guidance can be provided in order to ensure that the students properly acquired the intended understanding of the constant changes of the phases of the Moon.

Figure 70 Some guidance before the students continues their learning journey.

A new experiment is now presented where the students will be invited to put together all the new knowledge acquired in this scenario. The experiment is performed digitally using the Miro App. Students have to place around the Earth, the phases of the Moon as seen by an observer on Earth and the phases as seen from above its orbit. The teacher will receive a link to the Miro board that can be copied and freely used with their students.

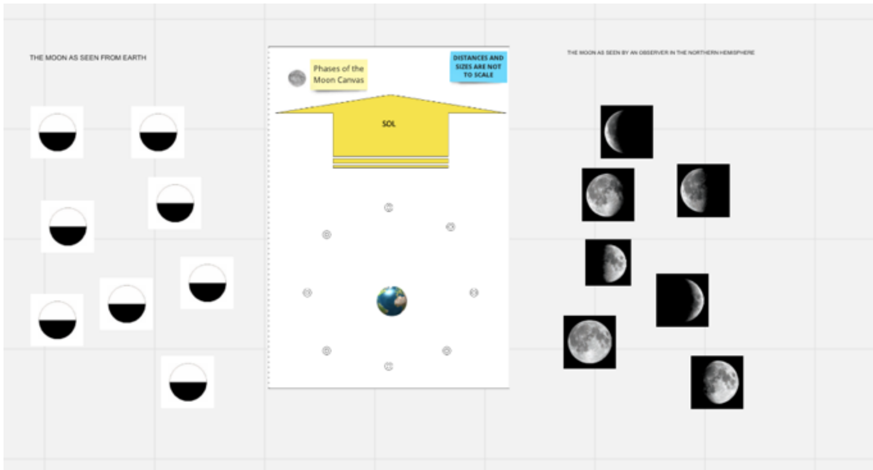


Figure 71 Phases of the Moon on a Miro Board.

Message for the teacher:

You will find this board in the following link:
https://miro.com/app/board/uXjVKJSEKzw=/?share_link_id=852508877023
You will have to create an account in the Miro App (a very useful tool to work with your students). Once you enter, click on the title of the board and duplicate. You will then have your own copy.

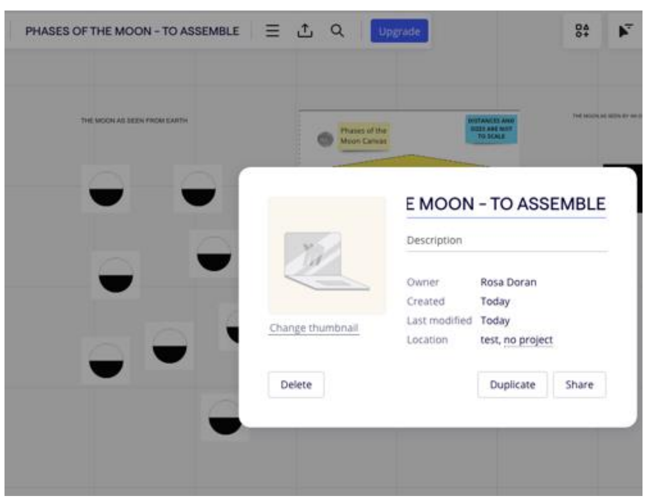
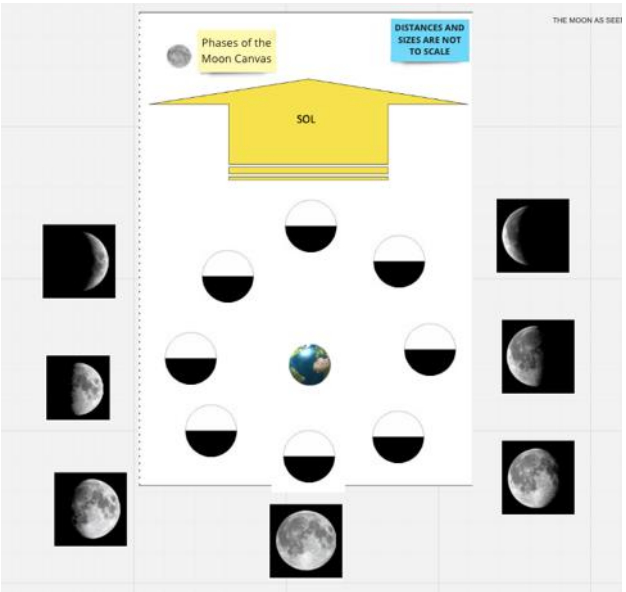


Figure 72 Instructions to copy the Miro board.

This is the correct result for the Phases of the Moon Board



On the outside, we see the phases as observed from Earth in the Northern Hemisphere. On the inside is what is seen by an observer watching the orbits from above. There is always one half of the Moon illuminated, the half pointing to the Sun.

After the students finalise their experiment a new question is presented a new question is presented, challenging students to review their recent learning.

Figure 73 Question inviting students to reflect on the spatial relation of the Earth, Moon and Sun

Q4c Now that you understand the phases of the Moon choose the correct statement. (you can use Stellarium to help you answer this question).
A. A new moon occurs when the Moon is not in the sky.
B. A full moon can only occur when the Moon is between the Earth and the Sun.
C. Full moon phase happens only when the Earth is between the Moon and the Sun

Message for the teacher:

A is not the correct answer as the Moon is always in the sky. But during the new moon, due to the brightness of the Sun, and the fact that only the part of the Moon facing aways from us being illuminated, we can't see the Moon. B is not correct, that is the part of the orbit where the new moon phase happens. C is correct, the full Moon happens when the Earth is between the Moon and the Sun. When this happens the Moon orbit around the Earth and the Earth's orbit around the sun are aligned we can see a lunar eclipse (a topic for the next experiment).

At this stage, students already understood that the phases of the Moon occur due to the spatial relation between the Earth, Sun and Moon. But it is possible that they didn't realise that the phases can only occur in specific parts of the orbit. This question is an invitation for the students to review and challenge their understanding. If the answer is not correct they are invited to repeat the last experiment and reflect again on the theme.

Those that correctly answered the question might not have considered what exactly is the relation of the phases and the time of the day that the Moon can be seen in the sky in each particular phase. The next question invites students to think about this new characteristic of the phases of the Moon.

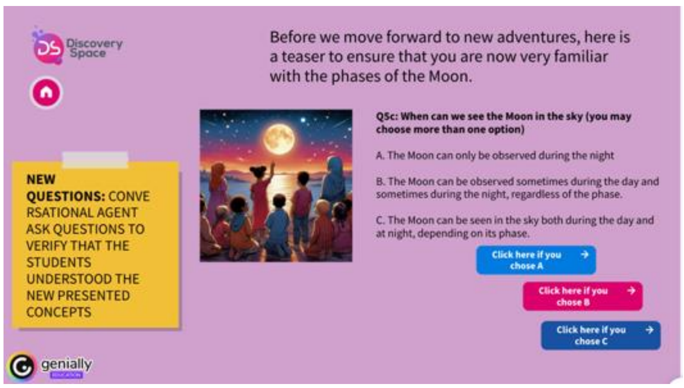


Figure 74 Question inviting students to reflect on the relation of the phase of the Moon and its visibility in the sky.

Q5c: When can we see the Moon in the sky (you may choose more than one option)
A. The Moon can only be observed during the night.
B. The Moon can be observed sometimes during the day and sometimes during the night, regardless of the phase.
C. The Moon can be seen in the sky both during the day and at night, depending on its phase.

Message for the teacher:
A is not correct as depending on the phase, the Moon can be observed in various parts of the day and the night.
B is not correct since the time we can observe the Moon on the sky is directly correlated to the phase of the Moon.
C. is the correct answer

Students choosing the wrong answer are invited to perform a new activity, using Stellarium. They are invited to build new hypotheses and then use Stellarium to test them. Students that answer correctly are invited to watch a summary video to finalise this phase.

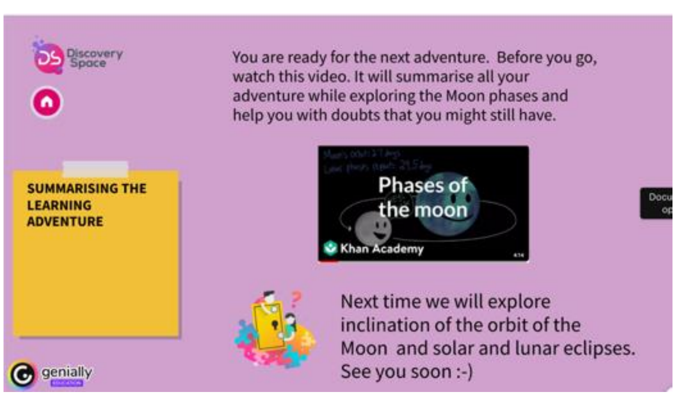


Figure 75 Last part of this scenario summarizing all the learning objectives.

This scenario is part of a collection of scenarios that bring the students from the basic understanding of the phases towards a more in depth perception. In the next scenarios they will be invited to:

- Explore the inclination of the orbit of the Moon and the Eclipses
- The phases of the Moon in the different hemispheres
- The phases of the Moon observed from the Sun and an observer of the Solar System
- The dark side of the Moon
- The phases of the Earth
- Day and night in the Moon

The following table presents the different trajectory taken by the students while navigating the Phases of the Moon Scenario.

Question	Path A - Knowledge and Competence level A	Path B - Knowledge and Competence level B	Path C - Knowledge and Competence level
Q1 – Experiment 1	**A**	**B**	**C**
Q2a	abc		
Q3a	abc		
Q4a	abc		
Q5a	A (more guidance and repeat the experiment)		
Q5a	B (proceed to the next question)		
Q6	**A (receive more guidance and repeat the experiment)**	**B (take path B)**	**C (move to the next question)**
Q2b – Experiment 2		abc	
Q3b		abc	
Q4b		A (take Path A)	
Q4b		B (restart Path B)	
Q4b		C (move to next question)	
Q5b		A (take path A)	
Q5b		B (take path B again)	
Q5b		C (move to the next question)	
Q7	**A (receives support and take path B again)**	**B (move to next activity)**	**C (move to next activity)**
Q2c – Experiment 3	**A , B, C continue to perform the experiment**		
Q3c	A (repeat the experiment)	B (repeat the experiment)	C move to the next stage
Q4c	A (repeat the experiment)	B (repeat the experiment)	C move to the next stage
Q5c	A is invited to make a new experiment.	C is invited to make a new experiment.	C is invited to review the experience and finalise the scenario.

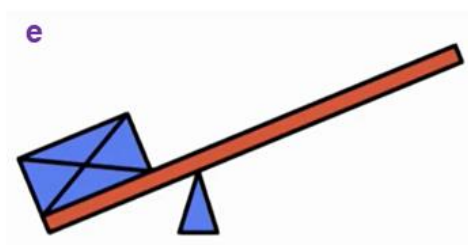
5.5. Simple Machine: Pulley

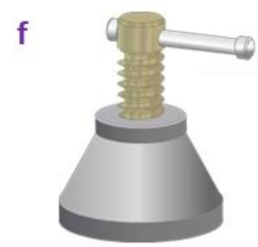
Engagement/Orientation

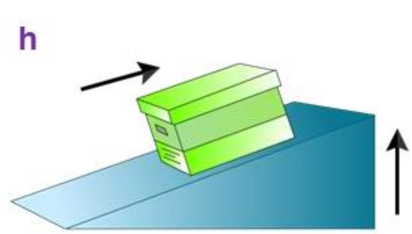
We assume you are aware that nearly all mechanical machines and tools apply in their functioning a few basic simple machines.

Q1.1: Look the picture and choose the classical simple machines:

> <u>Do you know</u>
> Six simple machines are wedge, wheel and axle, lever, inclined plane, screw, and pulley (Read more about the simple machines: https://www.britannica.com/technology/simple-machine OR https://en.wikipedia.org/wiki/Simple_machine)







A. b, d, e, f, h, i;
B. a, b, d, f, g, h;
C. b, d, e, f, g, h;

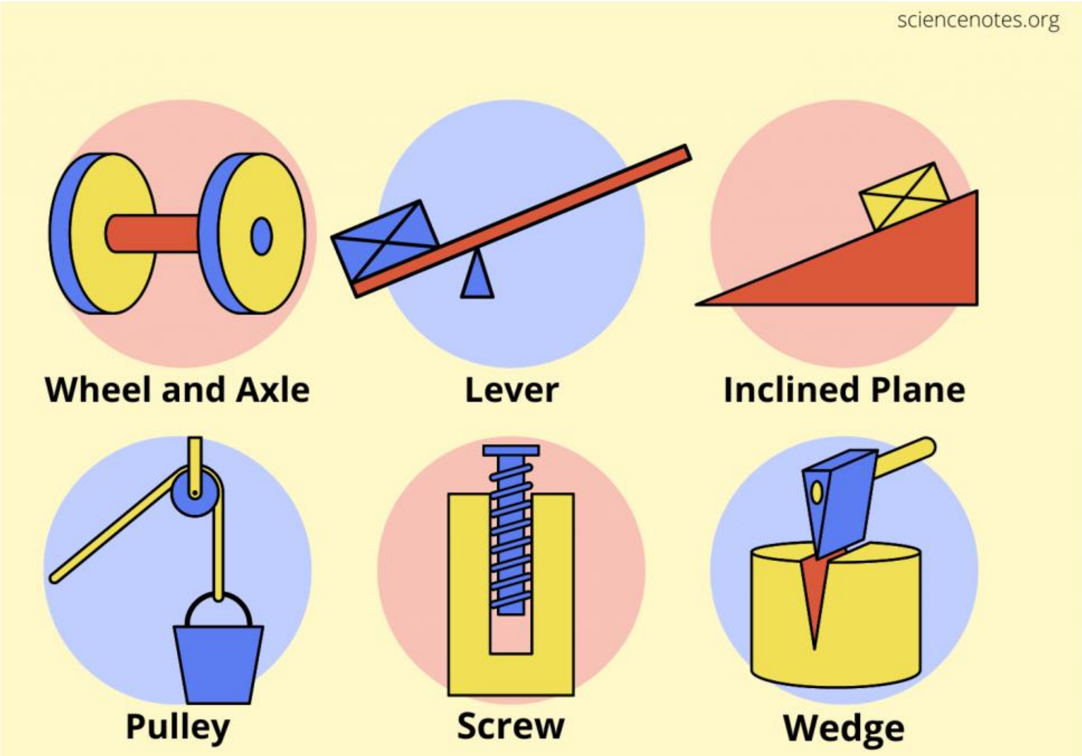
D. none of them;
E. all of them.

Message for the teacher:

Answer D or E is incorrect since it misses the key point of the question.
Answer A or B is partially correct.
Answer C is the correct answer.

Guided explanation for incorrect answers: Don't rush! Please think again about the fact that simple machines were used for thousands of years before electricity was available.

Q1.1.1. What will be your answer on the next question in this case?



A. lever, inclined plane, and pulley
B. wheel and axle, wedge, and screw
C. all of them
D. none of them

Message for the teacher:

Answer A or B or D is incorrect. Students need alternative explanation of the classic simple machines.
Answer C is the correct answer.

Direct information: Provide the wiki or Britannica text to read.

Let us think a little bit more about the simple machines.

Q1.2: Do you think basic simple machines help you accomplish job because
A. they do all the force for you
B. they increase the force you apply
C. actually, they are not very helpful
D. all of them
E. none of them

Message for the teacher:

Answer A or C or D or E is incorrect. Students need alternative explanation of the functionality of the classic simple machines.
Answer B is the correct answer.

Q1.3: We use the simple machines:
A. because they change direction and magnitude of the force;
B. because they decrease the amount of work;
C. because the developed by them energy can move or stop the object.
D. all of them
E. none of them

Response: We will check later whether your answers are correct of not.

Message for the teacher:

Answer B - E is incorrect. However, on this stage we will not explain students their mistakes and give them possibility to explore the physical process.
Answer A is the correct answer.

In order to measure or estimate the factor of the force amplification achieved by using a tool, people use the concept of **mechanical advantage.**

NOTE: The force applied to the machine may be called the input force, or FIN. The force delivered by the machine may be called the output force, or FOUT.

Q1.4: How you will define the mechanical advantage (MA) of a simple machine? You will define MA as:
A. sum of the input and output forces;
B. product of the input and output forces;
C. ratio of the input and output forces;

Message for the teacher:

Answer A or B is incorrect. The guided explanation is needed. It is advisable to check whether student understands the terms of input and output forces.
Answer C is the correct answer.

Guided explanation: Machines increase the force you apply. Therefore,
Q1.4.1: Output force will be:
A. larger than input force
B. smaller than input force
C. larger or the same, when the machine uses to change a direction

Message for the teacher:

Answer A is partially correct answer, since there are some simple machines that only modify the direction but not the output force.
Answer B is incorrect answer. Student does not understand the machine concept.
Answer C is the correct answer.

The answer **A** will be OK, but the **correct answer** is "**C**. Larger or the same, when the machine uses to change a direction". The fixed pulley is an example of the simple machine to change the direction but not the force.

Q1.4.2: How we can define how many times the output force is larger than the input force?

A. We have to divide the input force by the output force
B. We have to divide the output force by the input force
C. There is no correct answer above.

Message for the teacher:

Answer A or C is incorrect answer. The direct answer is provided.
Answer B is correct answer.

Direct Explanation for A and C

Direct Explanation:
Machines are devices which are designed to work smarter, not harder!
Machines **increase the force** you apply. Machines do this by changing the direction or magnitude—or both— of the applied force. By cleverly manipulating these two factors, machines allow us to accomplish tasks that would be difficult or impossible with our own strength alone.
The mechanical advantage of a machine is the output force (FOUT) divided by the input force (FIN). In this case, we define how the output force is amplified in comparison to input force. Therefore, the general formula for the mechanical advantage (MA):

$$MA = \frac{F_{OUT}}{F_{IN}} = \frac{Load}{Effort}$$

Q1.5: In your opinion, what is the units of the MA:

A. newtons
B. kilograms
C. unitless, just ratio

Message for the teacher:

Answer A is incorrect answer. Students do not understand that the MA is ration of FOUT and FIN, although student shows that (s)he aware that the unit of force is newtons.
Answer B is incorrect answer. Student need to understand that (1) the unit of the force is newtons, and (2) the MA is ration of FOUT and FIN.

Answer C is correct answer.

Guided explanation (A):
From previous activity we know that

$$MA = \frac{F_{OUT}}{F_{IN}} = \frac{Load}{Effort}$$

Q1.5.1 Please select the sentence you believe is correct.

A. The numerator and the denominator have the same units.
B. The numerator and the denominator have different units.
C. The numerator and the denominator don't have units.

Message for the teacher:
Answer A is correct answer.
Answer B or C is incorrect answer. Further explanation is needed.

Q1.5.1.1 If numerator and the denominator have the same units, what will be the MA:

A. just number, no units
B. it will still be newtons
Direct explanation for Q1.5.1.1 B.

Message for the teacher:
Answer A is correct answer.
Answer B is incorrect answer. Further explanation is needed.

Guided explanation (B):
Q1.5.2.1 The mass is measured in:
A. kilograms, grams, tonnes
B. newtons
C. center of mass

Message for the teacher:
Answer A is correct answer.
Answer B or C is incorrect answer.

Q1.5.2.2 The force is
A. same speed
B. newtons
C. a push or/and a pull
D. tensions

Message for the teacher:

Answer C is correct answer.
Answer A or B or D is incorrect answer.

Q1.5.2.3 A force is measured in …… (N)

A. newton
B. work
C. energy

Message for the teacher:

Answer A is correct answer.
Answer B or C is incorrect answer.

From previous activity we know that

$$MA = \frac{F_{OUT}}{F_{IN}} = \frac{Load}{Effort}$$

The numerator and the denominator represent by forces.

Q1.5.2.4 Please select the sentence you believe is correct.

A. The numerator and the denominator are measured in the same units.
B. The numerator and the denominator are measured in different units.
C. The numerator and the denominator don't have units.

Message for the teacher:

Answer A is correct answer.
Answer B or C is incorrect answer.

Q1.5.2.5 If numerator and the denominator have the same units, what will be the MA:

A. just number, no units
B. it still will be newton
Direct explanation for Q1.5.2.5 B.

Message for the teacher:

Answer A is correct answer.
Answer B is incorrect answer. Student will get direct explanation.

Direct explanation:

Did you notice that the force unit involved in the calculation, the newton (N) is present in both the numerator and the denominator of the fraction?

$$MA = \frac{\text{output force (N)}}{\text{input force (N)}}$$

These units cancel each other, leaving the value for mechanical advantage unitless.

$$\frac{\text{newtons}}{\text{newtons}} = \frac{N}{N} = 1$$

Therefore, the correct answer is no units, i.e. unitless, because it is a ratio of two forces
It is time for practice. Are you ready? Let's start!

Q1.6 PRACTICE

Q1.6.a If a machine has a mechanical advantage of 2 and the machine will deliver a force of 30 newtons then to the machine the user applies a force of

- *A. 32 newtons*
- *B. 15 newtons* (correct answer)
- *C. 60 newtons*

Q1.6.b. A 500-newton load is lifted to a height of 1 meter using a 10-meter long ramp. You can see that the worker only has to use 50 newtons of force to pull the cart. The mechanical advantage is:

- *A. 10* (correct answer)
- *B. 4,5*
- *C. 45,5*
- *D. 50*

Q1.6.c. A force of 250 newtons is applied to a machine in order to lift a 1,000-newton load. What is the mechanical advantage of the machine?

- *A. 250*
- *B. 750*
- *C. 4* (correct answer)

Q1.6.d. A machine with a mechanical advantage of 2.5 requires an input force of 120 newtons. What output force is produced by this machine?

- *A. 300* (correct answer)
- *B. 48*
- *C. 120*

Let us explore the functionality of the pulley. Please watch the short video:

https://www.youtube.com/watch?v=pxD3SHMp9Es&ab_channel=NextGenerationScience

Q1.7 Select the examples of the Pulley:

A. 1, 3, 6, 10, 12
B. 2, 5, 7, 9, 13
C. 2, 4, 5, 8, 11
D. None of them
E. All of them

Do you know
The origins of pulleys can be traced back to Ancient Egypt during the Twelfth Dynasty (1991–1802 BC) and Mesopotamia in the early 2nd millennium BC. Pulley was one of six simple machines employed for lifting weights during the Roman era in Egypt (c. 10–70 AD).

Message for the teacher:

This activity recalls the previous students' knowledge of about the pulleys, and students' analytical skills to understand an implementation in real life**.**

Answer B is correct answer.
Answer A or C or D or E is incorrect answer. Student will get direct explanation.

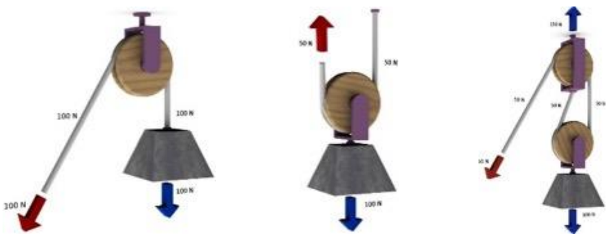
Text explanation: Pulley uses the rope, cable or something similar over the wheel or sheave (something round) on an axle or shaft. When the rope is pulled down, the other side goes up. In this case the lift work is easy to perform.
Let us learn the mechanics of how a pulley operates. In order to keep the problem simple, we will talk about the IDEAL pulley. For this, we assume that:

1. the pulley has no mass.
2. the pulley is frictionless.
3. the rope has no mass.

4. the rope does not slip.
5. the rope is inelastic.

Let us explore the mechanical advantages of the pulley - one of the six simple machines. There are three different types of pulleys:

1. fixed
2. movable
3. compound



Let us study single fixed pulleys.

Do you remember from the video what is the fixed pulley? Provide the definition in own words:

A fixed pulley system consists of a single pulley securely mounted on a fixed support structure (e.g., wall or ceiling). A rope or cable (further referred to simply as "rope") runs along the pulley's groove. One end of the rope is attached to the object you want to lift, while the other end remains free for you to pull.

Q1.8 Please choose a correct diagram[3] of a single fixed pulley.


A


B


C


D

Message for the teacher:

Answer C is correct answer.
Answer A or B or D is incorrect answer. Student will get guided explanation by system.

Guided explanation for A, B, and D:

[3] Images: César Rincón, CC BY-SA 3.0 <http://creativecommons.org/licenses/by-sa/3.0/>, via Wikimedia Commons

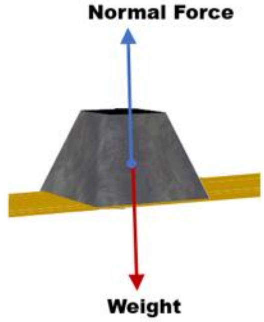
Q1.8.1 The gray object is the load placed on the ground is at rest. Is it experiencing a balanced force situation?

A. YES
B. NO

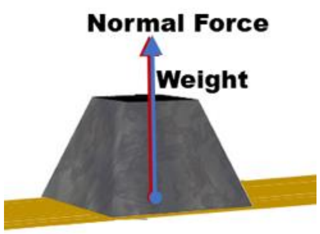
Message for the teacher:

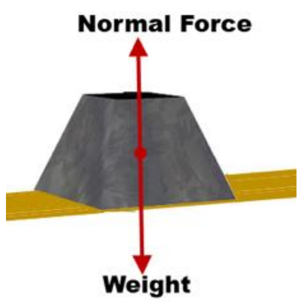
Answer A is correct answer.
Answer B is incorrect answer. Student will get guided explanation by system.

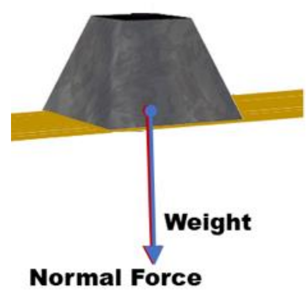
Guided explanation B. Put the book on the floor… is it moving? Right… it is not moving and in the rest. Look the image: the force of gravity (Weight) **pulls** the object **down**, while the surface pushes up with the same force (Normal Force) but in the **opposite direction**. These forces cancel out, keeping the object still.



Q1.8.1.1 Select the correct diagram:







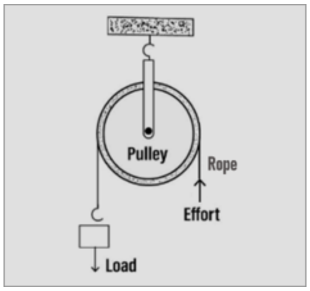
A B C

To raise the load, the effort is applied at the other end of the rope by pulling it in a downward direction.

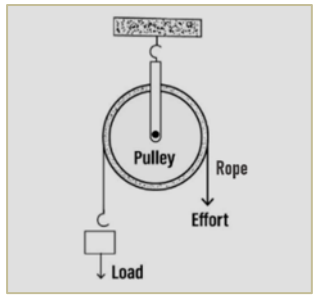
Message for the teacher:

The question checks whether students understand the diagrams and direction of the forces.
Answer B is correct answer.
Answer A or C is incorrect answer.

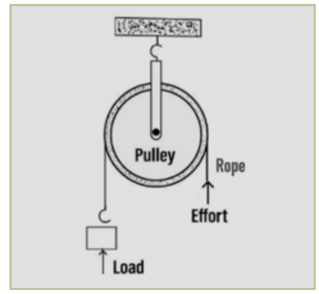
Q1.8.1.2 In your opinion, what is the correct diagram for the forces?



A



B



C

Message for the teacher:

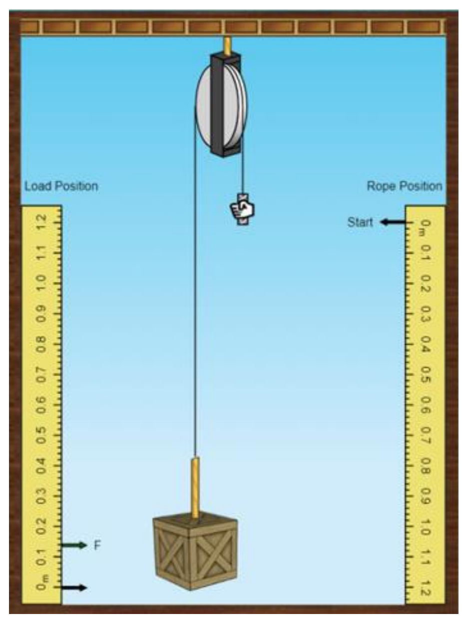
The question checks whether students understand the pulley diagrams and direction of the forces. The content of this question is similar to Q1.8, but with other visual presentation.

Answer B is correct answer.

Answer A or C is incorrect answer.

Explanation: B: It is correct,
A and C: The correct answer is B

Hypothesis:



Q2.1 - H1: If we have a system with a single fixed pulley, then

A. mechanical advantage will be greater than 1
B. mechanical advantage will be less than 1
C. the mechanical advantage will be 1.

Q2.1 - H2. If we have a system with a single fixed pulley, then the pulley

A. changes direction, but not force
B. changes directions of force
C. changes neither direction no force.

Message for the teacher:

The questions Q2.1 are the Hypothesis questions. During the next activities students should conduct the experiment and evaluate their answers. Teacher can suggest to students to create their own hypothesis.

Q2.1 – H1 Answer C is correct answer.

Answer A or B is incorrect answer.

Q2.1 – H1 Answer A is correct answer.

Answer B or C is incorrect answer.

Let us check your hypotheses

Experiment:
Go to the link to get a virtual simulation: https://compassproject.net/html5sims/pulleysim/pulley_en.html

Design the experiment to test your hypothesis. Create a table for the data collection.

Message for the teacher:
The questions Q3.1.1 and Q3.1.2 help students to create the experiment applying the terms of unchangeable and changeable as well as dependent and independent variables. To simplify the task Teacher can suggest to students the table created to collect the experimental data.

Q3.1.1 **Answer A** is correct answer.
Answer B or C is incorrect answer.
Q3.1.2 **Answer B** is correct answer.
Answer A or C is incorrect answer.

Q3.1.1 In the provided simulation the independent variables are:
A. Pulley Diameter, High to Lift, and Load;
B. Distance Pulled, Work Done and Potential Energy;
C. Pulley Diameter, Height to Lift, Load and Applied Force

Q3.1.2 In the provided simulation the dependent variables are:
A. Pulley Diameter, High to Lift, and Load;
B. Distance Pulled, Applied Force, and Potential Energy;
C. Pulley Diameter, Load and Work Done

Q3.2: While trying to confirm your hypothesis create a chart to record the experimental data.
Check whether in the chart you employ all required data and measurements: Load, Height Lifted, Applied Force, Distance Pulled, Input Work, Output Work, Actual MA, Ideal MA, Efficiency. Do not forget providing the unites for each measurement.

Option 1: Students with good understanding can create the experiment without a system or teacher support.
Option 2: Students with not good enough understanding will get the guided instruction and support, if is needed.
Do you have a difficulty from what to start? Please, check the hints.
Hint 1: Start with a discovery of the simulation. Manipulate the parameters, variables that are changeable in the provided experimental simulation and affect the results.
Hint 2: In order to test a hypothesis, test a single variable by changing it while keeping all other variables the same during the experiment. Think what a variable you could keep unchangeable and which one you could test.

1. Select single fixed pulley system.
2. Decide about the independent variables, such as load that you will lift.
3. Decide and select the distance or the height to lift the load. It would be smart to keep it constant during the entire experiment.
4. Think about and provide in the design of experiment which dependent variables such as forces, work done, energy, distance pulled, etc. that you can record during this experiment.

5. Think and provide in the experiment design how many times you have to repeat the selected experiment in order to reduce measurement error.
6. Create the chart to record your measurements.
7. Perform the experiment and record your data (including units) in the chart and complete your calculations.

Option 3: Students with less understanding will get the direct instruction and support.

1. Click on the single fixed pulley system.
2. You will pull/lift three Loads: 5 N, 10 N, and 15 N. Each weight will be lifted by 0.,10 meters.
3. Set your Load to 5 N and Height to Lift to 0,10 m. Pull down on the hand with the force needed to lift the load.
4. Record your data (including units) in the chart and complete your calculations.
5. Repeat the experiment with the Load 5 N at least 2 more time.
6. Repeat the action 3.-5. for the Load 10 N
7. Repeat the action 3.-5. for the Load 15 N.

Chart to record the experimental data:

	Load, Fl	**Height Lifted, *Dl***	**Applied Force, Fe**	**Distance Pulled, De**	**Input Work *Wi = Fe x De***	**Output Work *Wo = Fl x Dl***	**Actual MA, Fl/Fe**	**Ideal MA, De/Dl**	**Efficiency, Wo/Wi x 100%**
1.	5 N	0,1 m							
2.	5 N	0,1 m							
3.	5 N	0,1 m							
4.	10 N	0,1 m							
5.	10 N	0,1 m							
6.	10 N	0,1 m							
7.	15 N	0,1 m							
8.	15 N	0,1 m							
9.	15 N	0,1 m							

NOTE: as you notice we keep Height Lifted is unchangeable, i.e. without modification, while Load variable is changeable.

Data Analysis

Make a *Bar Graph* to show the pulley system data – the type of pulley and the effort it takes to lift the load. Remember title, labels, correct units of measurement, and spacing. For this activity, you'll need to use separate paper.

After conducting the experiment.

Q4.1: What relationship does the received data show?

Message for the teacher:

Students will in free style introduce their thoughts about the experiment data set.

Q4.2: Explain why your hypothesis was supported / not supported using actual data from the experiment.

Message for the teacher:

Students will in free style introduce their thoughts about the experiment data set.
The questions Q4.2.1, Q4.2.2 and Q4.2.3 will help student to reflect on their experience of experiment design and its conduction.

Q4.2.1 Did the experiment validate your hypothesis?

A. YES (proceed to the next question)
B. NO (teacher decide whether student should rebuild the hypothesis and do the experiment again)

Q4.2.2: After performing the experiment. Can you in own words explain the work of simple fixed pulley?

A. YES
B. NO
C. I can with help of teacher or parents

Q4.2.3: Do you still think your initial answer and experiment were reliable?

A. I think I need to review my understanding of the fixed pulley.
B. I want to redo my experiment in extracurricular time.
C. Yes, I am fine with the results.

Reflection

SUMMARY:

A fixed pulley changes the direction of the required force. For example, to lift a basket from the ground, the effort would be applied downward instead of pulling up on the object.
The same amount of force is still required, but is applied in different direction.

TIPS and TRICKS: A mechanical advantage (MA) is easy to calculate for pulleys. Simply count the number of ropes supporting the movable load.

A fixed pulley provides no mechanical advantage. Therefore, the Single Fixed Pulley MA equals 1.
Please, write down examples of single fixed pulley usage (5 min):

Example for teachers: weight machines at a gym, some elevators, flagpoles, window blinds, bicycle rings/chains, clotheslines, water well bucket/rope, rock climbing devices, and sailing and fishing boats

CONTROL UNDERSTANDING:

Q5.1 The efficiency of a *real* simple machine is always less than 100 percent because some fraction of the input work is always converted to heat energy due to friction.

A. True
B. False

> Good to remember
> The efficiency of a machine is the ratio of the **work done (or energy)** by the machine on the Load to the **work done (or energy) on the machine by the Effort.**
> Efficiency = WOUT/WIN
> Mechanical advantage of a machine is the ratio of the **output force** (FOUT) to the **input force** (FIN).
> MA = FOUT/FIN

Message for the teacher:

Answer A is correct answer.
Answer B is incorrect answer.

Explanation: in our lessons we assume that there is no friction and rope is inelastic. This is the ideal situation. In real life, there are friction and resistance among rope, pulley and air. Therefore, efficiency in real machines will always be less than 100 percent because of work that is converted to unavailable heat by friction and air resistance.

Q5.2 Can you lessen/reduce the amount of force you must apply by attaching weights to the end of the rope that you pull?

A. No, I cannot
B. Yes, I can

Message for the teacher:

Answer B is correct answer.
Answer A is incorrect answer.
The next question helps students to explain the phenomenon applying their knowledge in the weight and gravity.

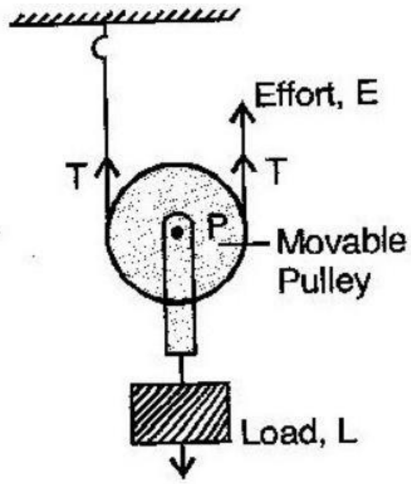
Q5.2.1 How can you explain your answer by considering an advantage of gravity?

> *Explanation*: By attaching objects of equal weight to both sides of the rope, we will create a balanced system, i.e., neither object moves. Once a force is applied to either side, the system continues moving in that direction.

Let us study movable pulleys

A single fixed pulley system is useful for raising an object. Although it doesn't provide a mechanical advantage, movable and compound pulleys provide it.
Let us prove that a movable pulley provides a mechanical advantage.

In a movable pulley system, the rope is attached to a fixed (non-moving) point, the pulley is free to move up and down and attached to the object (Load) that you want to move, and the other end of the rope is left free. As you pull on the rope, the pulley moves (rotates) causing the object to be lifted.



Hypothesis:

Q6.1 – H1: If we use an ideal single movable pulley system, then the force applied by the pulley to the Load will be

A. greater than the force (Effort) you put in
B. less than the force you put in
C. equal to the force you put in

Q6.1 – H2: In a single movable pulley, if the load increases, then the required the Effort/applied force to lift this load also increases. Is this a correct statement?

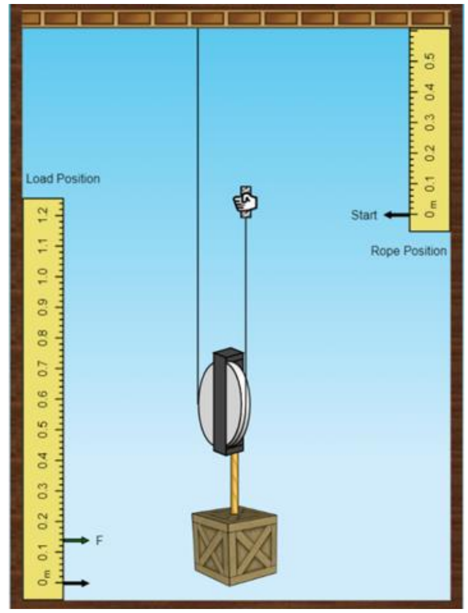
YES / NO

Q6.1 – H3: If we use an ideal single movable pulley, then the mechanical advantage of this system is:

A. MA = 1
B. MA = 2
C. MA = 4

Message for the teacher:

The questions Q6.1 are the Hypothesis questions. During the next activities students should conduct the experiment and evaluate their answers. On this phase a teacher can suggest to students to create their own hypothesis.



Q6.1 – H1 Answer A is correct answer.
Answer B or C is incorrect answer.
Q6.1 – H2 Answer A is correct answer.
Answer B is incorrect answer.
Q6.1 – H3 Answer B is correct answer.
Answer A or C is incorrect answer.

Let us check your hypotheses

Experiment:
Go to the link to get a virtual simulation:
https://compassproject.net/html5sims/pulleysim/pulley_en.html

I. If your students already performed the experiment to the single fixed pulley, then they can repeat the same experiment for the movable pulley.

Q7.1: Repeat the experiment for the movable pulley similar to fixed pulley.

Note for students: Test a single variable by changing it while keeping all other variables constant without modification during the experiment. Think what a variable you could keep unchangeable and which one you could test.
Pay additional attention to the connection between Energy and Applied Force.

Click on the Movable pulley. Record your data in the chart for a data collection and complete your calculations. Please do not forget to provide the units.

II. If your students did not perform the experiment to the single fixed pulley, then please introduce them the process of experiment design and its implementation to check the hypothesis formulated above.

Process of experiment design
Option 1: Students with good understanding can create the experiment without a system or teacher support.

Option 2: Students with not good enough understanding will get the guided instruction and support, if is needed. Do you have a difficulty from what to start? Please, check the hints.
Hint: In order to test a hypothesis, test a single variable by changing it while keeping all other variables the same during the experiment. Think what a variable you could keep unchangeable and which one you could test.

1. Select movable pulley system.
2. Decide about the independent variables, such as load that you will lift.
3. Decide and select the distance or the height to lift the load.
4. Think about and provide in the design of experiment which dependent variables such as forces, work done, energy, distance pulled, etc. that you can record during this experiment.
5. Think and provide in the experiment design how many times you have to repeat the selected experiment in order to reduce measurement error.

6. Create the table to record your measurements.
7. Perform your experiment. Record your data (including units) in the table and complete your calculations.

<u>*Option 3:*</u> Students with less understanding will get the direct instruction and support.

1. Click on the movable pulley system in the application.
2. You will pull/lift three Loads: 5 N, 10 N, and 15 N. Each weight will be lifted by 0,10 meters.
3. Set your Load to 5 N and Height to Lift to 0,10 m. Pull up on the hand with the force needed to lift the load.
4. Record your data (including units) in the chart and complete your calculations.
5. Repeat the experiment with the Load 5 N at least 2 more times.
6. Repeat this experiment for the Load 10 N.
7. Repeat this experiment for the Load 15 N.

<u>Note:</u> please pay attention that we keep all the variables of the experiment unchangeable while modify only the Load.

Chart to record the experimental data:

	Load, Fl	**Height Lifted, *Dl***	**Applied Force, Fe**	**Distance Pulled, De**	**Input Work *Wi = Fe x De***	**Output Work *Wo = Fl x Dl***	**Actual MA, Fl/Fe**	**Ideal MA, De/Dl**	**Efficiency, Wo/Wi x 100%**
1.	5 N	0,1 m							
2.	5 N	0,1 m							
3.	5 N	0,1 m							
4.	10 N	0,1 m							
5.	10 N	0,1 m							
6.	10 N	0,1 m							
7.	15 N	0,1 m							
8.	15 N	0,1 m							
9.	15 N	0,1 m							

NOTE: we hope that you notice that we keep Height Lifted the same, while the Load variable is changed. Modifying only one variable, in our case, the Load, you can observe how it influences the other variables.

Data Analysis

Make a *Bar Graph* to show the pulley system data – the type of pulley and the effort it takes to lift the load. Remember title, labels, correct units of measurement, and spacing. For this activity, you'll need to use a separate paper.

After conducting the experiment.

Q8.1: What relationship does the received data show?

Q8.2: Explain why your hypothesis was supported / not supported using actual data from the experiment.

Q8.2.1: Did the experiment validate your hypothesis?
A. YES (proceed to the next question)
B. NO (teacher decide whether student should rebuild the hypothesis and do the experiment again)

Q8.2.2: After performing the experiment. Can you in own words explain the work of simple fixed pulley?
A. YES
B. NO
C. With help of teacher or parents

Q8.2.3: Is the Energy depends on the applied Force?
YES/NO

Could you please justify your answer?

Q8.2.4: Do you still think your initial answer and experiment were reliable?
A. I think I need to review my understanding of the fixed pulley.
B. I want to redo my experiment in extracurricular time.
C. Yes, I am fine with the results.

Q8.3: Please draw the pulley system that combined single fixed and single movable pulleys. For this activity, you'll need to use separate paper. Take a photo and send to the Padlet (https://padlet.com/)

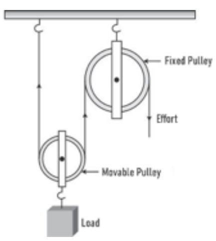
Message for the teacher:

The questions Q8.3 and Q8.4 are the linked questions. They enable the development of visual and engineering competencies through the visual presentation of objects based on their descriptions.
Q9.0 Answer D is correct answer.
Answer A or B or C is incorrect answer.

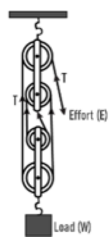
Let us study compound pulleys.

A compound pulley system combines a fixed (not moving, attached to the ceiling or wall) pulley with N movable pulleys (attached to the load). The single compound system consists of one fixed pulley and one (N=1) movable pulley.

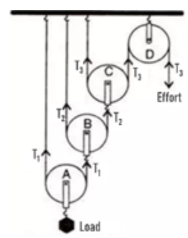
Q9.0: The compound pulleys are presented in the images below. Select the images that demonstrate compound pulleys diagramme:



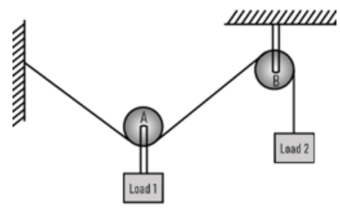
A



B



C



D

A. A, C & D
B. A, B & D
C. A, B & C
D. A, B, C & D

Hypothesis:

Q9.1 – H1: If we use an ideal **single** compound pulley system, then the mechanical advantage of this system is:

A. MA = 1
B. MA = 2
C. MA = 3

Hints for (M & L):
Calculating the IMA for pulleys is simple! Just count the ropes holding the load.

Q9.1 – H2: If we use an ideal double compound pulley system, then the mechanical advantage of this system is MA= (provide your answer)

Q9.1 – H3: If we use an ideal triple compound pulley system, then the mechanical advantage of this system is MA= (provide your answer)

Message for the teacher:

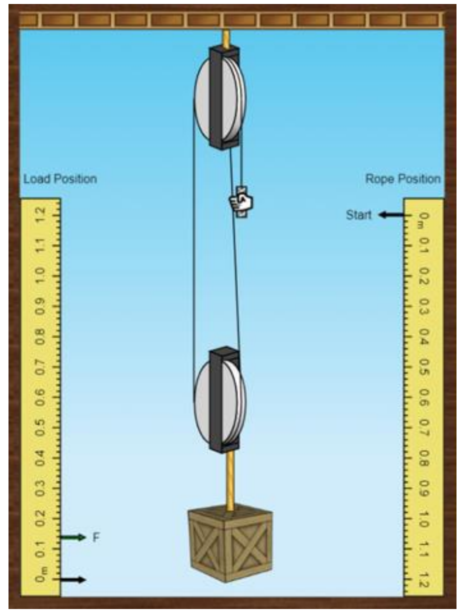
The questions Q9.1 are Hypothesis questions. One of them is multiple choice.

Q9.1 – H1: Answer B is correct answer.

Answer A or C is incorrect answer.

Two others are with open answers. We should not expect the correct answers, which will be tested during the experiment. For some students teacher can suggest the multiple choice questions (please see page 31).

Let us check this hypothesis



Experiment:

Q10.1: Repeat the experiment for the single, double and triple compound pulley similar to fixed and movable pulley.

Note for students: Test whether energy and output work depend on the Load, High lifted, Applied Force; whether does exist difference between actual and ideal MA and Efficiency.

Select the single compound pulleys. Repeat the experiment similar to fixed and moveable pulleys. Record the data into the chart:

	Load, Fl	**Height Lifted, *Dl***	**Applied Force, Fe**	**Distance Pulled, De**	**Input Work *Wi = Fe x De***	**Output Work *Wo = Fl x Dl***	**Actual MA, Fl/Fe**	**Ideal MA, De/Dl**	**Efficiency, Wo/Wi x 100%**
1.	5 N	0,1 m							
2.	5 N	0,1 m							
3.	5 N	0,1 m							
4.	10 N	0,1 m							
5.	10 N	0,1 m							
6.	10 N	0,1 m							
7.	15 N	0,1 m							
8.	15 N	0,1 m							
9.	15 N	0,1 m							

Double compound pulleys (one fixed pulley and two movable ones). Select the correct MA for it.

A. MA = 1
B. MA = 2
C. MA = 4 (correct answer)

Check whether your answer is correct with the experiment:

	Load, Fl	Height Lifted, *Dl*	Applied Force, Fe	Distance Pulled, De	Input Work *Wi = Fe x De*	Output Work *Wo = Fl x Dl*	Actual MA, Fl/Fe	Ideal MA, De/Dl	Efficiency, Wo/Wi x 100%
1.	5 N	0,1 m							
2.	5 N	0,1 m							
3.	5 N	0,1 m							
4.	10 N	0,1 m							
5.	10 N	0,1 m							
6.	10 N	0,1 m							
7.	15 N	0,1 m							
8.	15 N	0,1 m							
9.	15 N	0,1 m							

Triple compound pulleys. Select the correct MA for it.

A. MA = 6 (correct answer)
B. MA = 2
C. MA = 4

Explain your answer, please.

Data Analysis:

Make a *Bar Graph* to show the pulley system data – the type of pulley and the effort it takes to lift the load. Remember title, labels, correct units of measurement, and spacing. For this activity, you'll need to use separate paper.

Message for the teacher:

The Data Analysis activity devoted to the student's reflection on the experiment design and experimental data collected during this experiment. Student is encouraged to show the relations between the data received and hypothesis questions (s)he is selected. The guided questions assist in constructing the reflections.

After conducting the experiment.

Q11.1: What relationship does the received data show?

Q11.2: Explain why your hypothesis was supported / not supported using actual data from the experiment.

Q11.2.1: Did the experiment validate your hypothesis?

A. YES (proceed to the next question)
B. NO (teacher decide whether student should rebuild the hypothesis and do the experiment again)

Q11.2.2: After doing the experiment. Can you in own words explain the work of simple movable pulley?

A. YES
B. NO
C. I can with help of the teacher or parents.

Q11.2.3: Is the Energy depends on the applied Force?

YES/NO

Q11.2.4: Is the output Work depends on the Load?

YES/NO

Q11.2.5: Is the output Work depends on the Load?

YES/NO

Could you please justify your answers to Q11.2.3-Q11.2.5?

Hints: check your completed charts/tables

Q11.2.6: Do you still think your initial answer and experiment were reliable?

A. I think I need to review my understanding of the fixed pulley.
B. I want to redo my experiment in extracurricular time.
C. Yes, I am fine with the results.

Reflection:

Q12.1: If the type of the pulley system is changed, then the mechanical advantage it provides is also changed.

A. True
B. False

Please provide your reasoning.

Q12.2: Please elaborate your thoughts on the question: Based on the experiment, you've observed that the pulley systems multiply the force, do they multiply work or energy? What will your answer be?

YES, they multiply work or energy /NO, they do not multiply work or energy.
Please, elaborate your reasoning.

Explanation for the students who have answered "YES, they multiply work or energy": *Please check the data in your tables of the experiments fixed, movable and compound pulleys system. Compare input work and output work. What do you notice? What will be your conclusion?*

Message for the teacher:

The questions Q12.1 engages the student to reflect on the whole set of the experiments and explains why when the pulley system is changed, the mechanical advantage is also changed. The reasoning should be based on the performed experiments data. If student has a difficulty to answer, we suggest to a teacher to interview him/her to understand the misconception.

Q12.1 – H1: Answer A is correct answer.
Answer B is incorrect answer**.**

The question Q12.2 (correct answer is "**NO, they do not multiply work or energy**") allows to control whether student grasps that the force and the energy are interchangeable. Students should know that a simple machine, in our case pulley, increases the forces, but not the performed work. A teacher may encourage students to check their experimental data one more time otherwise an interview performed by a teacher is needed to explain this phenomenon to the student.

Q (Bonus): Find at least one image of sport equipment applying the pulleys system and explain how it works (a teacher can suggest an image)

Watch the video:
https://www.youtube.com/watch?v=r3Ru1zZjvug&ab_channel=funsciencedemos

Message for the teacher:

During Engagement /Orientation stage you may introduce students the real pulley. Students play with real pulley in the class before performing the experiment. Then you can use simulation out of the list of PhET Interactive Simulations or hands-one experiment.

Alternatively, you can introduce Engineering component in your instruction by implementing science project – a practical activity for your students. Depends on your students' age, you can find some idea for the project:

- https://www.education.com/science-fair/article/flag-raiser/
- https://www.sciencebuddies.org/science-fair-projects/project-ideas/ApMech_p010/mechanical-engineering/pulleys-lighten-loads
- https://www.teachengineering.org/activities/view/cub_simple_lesson05_activity1

Trajectory for Learners

The following table presents the different trajectory taken by the students while navigating the Phases of the provided above Scenario - Simple Machine: Pulley.

<table>
<tr><th>Question</th><th>Path A - Knowledge and Competence level A</th><th>Path B - Knowledge and Competence level B</th><th>Path C - Knowledge and Competence level C</th></tr>
<tr><td colspan="4">Engagement/Orientation</td></tr>
<tr><td>Q1.1</td><td>C
(Q1.2)</td><td colspan="2">A, B, D, E
(guided explanation with Q1.1.1)</td></tr>
<tr><td>Q1.1.1</td><td>C
(Q1.2)</td><td colspan="2">A, B
(direct explanation, internet resources)</td></tr>
<tr><td>Q1.2</td><td>B</td><td colspan="2">A, C, D, E</td></tr>
<tr><td>Q1.3</td><td>A</td><td colspan="2">B, C, D, E</td></tr>
<tr><td>Q1.4</td><td>C
(Q1.5)</td><td colspan="2">A, B
(guided explanation with Q1.4.1 & Q1.4.2)</td></tr>
<tr><td>Q1.4.1</td><td>C</td><td>A</td><td>B</td></tr>
<tr><td>Q1.4.2</td><td>B
(Q1.5)</td><td>A, C
(direct explanation)</td><td>A, C
(direct explanation)</td></tr>
<tr><td>Q1.5</td><td>C
(Q1.6)</td><td>A
(guided explanation Q1.5.1)</td><td>B
(guided explanation Q1.5.2.x)</td></tr>
<tr><td>Q1.5.1</td><td>A
(Q1.5.1.1)</td><td>B
(direct explanation)</td><td>C
(direct explanation)</td></tr>
<tr><td>Q1.5.1.1</td><td>A</td><td>B
(direct explanation)</td><td></td></tr>
<tr><td>Q1.5.2.1</td><td>A</td><td>B, C</td><td>B, C</td></tr>
<tr><td>Q1.5.2.2</td><td>C</td><td>A, B, D</td><td>A, B, D</td></tr>
<tr><td>Q1.5.2.3</td><td>A</td><td>B, C</td><td>B, C</td></tr>
<tr><td>Q1.5.2.4</td><td>B</td><td>A, C</td><td>A, C</td></tr>
<tr><td>Q1.5.2.5</td><td>A</td><td>B
(direct explanation)</td><td>B
(direct explanation)</td></tr>
<tr><td>Q1.6</td><td>>80%</td><td>From 50% to 80%
(interview by teacher)</td><td><50%
(Teacher involvement is needed)</td></tr>
</table>

Q1.7	B	A, C, D, E (explanation)	
Q1.8	C (Hypothesis)	A, B, D (guided explanation 1.8.1)	
Q1.8.1	A (Q1.8.1.2)	B (guided explanation 1.8.1.1)	
Q1.8.1.1	B	A, C (Q1.8.1.2)	
Q1.8.1.2	B	A, C (correct answer)	
The single fixed pulley			
Hypothesis			
Q2.1 -H1	C	A	B
Q2.1 -H2	A	B	C
Q2.1 -H3	A (Experiment)	B (Experiment)	B (Experiment)
Experiment, Planning			
Q3.1.1	D	A or B	C, E
Q3.1.2	A	C	B
Q3.1.3	B	C	A
Experiment			
Q3.2	Experiment design and performance without or little support	The guided instruction and support, if is needed	The direct instruction and support
Data Analysis			
Q4.1, Q4.2	(Reflection, Q5.1, Q5.2)	(Reflection Q5.2)	Q4.2.1, Q4.2.2, Q4.2.3
Reflection			
Q5.1	A	B	
Q5.2	B	A (hint Q5.2.1)	
The single movable pulley			
Hypothesis			
Q6.1 – H1	A	**C**	B
Q6.1 – H2	A	B	
Q6.1 – H3	B	C	A
Experiment			
Q7.1	Experiment design and performance without or little support	The guided instruction and support, if is needed	The direct instruction and support
Data Analysis, Reflection			
Q8.1, Q8.2, Q8.2.3	Q8.3	Q8.2.1, Q8.2.2, Q8.2.3, Q8.2.4, Q8.2.5, Q8.2.6, Q8.3	Q8.2.1, Q8.2.2, Q8.2.3, Q8.2.4, Q8.2.5, Q8.2.6, Q8.3
The compound pulley			

Hypothesis			
Q 9.1 – H1	B	C	A
Q 9.1 – H2	Open answer	multiple-choice	multiple-choice
Q 9.1 – H3	Open answer	Open answer	multiple-choice
Experiment			
Q10.1	Repeat the experiment with new parameters	Repeat the experiment with new parameters and support, if is needed	The direct instruction and support
Data Analysis			
Q11.1	Open answer	Open answer	-
Q11.2	Open answer + Q11.2.3, Q11.2.4, Q11.2.5	Open answer + Q11.2.3, Q11.2.4, Q11.2.5	Q11.2.1 - Q11.2.6
Reflection			
Q12.1	A	B	
Q12.2	B	A (guided explanation)	
	Q(bonus)		

5.6. Ohm Law

Figure 76 Scenario presentation

The first phase of the scenario is devoted to awakening the curiosity of the student about the topic:

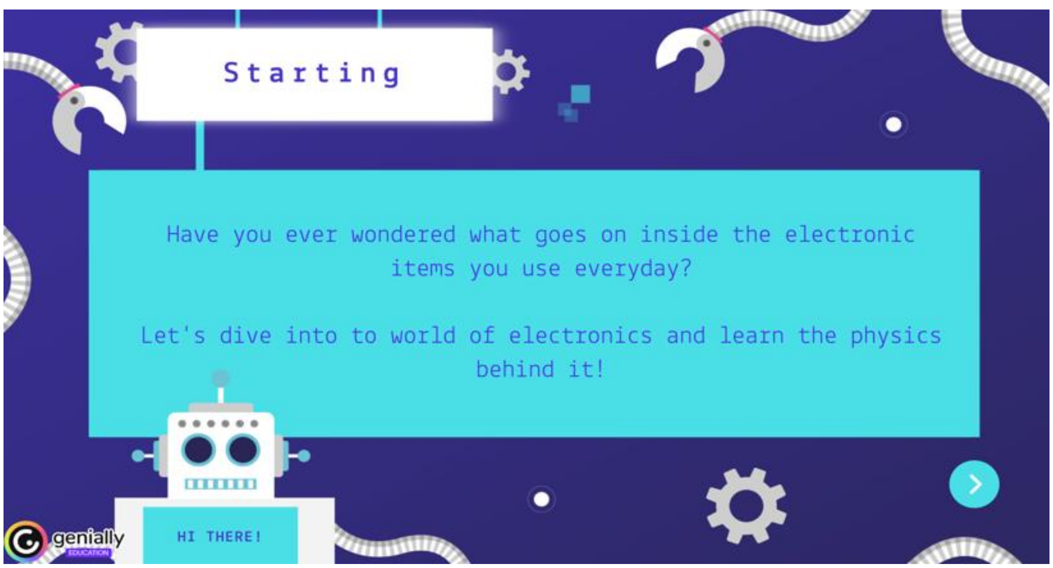


Figure 77 Engagement Phase

Students are invited to explore the virtual lab where they can learn about how to build electric circuits and what are the basic components. Using the lab offers an intuitive understanding of the relationship between voltage, current and resistance. Different material can be use and compared. This stage intends to increase their curiosity and spark their creativity.

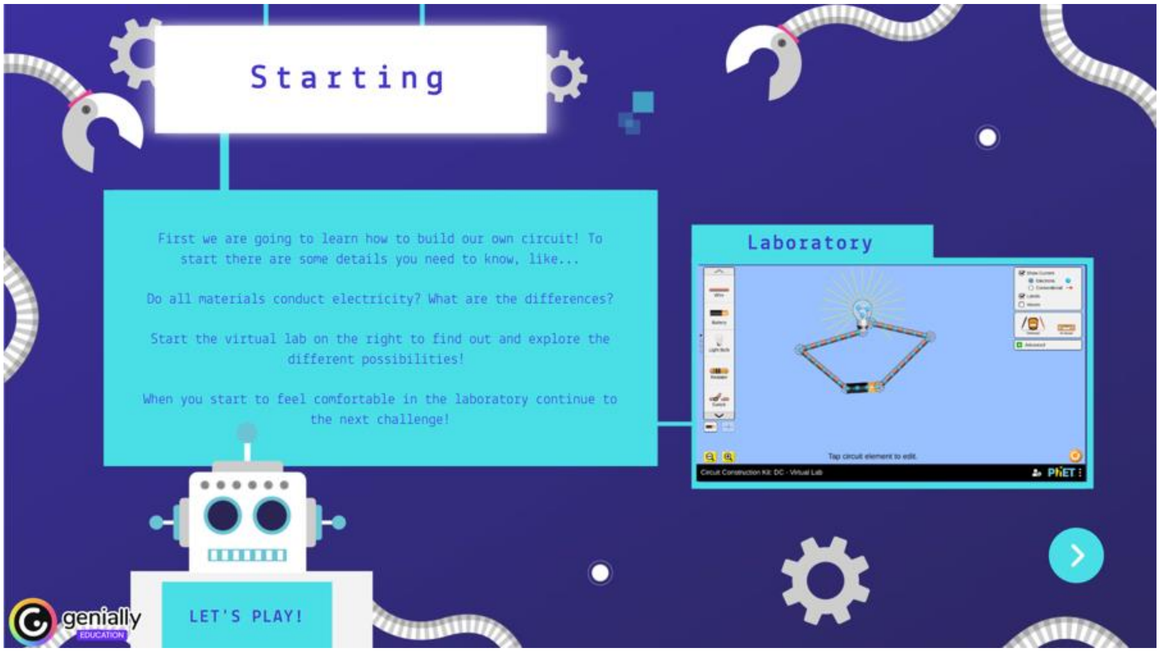


Figure 78 Engagement phase laboratory activity

Guidance for teachers:

With a little guidance, students are challenged to light up a lamp but given freedom to explore the different circuit components and try different materials. Curiosity and exploration can be triggered through questions such as: “Do all materials conduct electricity? How differently” Let students categorize materials by themselves. Teach how to use the voltmeter and ammeter. Ask them to describe voltage and current according to the output of their experiments in the virtual lab. Explain to students what voltage is, current and resistance.

After exploring the laboratory functionalities and learning how to create simple electric circuits, it is time for the students to start thinking about the physics behind what they are doing. They can still use the simulation while trying to answer the questions that follow. In fact, this will reinforce the acquisition of the competences they are activating during these activities.

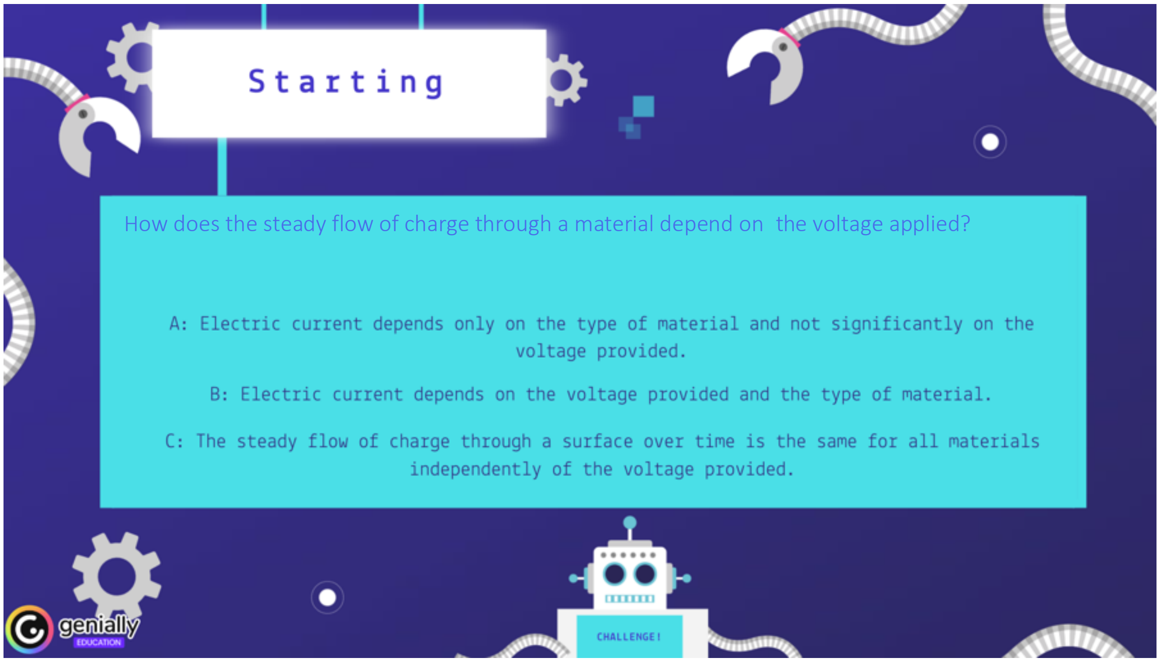


Figure 79 Engagement question Q1

This question is meant to test their basic understanding of how current depends on voltage and the type of material. Choosing **B** demonstrates a good understanding and leads directly to the **hypothesis phase**. Choosing **C** shows no understanding leading to further questions and extra guidance about the same topic. The same happens when students choose **A** – a limited understanding of the topic.

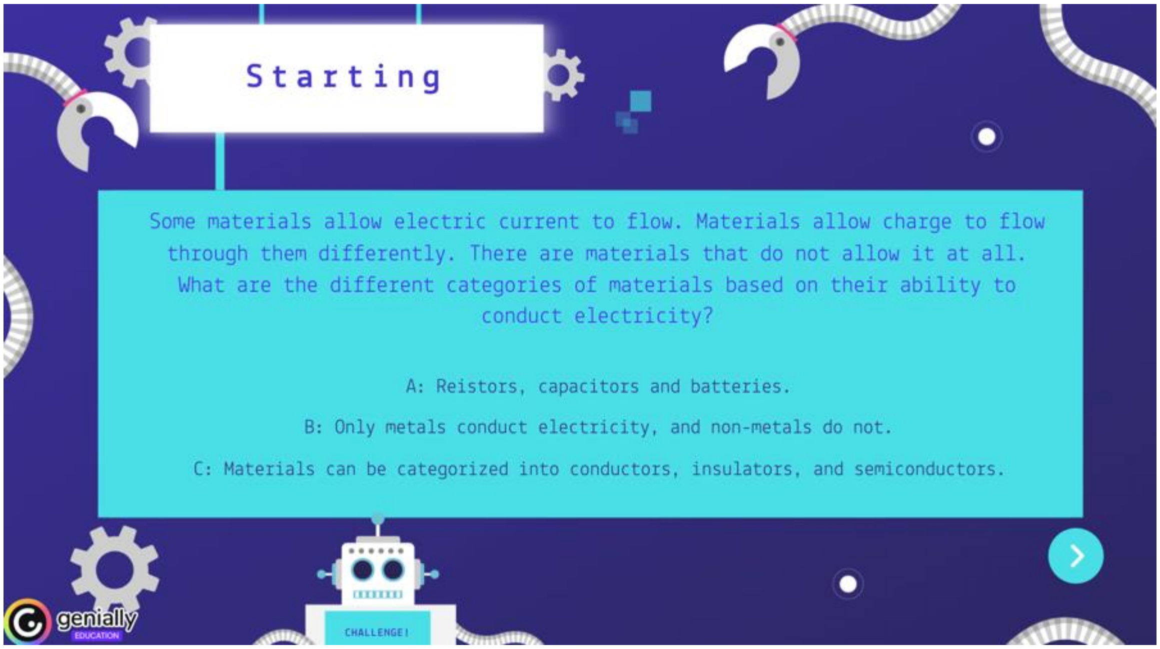


Figure 80 Engagement phase Q2.

Students who fail the **Q2** question of the engagement phase are provided with extra guidance and proposed to explore different types of materials in the to understand the current dependence on the type of material. After completing the challenge proposed, students proceed to the **Q3** question to understand how current depends on the voltage provided. If they answer the **Q2** correctly that are sent directly to **Q3.**

Figure 81 Engagement phase guidance for Q2 and virtual lab experiment.

In the **Q3** of the engagement phase students are provided with little extra guidance and asked to specify how exactly current depends on the voltage provided. As in the **Q2** question there are only correct/incorrect answers. Answering correctly leads directly to the **hypothesis phase**, otherwise, extra guidance is given and a laboratory activity is proposed to solidify students' understanding of the current dependence on the voltage provided. Only after will they proceed to the **hypothesis phase.**

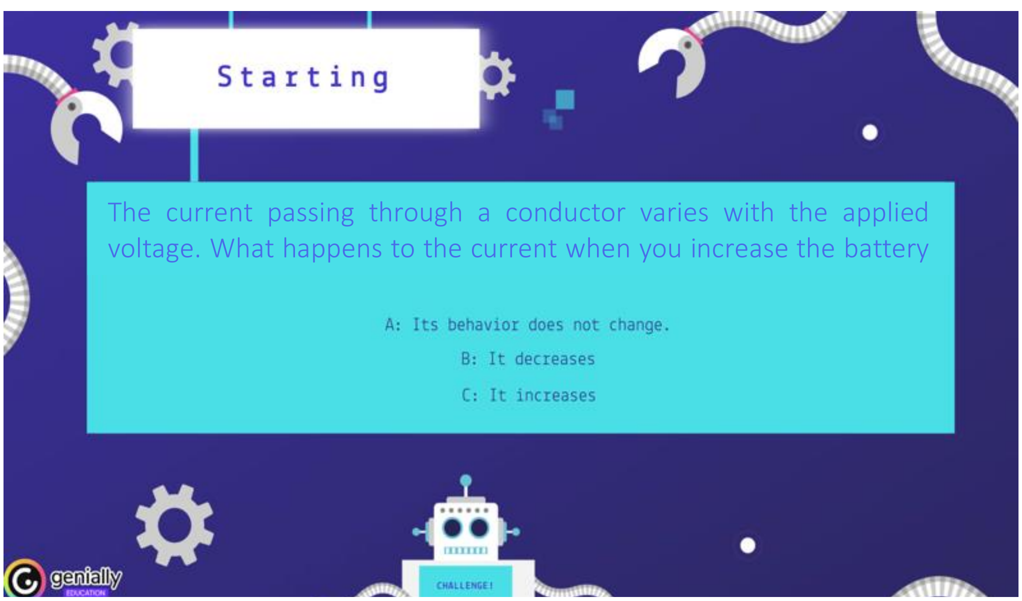


Figure 82 Engagement phase Q3.

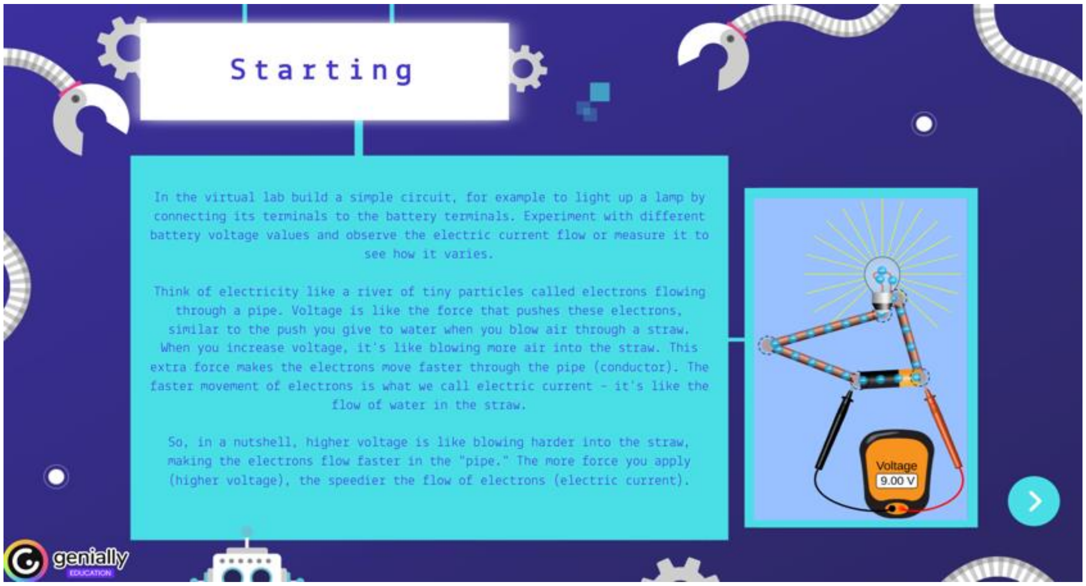


Figure 83 Engagement phase guidance for Q3 and virtual lab experiment

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Guidance for teachers:

Motivate students to explore the laboratory as much as they want until they feel comfortable to proceed to further challenges. Exploring the laboratory and observing the effects of trying different materials, components and parameters will provide them with a good intuition to start building hypotheses in the **hypothesis phase**. This is also the perfect moment to start using the voltmeter and ammeter to visualize and confirm the definitions of voltage, current and resistance.

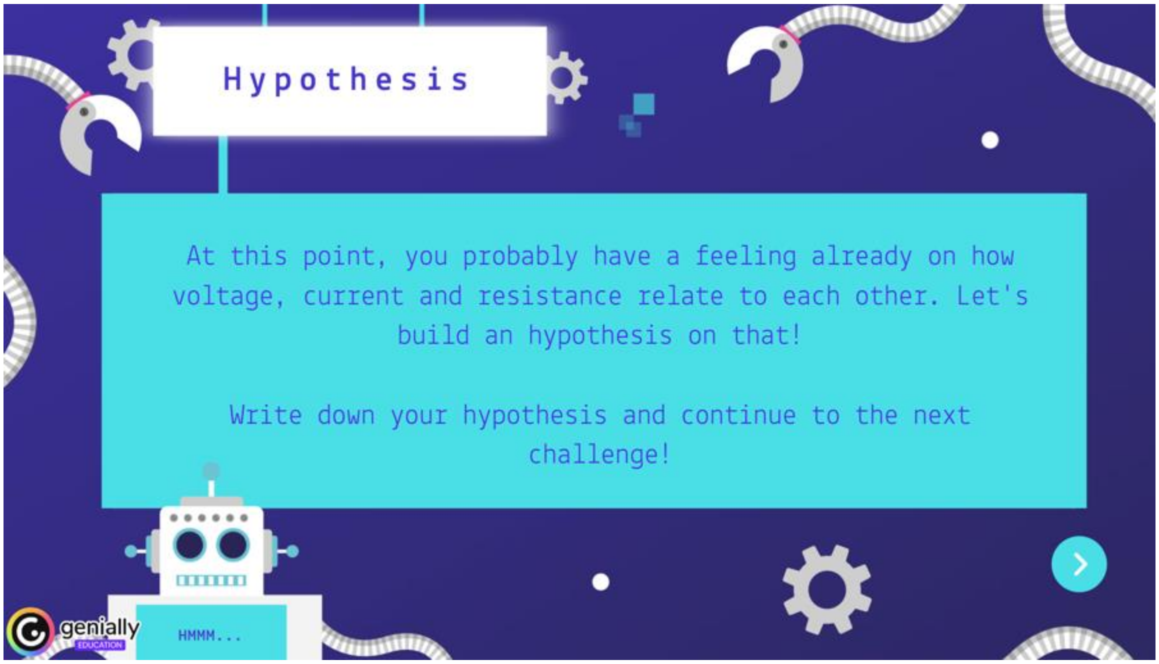

Figure 84 Hypothesis phase.

At this point students should have already understood, based on previous experiments and/or guidance, that different materials are like resistors with different resistance values. Teachers are instructed on how to support students in the process of building their hypotheses. After, students will be tested on whether their hypothesis implies a correct understanding of the concepts they came across with until now.

Guidance for teachers:

Start by suggesting creating a simple circuit composed of one energy source, a lamp (to help visualise the consequences of changing parameters) and a pencil/coin/clipper/etc. Simple circuits will make it easier to identify the variables at play. Using an ammeter in series with the battery and the pencil/coin/clipper/etc will allow students to measure the current in the circuit. Explain the importance of changing only one variable at a time. Suggest that they pick one variable that they believe is the cause for the change in electric current (e.g., voltage in the battery, the material used - pencil/coin/clipper/etc). Help them think about what changes will affect the results. Now suggest the construction of the predictions about what will happen when the variable changes (e.g., if the material is swapped when the voltage is held constant, then a certain current will be observed). Example Hypotheses: "If the resistance ________________ with voltage help constance, then we will observe________________."; “It the voltage _______________ with the circuit held constant, then we will observe ____________ ”. Encourage students to avoid vague statements and ensure their hypotheses are clear and measurable. Relate to the experiment they will perform. Help students connect their hypotheses to the material they will use. Guide them to think about how they can manipulate the parameters in order to test their hypotheses.

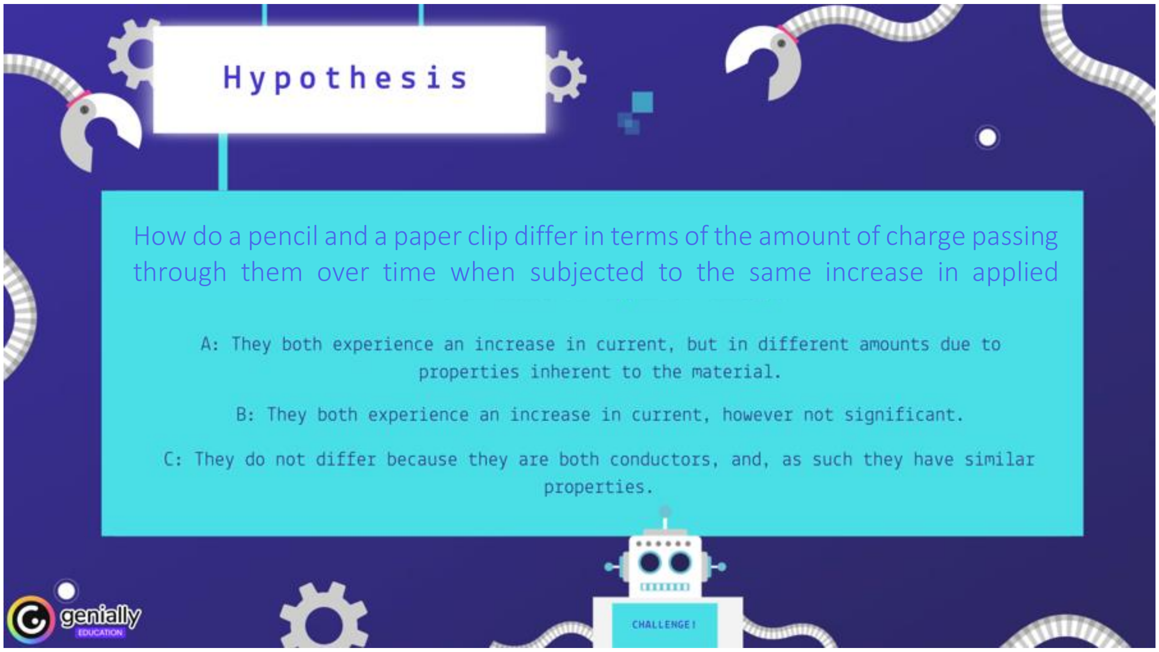

Figure 85 Hypothesis phase Q4 – testing on whether students' hypotheses rely on a correct understanding of the basic concepts.

Those who answer the question **Q4** correctly, whatever their hypothesis is, show a correct understanding of the basic concepts and thus can proceed to the experiment phase where their hypothesis will be tested. Those who do not answer the question correctly do not have a correct understanding of the basic concepts and are sent back to the engagement phase **Q2**. Those who show a limited understanding can also proceed to the **experiment phase but** will make an extra experiment **E1** before being presented and tested with the **Q4** again. Only after answering it correctly can they proceed to test their hypothesis **E2.** This is to ensure they understand the basic concepts well.

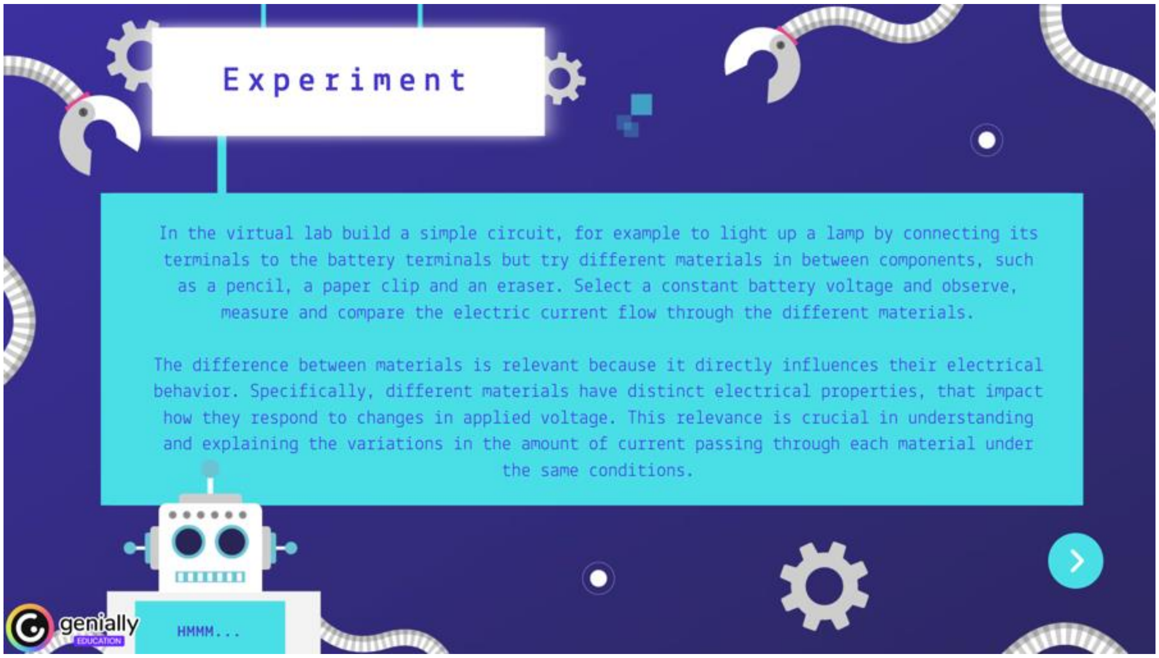

Figure 86 Experiment phase basic experiment E1.

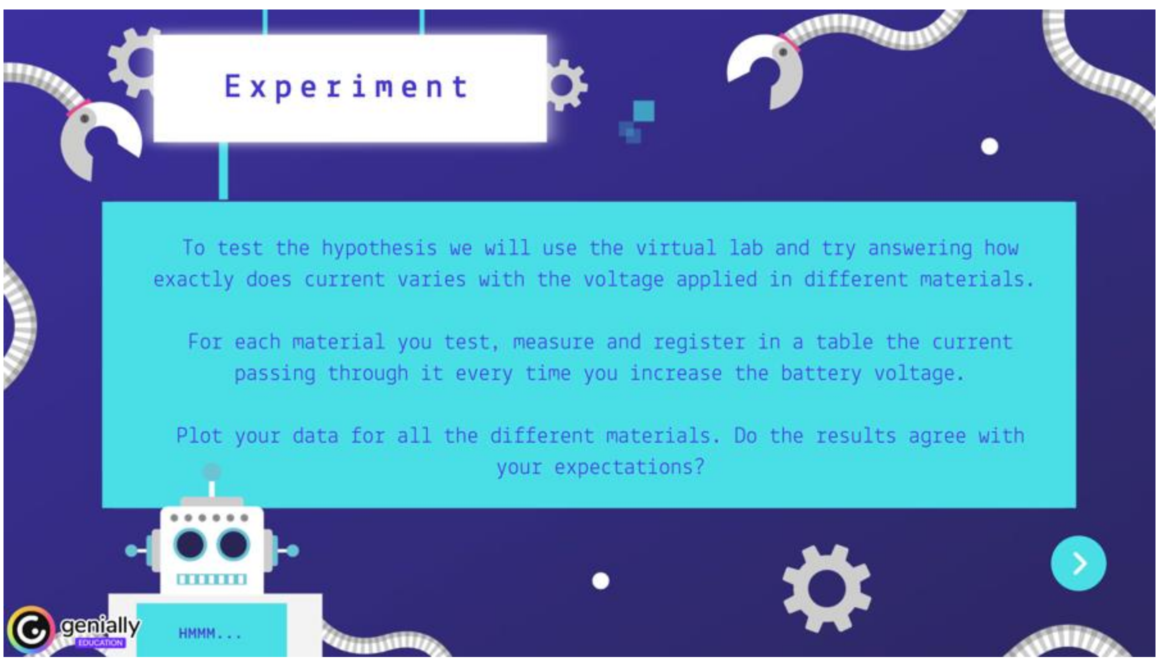

Figure 87 Experiment - experiment to test hypothesis E2.

Guidance for teachers:

For further guidance to students, you can suggest that students log all the data they gather as they progress with the experiments and create one table with the type of material and current with voltage held current, and another one with voltage and current with the circuit held constant. If their hypothesis about the relationship between voltage, current and resistance is correct and confirmed they must be able to predict they experiments' results from their model Most importantly, at this stage, students must have learned how to design experiments and collect the data. It is possible that they will reach inconclusive results due to the change of multiple variables at the same time. It is important to guide them on this reflection moment until they understand that the only way to collect the necessary evidence is to change one variable at a time. Always, make an effort to ensure that they understood how to design their experiments and collect the data.

After testing their hypotheses, students proceed to the analysis phase. The two main questions of the **analysis phase** are asked in sequence to test whether students have a correct understanding of their results, their model, and implications. Only if they answer to both **Q5** and **Q6** correctly can they proceed directly to the reflection phase. If they fail **Q5**, they proceed to **Q7.** (Even if **Q6** is correct because it implies understanding **Q5**). If **Q5** is correct but **Q6** is not, they proceed to **Q8.** In both cases they will receive extra guidance.

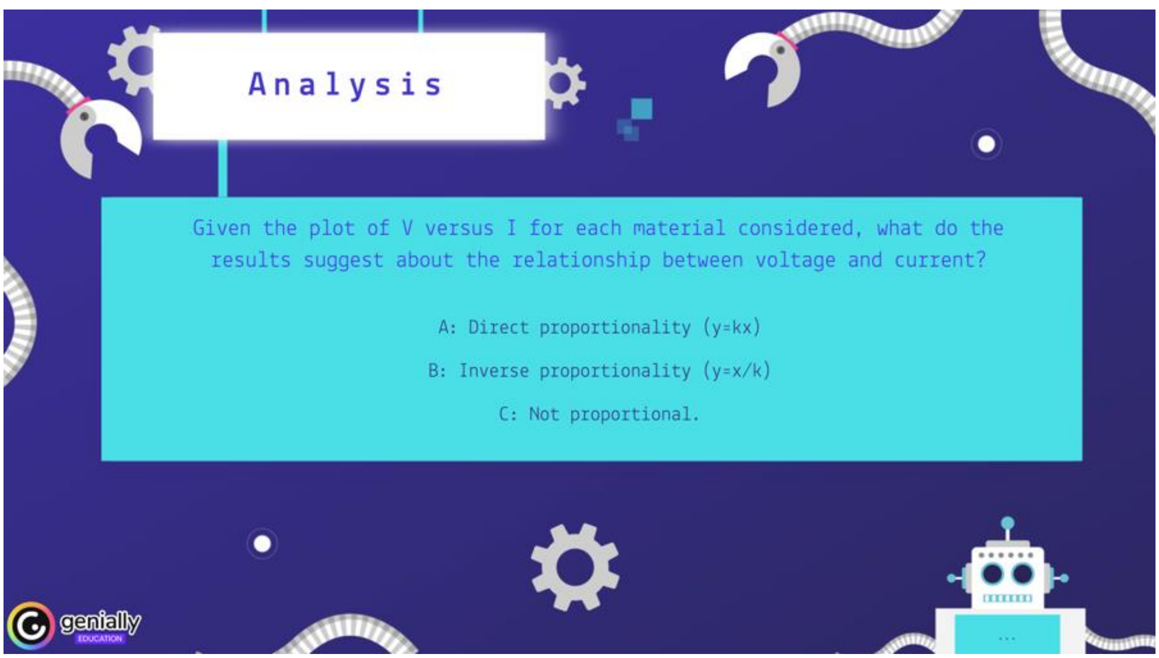

Figure 88 Analysis phase Q5.

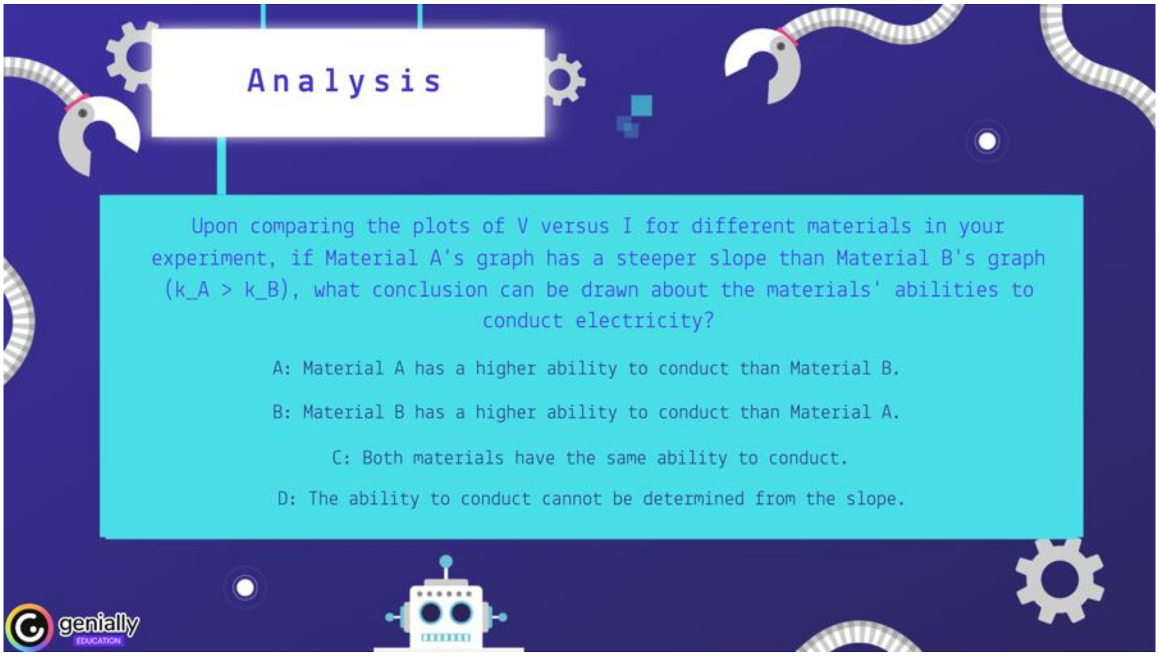

Figure 89 Analysis phase Q6.

Q7 is about inspiring critical analysis of their results. It is possible that they might have misinterpreted their results although they performed the experiments correctly. **Q7** encourages them to review their results and conclusions. If it is the case that results were misinterpreted they must eventually realize that, in fact, they can build a model that can predict their results, and thus they are sent back do **Q5.** However, if upon reviewing their results they conclude they are not able to build a predictive model, they are sent back to the **experiment phase.**

Guidance for teachers:

If students conclude that they are not able to build a predictive model, encourage them to remake their experiments and eventually review their hypothesis-

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Failing **Q6** shows that, although students arrived at a correct predictive model, they do not have a correct understanding of it. **Q8** provides extra guidance on this and challenges them to think again about it new information. If they answer to the question correctly they proceed to directly to the **reflection phase**. Otherwise, they are given more guidance and challenged with a new laboratory activity that helps them visualize the effects of manipulating the variables of their predictive model. After that, they are sent back to **Q5** to test their knowledge again.

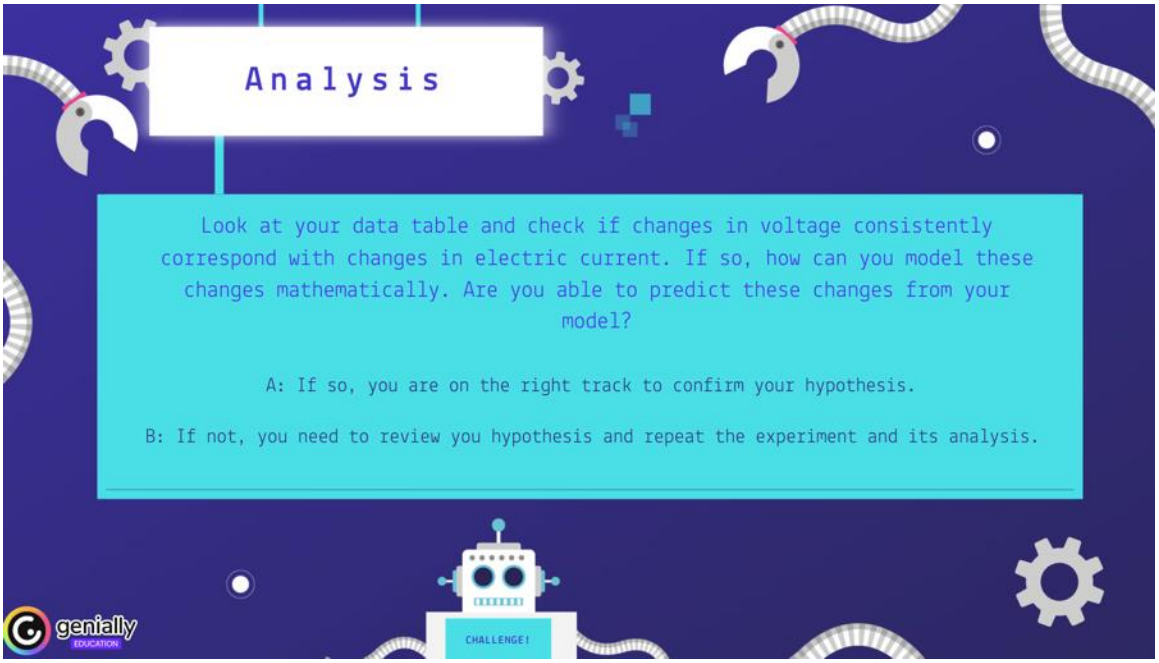


Figure 90 Analysis phase Q7.

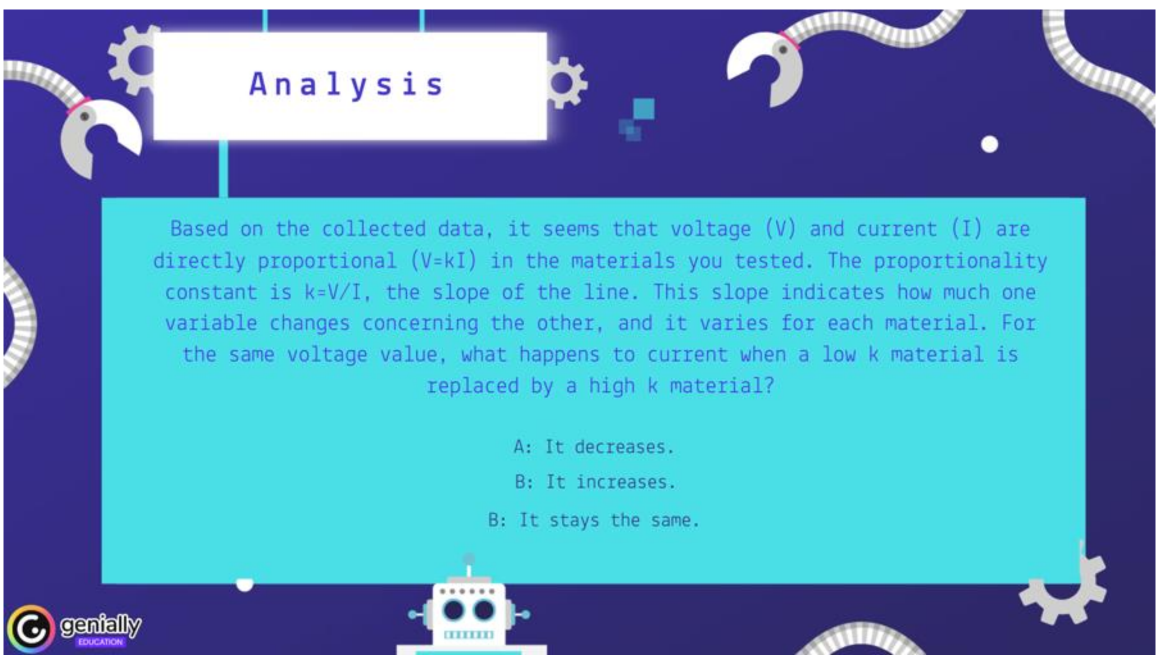


Figure 91 Analysis phase Q8.

Figure 92 Analysis phase Q8 guidance.

In the reflection phase, students are challenged to think about the implications of their conclusions. Here they are present with the same laboratory activity provided in the guidance of **Q8**. For those who did not go through the **Q8** guidance path, this activity will help students visualize the effects of changing the parameters V and R of the ohm's law. This is meant to solidify their knowledge.

Figure 93 Reflection phase

Students are again challenged to answer new questions and invited to reflect on some of the implications of their results. Moreover, these questions present new concepts and numeric examples to exemplify how the Ohm's law can be used in practice.

Failing **Q9** question shows a limited understanding of the implications of their experiments. As such it sends students back to **Q8** with extra guidance. Answering correctly allows them to proceed to **Q10**.

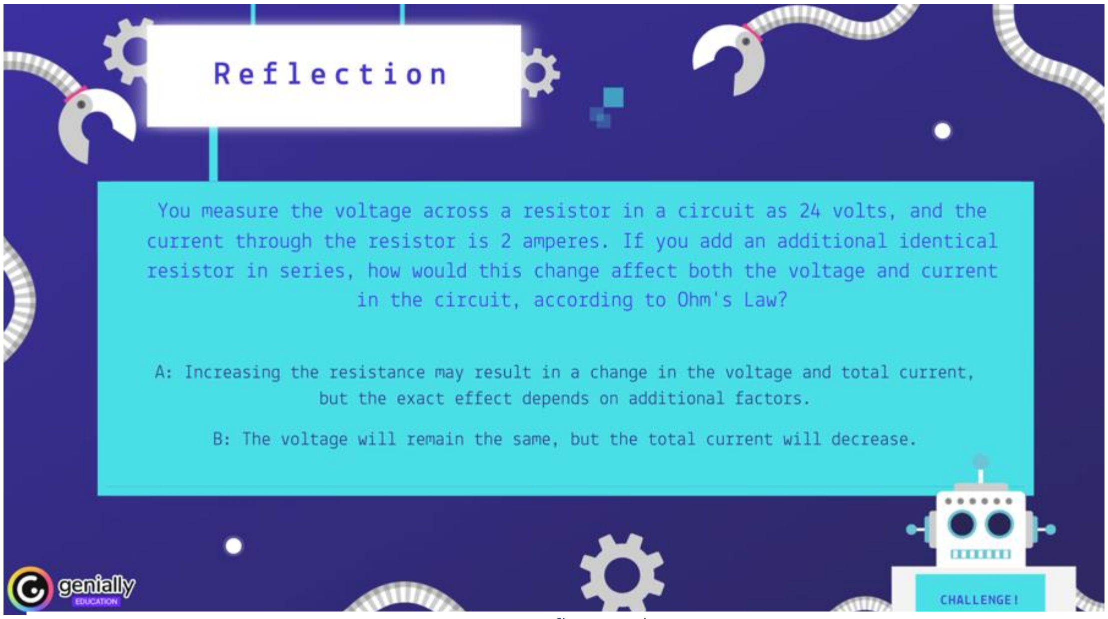


Figure 94 Reflection phase Q9

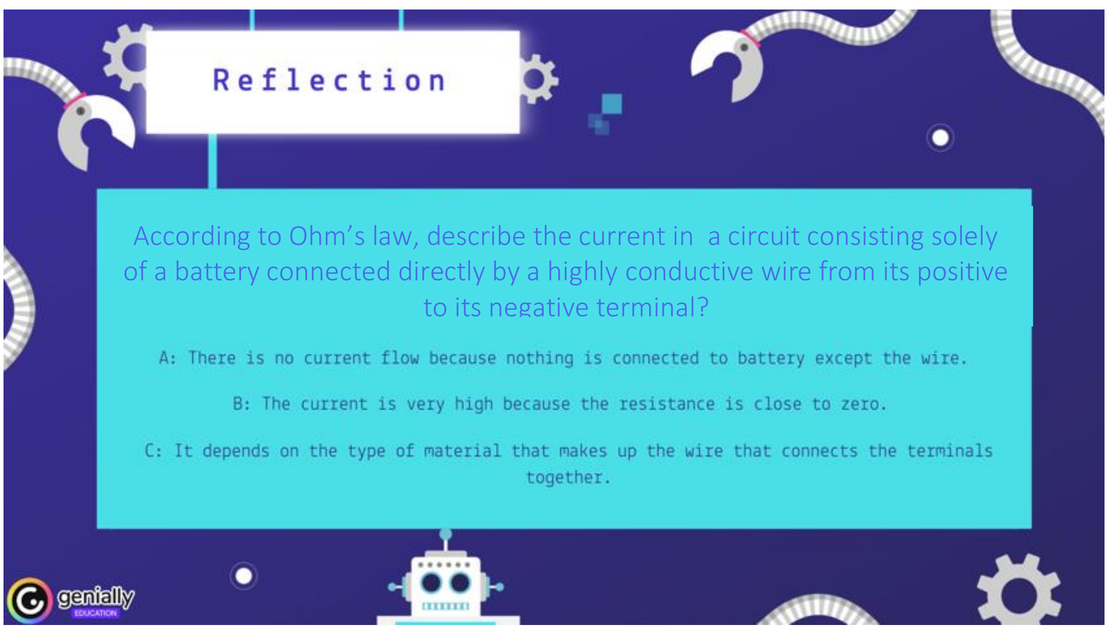


Figure 95 Reflection phase Q10

Q10 is a more abstract question that requires a deeper understanding of mathematics. It challenges students to relate mathematical abstractions and physical phenomena. Not answering it correctly will provide extra guidance with **Q10** and then let them proceed to **Q10**. The moderate knowledge answer will lead directly to **Q10**.

Figure 96 Reflection phase Q10LG

Figure 97 Reflection phase Q10M

Q10 challenges students to think more critically and in an abstract mathematical perspective. If they fail to understand the basic idea behind this question they are provided extra guidance and challenged with a virtual lab activity to measure the current in a circuit consisting solely of a battery with its terminals connected together through wires with no other components. After this, they are sent back to **Q11** to test their knowledge again on these topics.

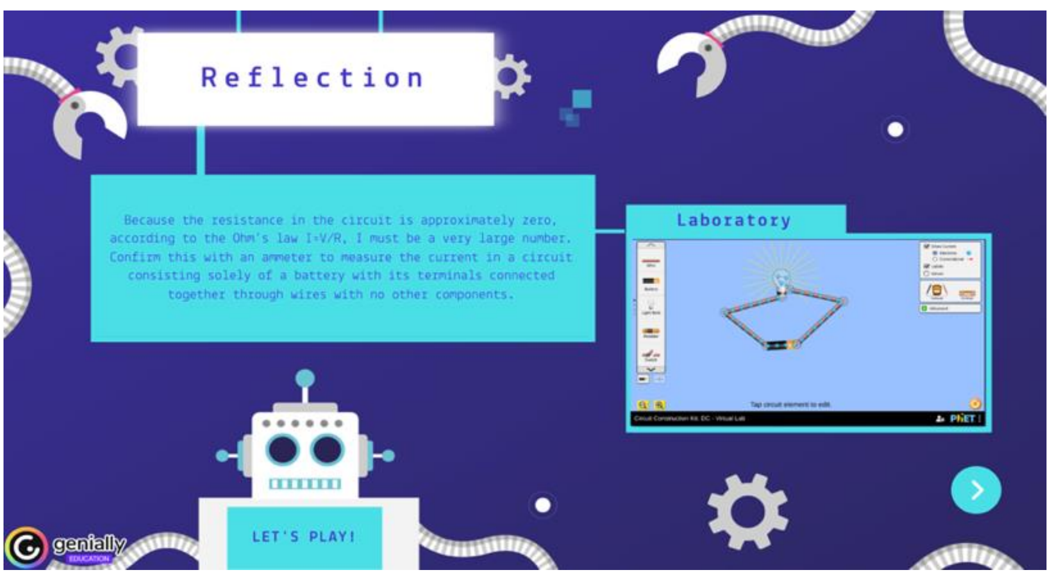


Figure 98 Reflection phase Q10M guidance

The activity ends with a last reflection about short circuits and a laboratory activity about it. The goal is to understand the physical implications of hm's law in electronic circuits and to promote a safe behaviour in the real-life laboratories.

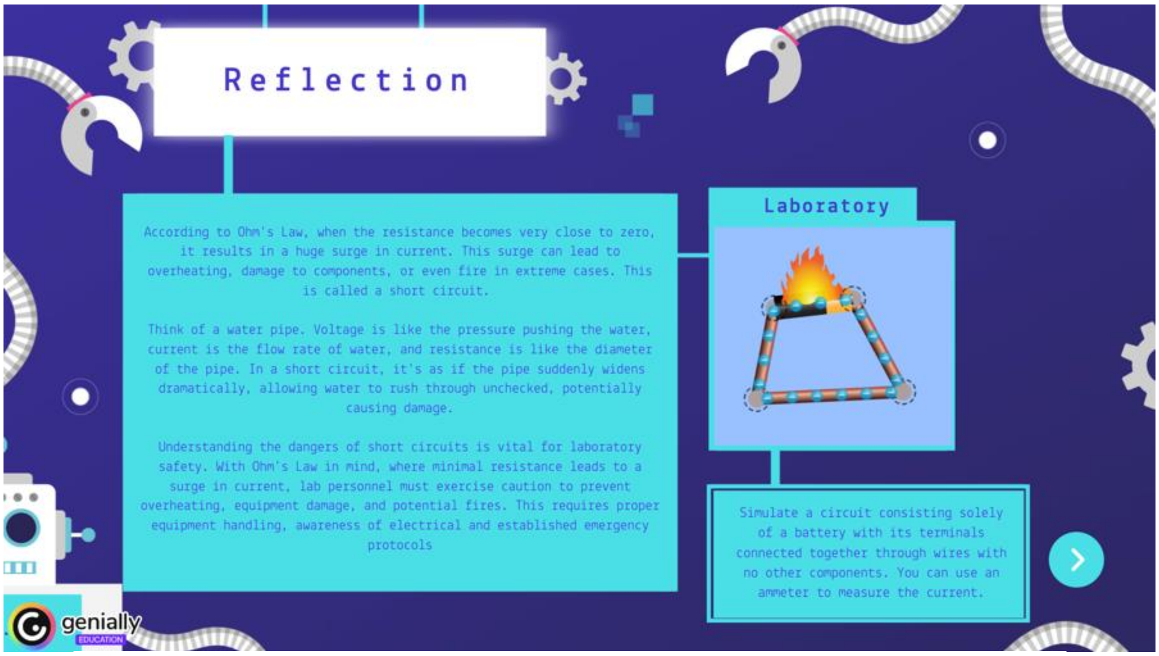


Figure 99 Reflection phase fina activity.

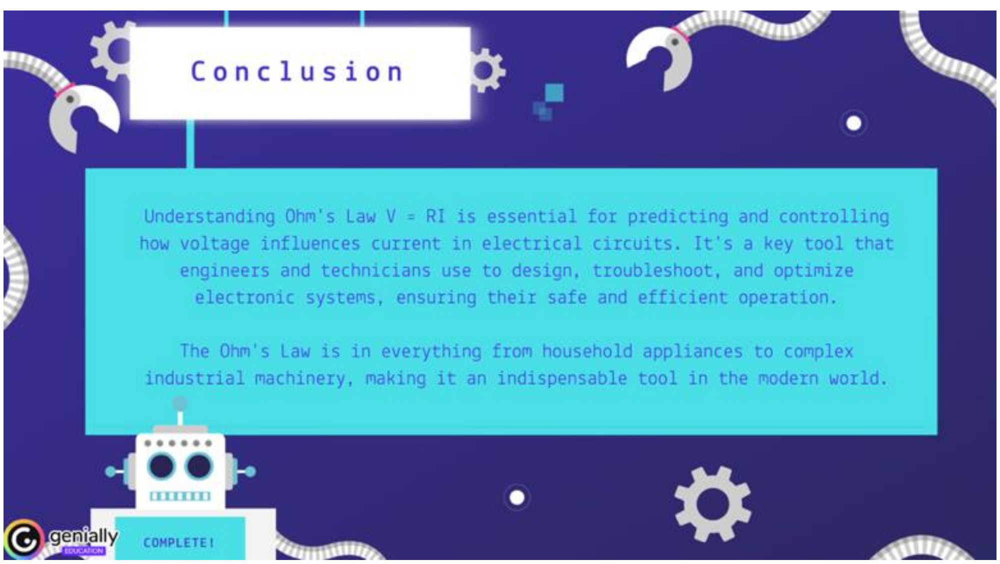


Figure 100 Conclusion.

The following table presents the different trajectories taken by students while navigating the scenario:

Table 27 Ohms Law Scenario Navigation

Question	Start	Path A	Path B	Path C
Q1	C (go to Q2)			
	A (go to Q3)			
	B (go to Q4)			
Q2		A (receive guidance and go to Q3)		
		B (receive guidance and go to Q3)		
		C (go to Q3)		
Q3			A (receive guidance and go to Q4)	
			B (receive guidance and go to Q4)	
			C (go to Q4)	
Q4				C (return to Q2)
				B (do **experiment 1**)
				A (do **experiment 2**)
Q5				B (go to Q7)
				C (go to Q7)
				A (go to Q6)
Q6				A (go to Q8)
				C (go to Q8)
				D (go to Q8)
				B (go to Q9)
Q7		B (receive guidance, **review hypothesis/repeat experiments**)		
		C (receive guidance, **review hypothesis/repeat experiments**)		
		A (return to Q5)		
Q8			B (receive guidance and return to Q5)	

			C (receive guidance and return to Q5)	
			A (go to Q9)	
Q9				A (return to Q8)
				B (go to Q10)
Q10				A (receive guidance and go to Q11)
				C (go to Q11)
				B (End)
Q11		B (receive guidance and return to Q10)		
		A (End)		

5.7. Population Genetics

The first phase of the scenario is devoted to awakening the curiosity of the student about the topic.

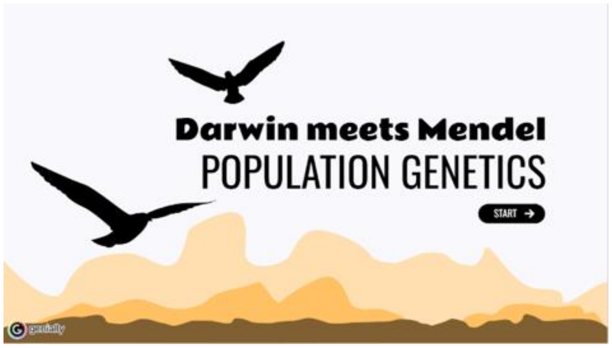


Figure 101 Population Genetics Scenario

Students are invited to reflect on why a population needs to evolve to survive and what they think is the answer. After a brief introduction of the topic of "Evolutionary Arms Race", they are invited to imagine a scenario, where there's a predator resistant to a toxin produced by its prey, and where the prey produces the toxin in lethal amounts, except for the predator that is resistant to it. Part I focuses on testing individual predators, while the data in Part II represents population averages.

Figure 102 Evolutionary Arms Race Introduction to the topic and beginning of the activity

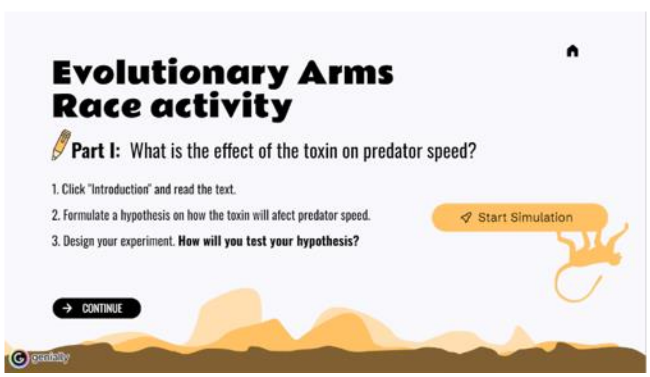
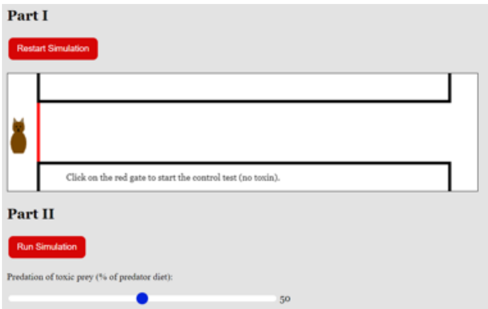


Figure 103 Evolutionary Arms Race Activity: Instructions at the beginning of Part I

Before the experiment, students are asked to formulate a hypothesis on the effect of the toxin on predator speed and reflect on how they are going to design their experiment in order to test their hypothesis.

Students will then be invited to start the simulation at https://www.labxchange.org/library/items/lb:LabXchange:50f51eaf:lx_simulation:1?fullscreen=true.



The students can click the button “Introduction” to learn more about the experiment. During the first part of the experiment, four trials are performed: one without any toxin (control) and three others with 1, 2, and 3 units of toxin administered before the trial. During each of these four trials, the time it takes for the predator to navigate the track is recorded.

Figure 104 Evolutionary Arms Race Virtual Simulation

After being introduced to the simulation lab, students are invited to answer the first question of the scenario.

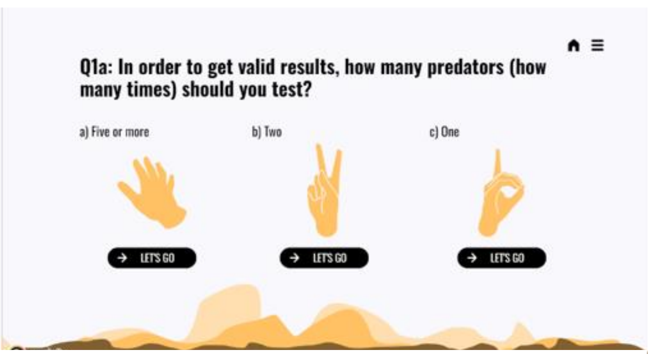


Figure 105 Q1a: In order to get valid results, how many predators (how many times) should you test?

Q1a: In order to get valid results, how many predators (how many times) should you test?

a) Five

b) Two

c) One

Three options are presented. Students selecting answer c) will probably have little knowledge about sampling and sample sizes, those selecting answer b) might have some understanding but don’t fully grasp the whole topic yet, while answer a) is the most complete one, showing that the student understands what is being asked.

There are paths designed related to each specific answer. Students choosing c) will have more information provided to them and invited to reflect more in-depth on the differences between single trials versus multiple trials. Students choosing b) will also be asked to rethink their choice based on the possible benefits of larger sample sizes.

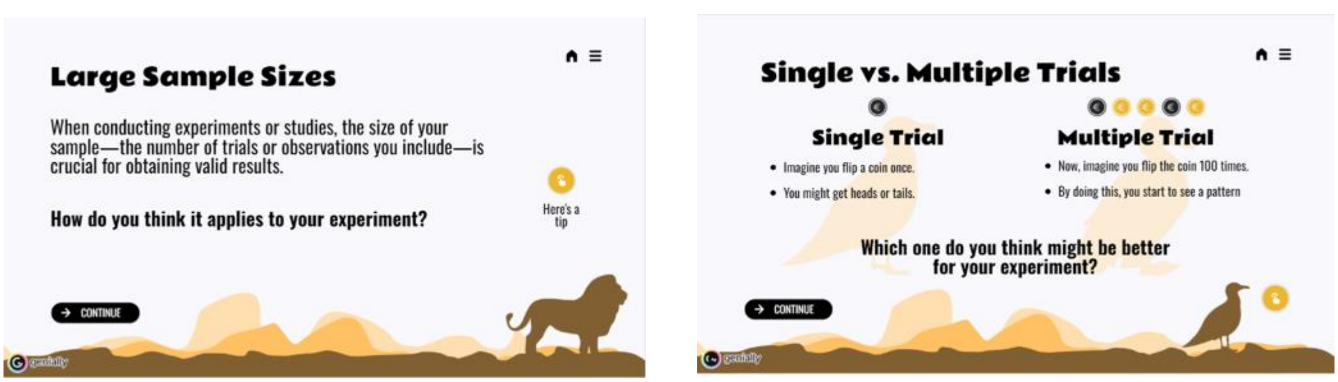


Figure 106 Slides for Q1a: Path b) - Lion and Path c) - Seagull.

“Here’s a tip: When performing your experiment, compare the results from only two trials to those from five trials. Are there differences?” On Path b) – Lion, students get the suggestion of comparing a smaller sample size to a bigger one during the analysis of their results of the simulation experiment.

“For the teacher: This analogy can also be demonstrated through this simulator.” On Path c) – Seagull, the teacher can also demonstrate the information described on the slide, via a small experiment using a coin flip simulator at: https://www.geogebra.org/m/LZbwMZtJ.

Those who choose a) will move forward to a second question that will add more evidence that they possess the necessary knowledge to move forward in their exploration.

Q1b: Which number of repetitions will make your results the most robust?

a) **Five**
b) **Three**
c) **Two**

Again, three options are presented, each of them with their respective path. The correct answer is a).

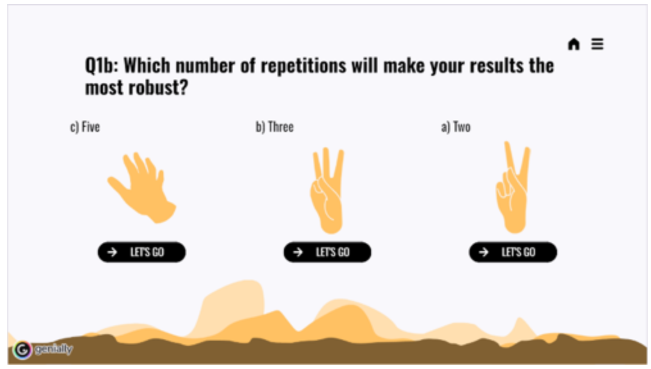
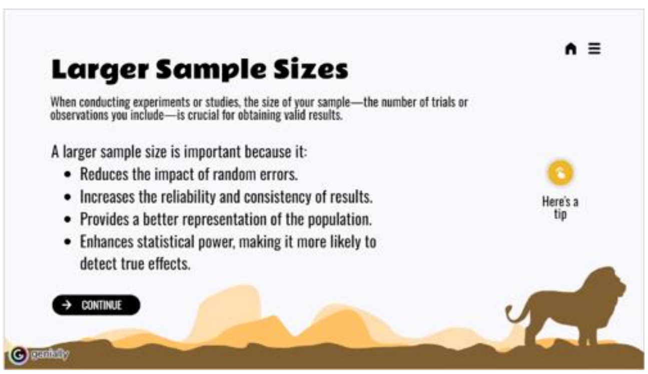


Figure 107 Q1b: Which number of repetitions will make your results the most robust?



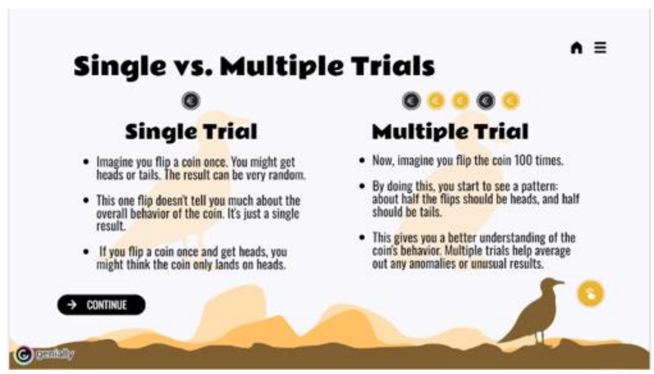


Figure 108 Slides for Q1b: Path b) - Lion and Path c) Seagull

Students choosing b) or c) will be once again directed to slides with more information regarding the advantages of Multiple Trials and larger sampling sizes, before progressing to the next question.

“Here’s a tip: When performing your experiment, compare the results from only two trials to those from five trials. Are there differences?” On Path b) – Lion, students get the suggestion of comparing a smaller sample size to a bigger one during the analysis of their results of the simulation experiment.

“For the teacher: This analogy can also be demonstrated through this simulator.” On Path c) – Seagull, the teacher can also demonstrate the information described on the slide, via a small experiment using a coin flip simulator at: https://www.geogebra.org/m/LZbwMZtJ.

Once again, students who answered the correct answer (choice a) will progress to the next question.

Q2a: Should you include the first test (with zero toxin) in your data analysis?
a) Yes, it's the control.
b) No, because it doesn't test the effect of the toxin.

Correct answer is a).

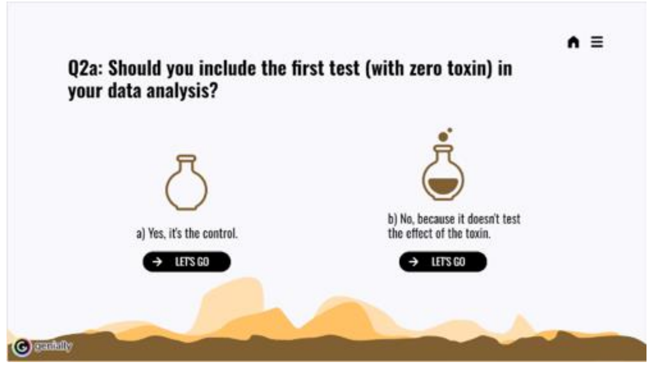


Figure 109 Q2a: Should you include the first test (with zero toxin) in your data analysis?

Students who answered b) will be directed to a slide that defines what is a control group and incentivized to reflect on how they may apply to their experimental design, before proceeding to the next question.

Figure 110 Q2a Path b) - What is a Control Group?

Students who answered correctly proceed directly to the next question.

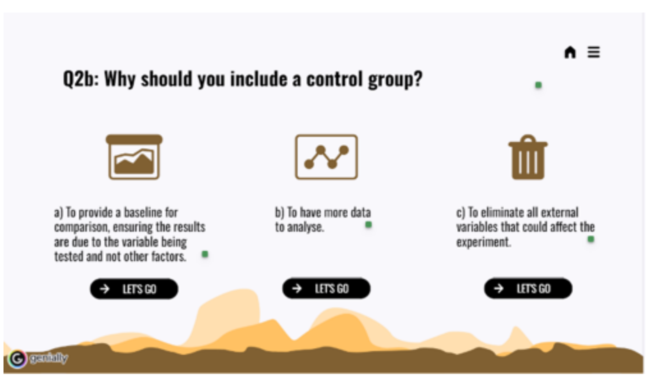
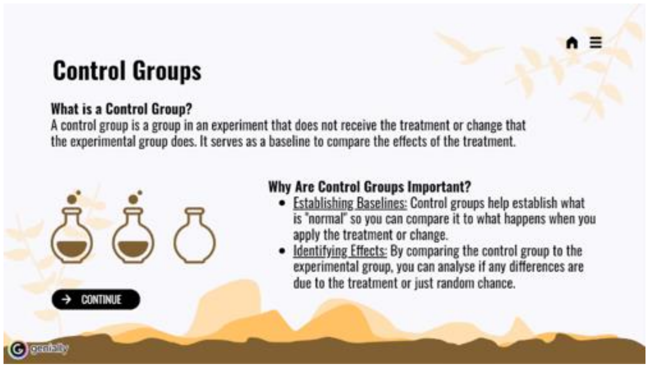


Figure 111 Q2b: Why should you include a control group?

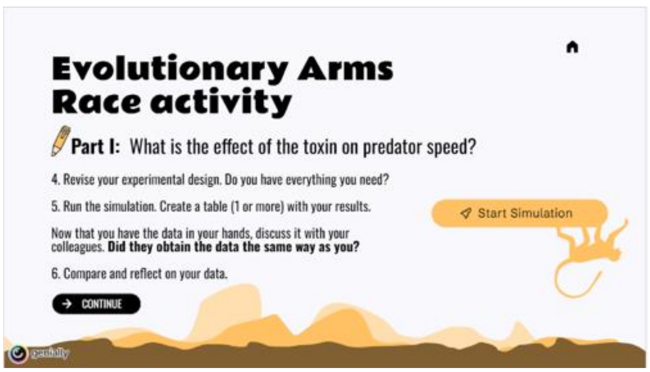
Q2b: Why should you include a control group?
a) To provide a baseline for comparison, ensuring the results are due to the variable being tested and not other factors.
b) To have more data to analyse.
c) To eliminate all external variables that could affect the experiment.

The correct answer is a).



Should they fail to answer this question correctly, students who chose b) or c) will again be directed to a new slide that expands more on the concept of Control Groups and why they might be important for interpreting data. After this slide, they will continue with the Evolutionary Arms Race Activity.

Figure 112 Q2b Path b) and c)



The students who answered the question correctly will be able to proceed and resume their Evolutionary Arms Race Activity. Here all of the students will be encouraged to revise their experimental design, especially taking into account the points discussed before. The role of the teacher in this activity is to simply guide students in their experiment, but let them uncover how should they register, calculate and analyse the data themselves, when possible.

Figure 113 Evolutionary Arms Race Activity Part I

Students are asked to register the results they obtained and organise them in one or more tables (examples on Figure 14).

Part I: Toxin Resistance "Cost"

1. Click on the "Introduction" button to read the Part I information.
2. Run the simulation 5 times and record the times.
   a. Each trial will randomly select a different predator from the population.
   b. Each selected predator will have their speed tested after injecting 0, 1, 2, and 3 units of toxin.
   c. Click on the red gate to start the first (control - 0 toxin) test
   d. At the end of the test run, click on the predator to start the next test.
   e. The simulation will automatically increase the amount of toxin for each test run.
   f. After the 3-unit test run, click "Restart Simulation" to repeat with a new predator.
3. Record time data:

Chart 1	Time (seconds)				
Units of Toxin	Predator 1	Predator 2	Predator 3	Predator 4	Predator 5
0					
1					
2					
3					

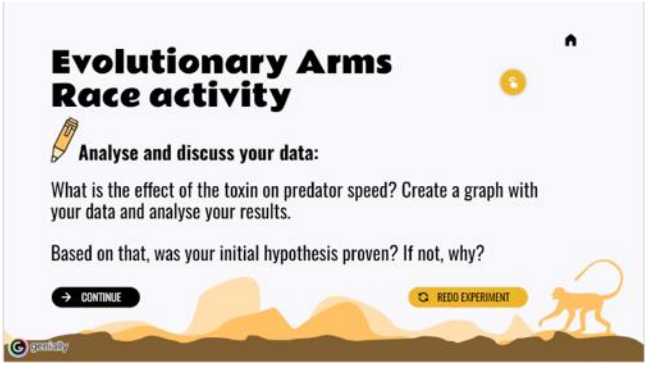
For each predator, calculate and record the difference between the control time and the time for each toxin injection (0 toxin time - toxin time). For example, if the predator ran the 0 toxin test in 7.9 seconds and the 1 unit trial in 7.5 seconds, the difference is 0.4.

Chart 2	Difference from control *(0 unit time - toxin time)*				
Units of Toxin	Predator 1	Predator 2	Predator 3	Predator 4	Predator 5
1					
2					
3					

Figure 114 Examples of tables students can create for Part I of the Evolutionary Arms Race Virtual Simulation

(examples taken from https://docs.google.com/document/d/1oS14SANUGJS_lb6oCzEpnPv9irb_ap56ea_CCbO6zFk/edit)

This exercise will help students understand and implement the scientific method, in order to properly test a hypothesis. After collecting the data, students are invited to compare their results with the ones their colleagues obtained and to reflect on what they mean in terms of the effect of the toxin on predator speed.



The final stage of Part I of the Evolutionary Arms Race activity, asks students to create a graph with the data they obtained and analyse it. Students will be able to visually represent their data, which might facilitate their understanding of it and help them respond to the question "What is the effect of the toxin on predator speed?". Lastly, students will be able to confront their initial hypothesis and examine if it was confirmed or denied.

In case the students (or the teacher) want to redo the experiment, there's a button on the bottom right corner that directs the user to the beginning of the Evolutionary Arms Race Activity.

Figure 115 - Evolutionary Arms Race Activity - Discussion Slide

In the second part of the experiment, students can adjust the proportion of toxic prey in the predator's diet. The results display the difference in predator speed between the control and toxin conditions at the beginning of the study ("Start") and after 10 generations ("End"). Students will examine how varying percentages of toxic prey in the diet influence the population's resistance level over time.

Figure 116 Evolutionary Arms Race Activity Part II - Introduction Slide

For the second time, students are invited to create a hypothesis to describe how the percentage of toxic prey in the predator's diet affects predator toxin resistance across generations and to design an experiment to test their hypothesis.

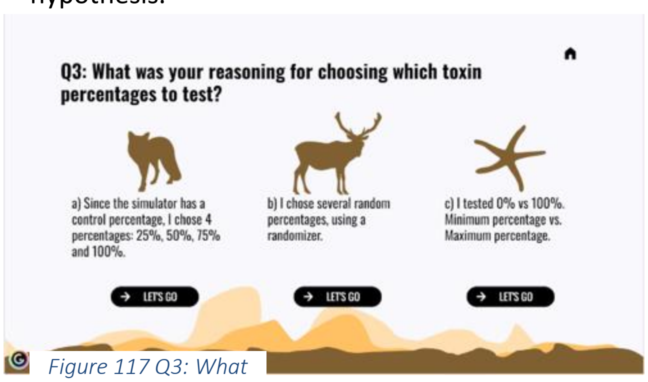


Figure 117 Q3: What was your reasoning for choosing which toxin percentages to test?

Q3: What was your reasoning for choosing which toxin percentages to test?

a) Since the simulator has a control percentage, I chose 4 percentages: 25%, 50%, 75% and 100%.

b) I chose several random percentages, using a randomizer.

c) I tested 0% vs 100%. Minimum percentage vs. Maximum percentage.

The correct answer is a).

This question's aim is to assess students' understanding of experimental design principles, particularly in the context of selecting appropriate test variables. The correct answer (Path a) – Fox) reflects a well-thought-out approach to experimental design, where a range of toxin percentages is chosen systematically to provide a comprehensive analysis. This demonstrates that the student understands the importance of having a control group and a variety of test conditions to observe different effects and draw meaningful conclusions. Path b) - Deer indicates a lack of a systematic approach in selecting percentages, which can lead to inconsistent and less reliable data, and Path c) - Starfish, despite showing an understanding of the importance of testing the extreme values, lacks the insight to include intermediate values that might provide a more complete picture.

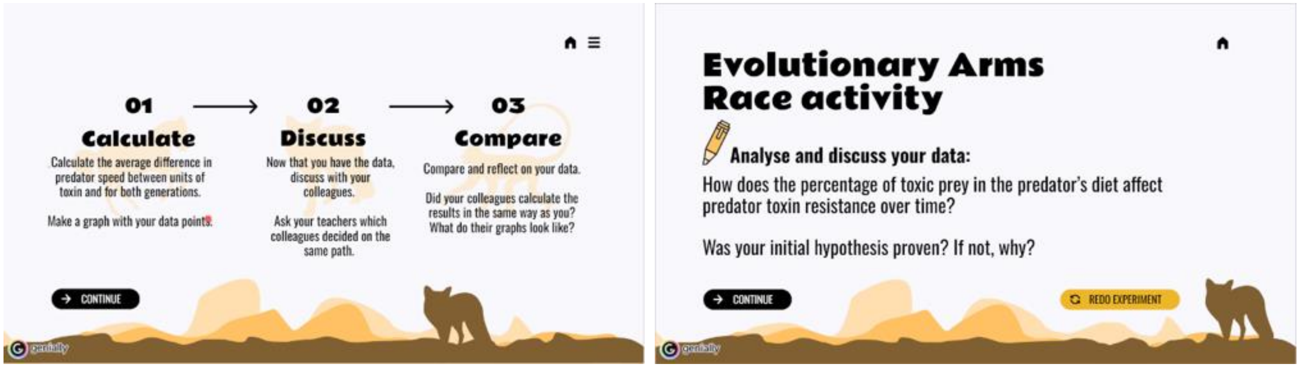


Figure 118 - Q3: Path a) - Fox slides

Each of the paths invites students to calculate the average difference in predator speed between units of toxin and for generations 0 and 10. During this step, students can also create tables to organise their data, like the ones presented in Figure 19. The students are then asked to create a graph with their data points and discuss the data, calculations, and results with colleagues who chose the same path as them. At the end, they are asked to revisit their hypothesis and confirm if, through their results, they were able to prove it or deny it.

	Predation of toxic prey %:			
	Generation 0		Generation 10	
Speed (m/s)	*0 units*	*2 units*	*0 units*	*2 units*
Trial 1				
Trial 2				
Trial 3				
Average				

Calculate the average decrease in speed between 0 and 2 units of toxin for generation 0 and generation 10 for each of your selected predation percentages.

	Speed decrease (0 units - 2 units)	
Predation of toxic prey %	*Generation 0*	*Generation 10*

Figure 119 - Examples of tables students can create for Part II of the Evolutionary Arms Race Virtual Simulation

(examples taken from https://docs.google.com/document/d/1oS14SANUGJS_lb6oCzEpnPv9irb_ap56ea_CCbO6zFk/edit).

On path b) and c) there's an additional question that invites students to reflect if the choice they made in Q3 is the most correct. This allows students to develop their critical thinking about their experimental design choices. By prompting students to reconsider their initial selections and compare them with other options, they can better understand the principles of robust experimental design. With this reflection on their choices and the consideration of why other options might be better, students engage in a process of self-assessment and learning that reinforces their notions of scientific inquiry and experimental design. The students are then asked to return to the beginning of the experiment to try other ways of selecting the appropriate test variables.

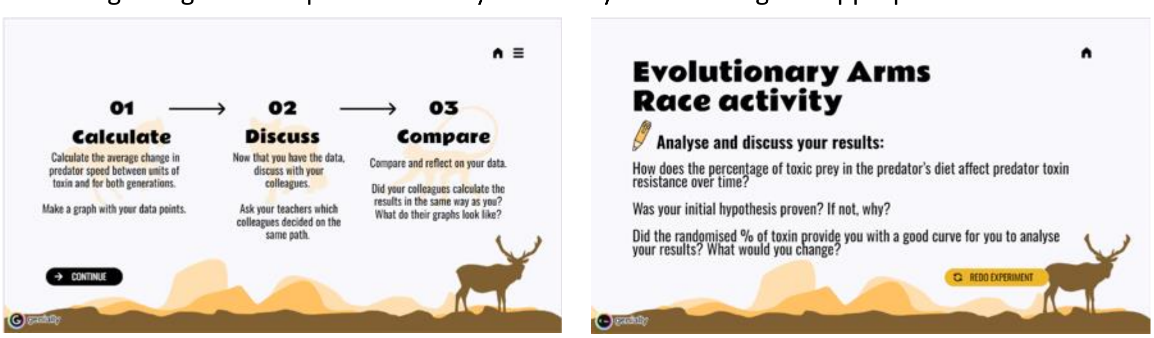
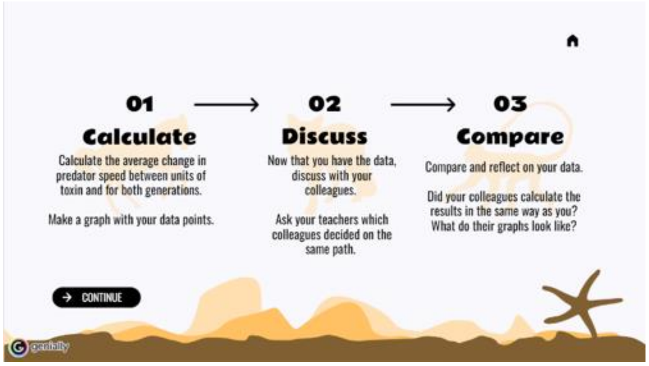


Figure 120 - Q3: Path b) – Deer slides



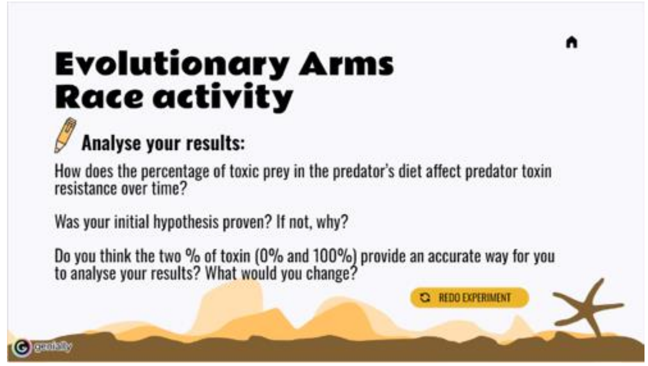


Figure 122 Q3: Path c) - Starfish slides

After all the students go through Path a), they can continue to the last question of the scenario (which is also the first). Students are now invited to reflect not only on their experiment results but also to consider the possible reasons why organisms evolve based on what they learned. This approach aims to compare students' initial understanding and assumptions with the knowledge they have gained through the experimental activity. By revisiting the question, students are encouraged to reflect on their new knowledge and confront their previous assumptions with more informed perspectives. This reflective practice helps solidify their learning and highlights the progression of their understanding, allowing them to see the value of the learning journey and understand the dynamic nature of scientific inquiry.

Figure 121 - Final question of the scenario - So, why do you think a population evolves over time?

After the discussion is finished, the following slide answers the question while introducing the topic of the evolution mechanisms.

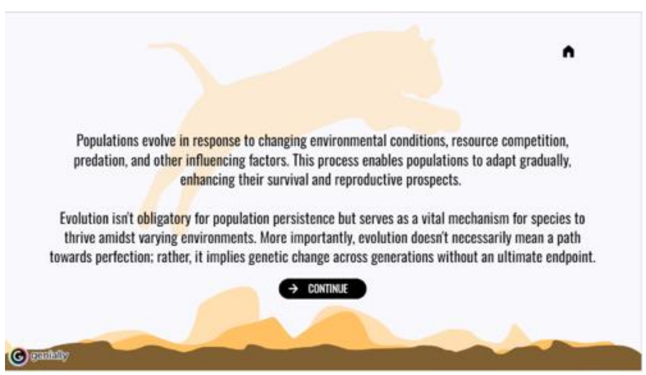
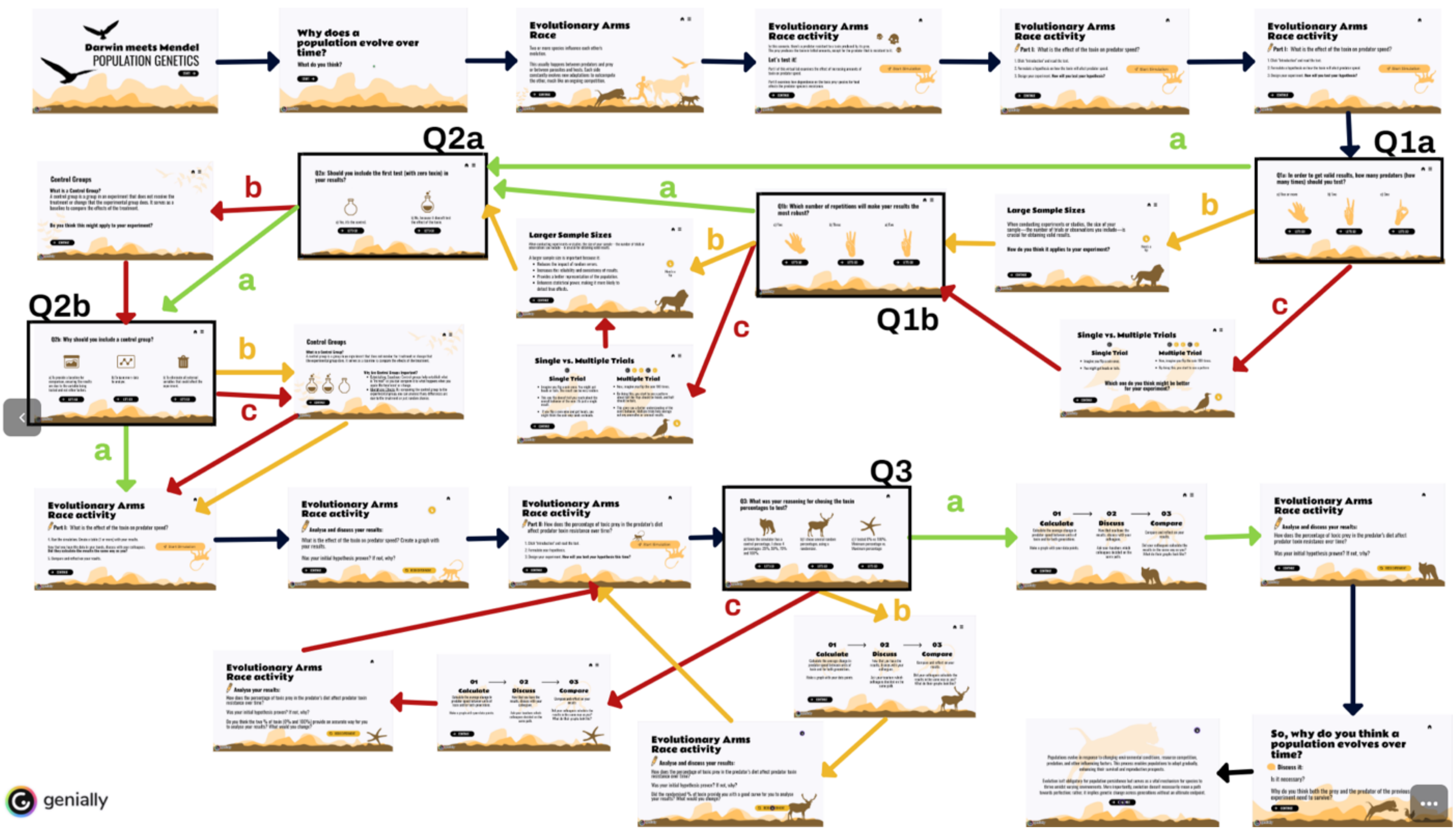


Figure 123 Last slide of the scenario.


Darwin meets Mendel
POPULATION GENETICS
Why does a population evolve over time?
Evolutionary Arms Race
Evolutionary Arms Race activity
Q1a
Q1b
Q2a
Q2b
Q3
Control Groups
Larger Sample Sizes
Large Sample Sizes
Single vs. Multiple Trials
So, why do you think a population evolves over time?
a
b
c
genially

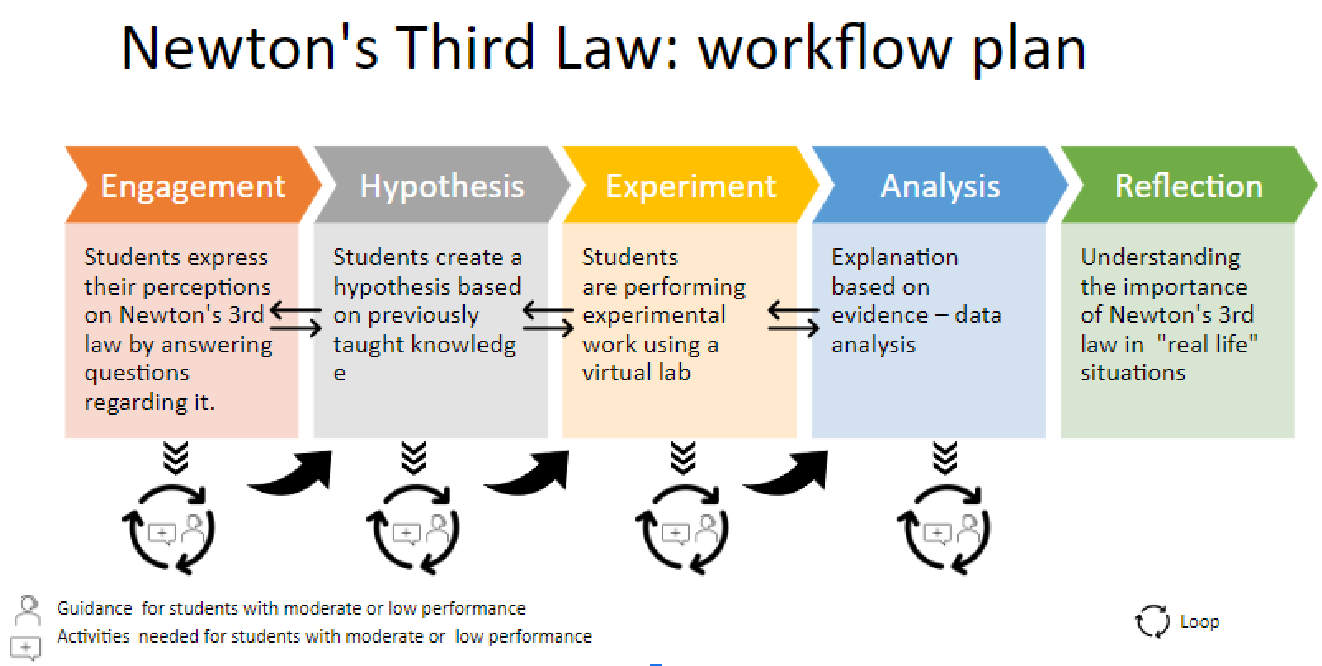
5.8. Newton's 3rd Law

This scenario is currently built on a power point but for harmonisation purposes, in this deliverable, the content is migrated to this annex.

The overall goals of the scenario to enable students to:

1. Formulate Newton's 3rd Law
2. Understand that forces in nature occur in pairs.
3. Understand that action and reaction are exerted on different bodies; therefore, no constitutive force of these forces arises.
4. Combine Newton's 3 laws to solve problems

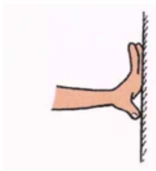
The work plan is presented to the teachers highlighting the expected workflow for each of the students according to their competence profile



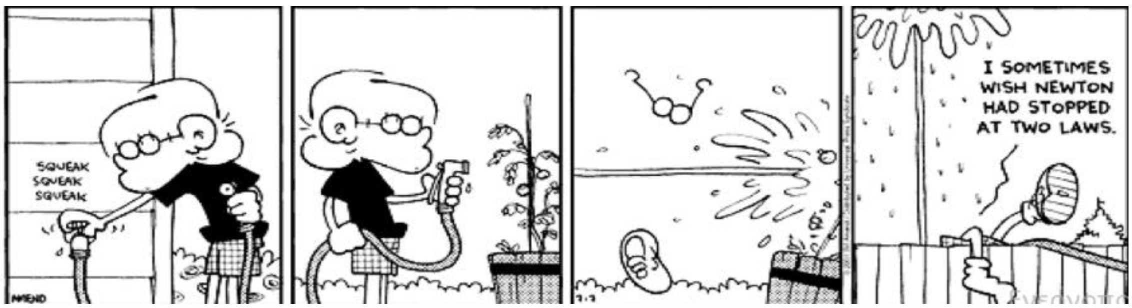
Phase 1: Engagement of the students – Exploring their ideas

The activity starts by prompting the student to consider what happens when we push a wall.

Q1. When you push a wall, what do you feel in your hand? What forces are exerted on the bodies here and where is each one exerted from?



A. The hand exerts a force on the wall and the wall exerts an equal and opposite force on the hand. Their component is zero.
B. The hand exerts a force on the wall and the wall exerts an equal and opposite force on the hand. They have no component.
C. The hand pushes the wall.



Q2. Why did the child lose the balance and end up on the ground?

A. The water fell on the plant and was thrown with force to the child to the left.
B. The plant exerted a force on the water that was transferred onto the child.
C. The child - "hose" - water system exerted a force on the plant to the right and it exerted an opposing force on the system to the left.

Students will be directed to different paths depending on their answer.

Table 28 Table indicating the students' different paths.

	LOW	MEDIUM	HIGH
Question 1	C	A	B
Question 2	A	B	C
	Guidance/Activity Go to slides 4-5	Guidance/Activity Go to slides 4-5	Next Phase

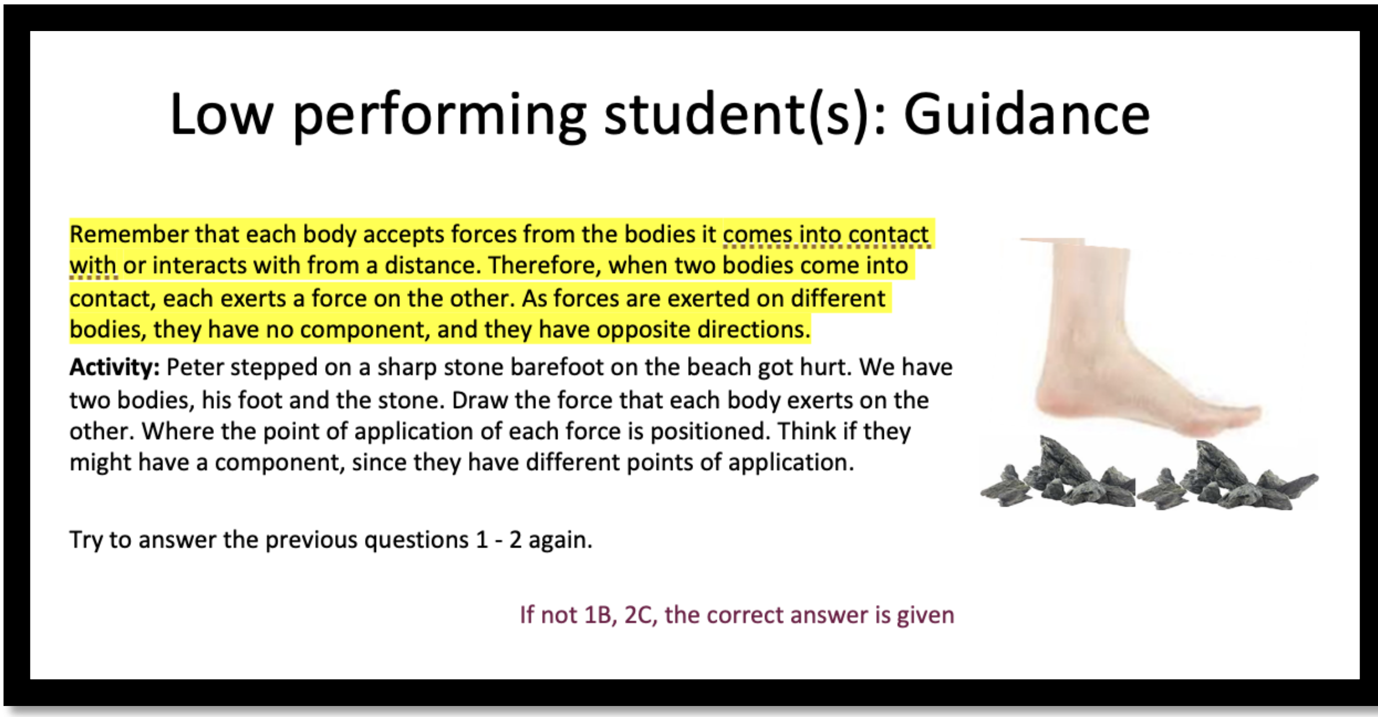


Figure 124 Guidance to students in need of more in-depth support.

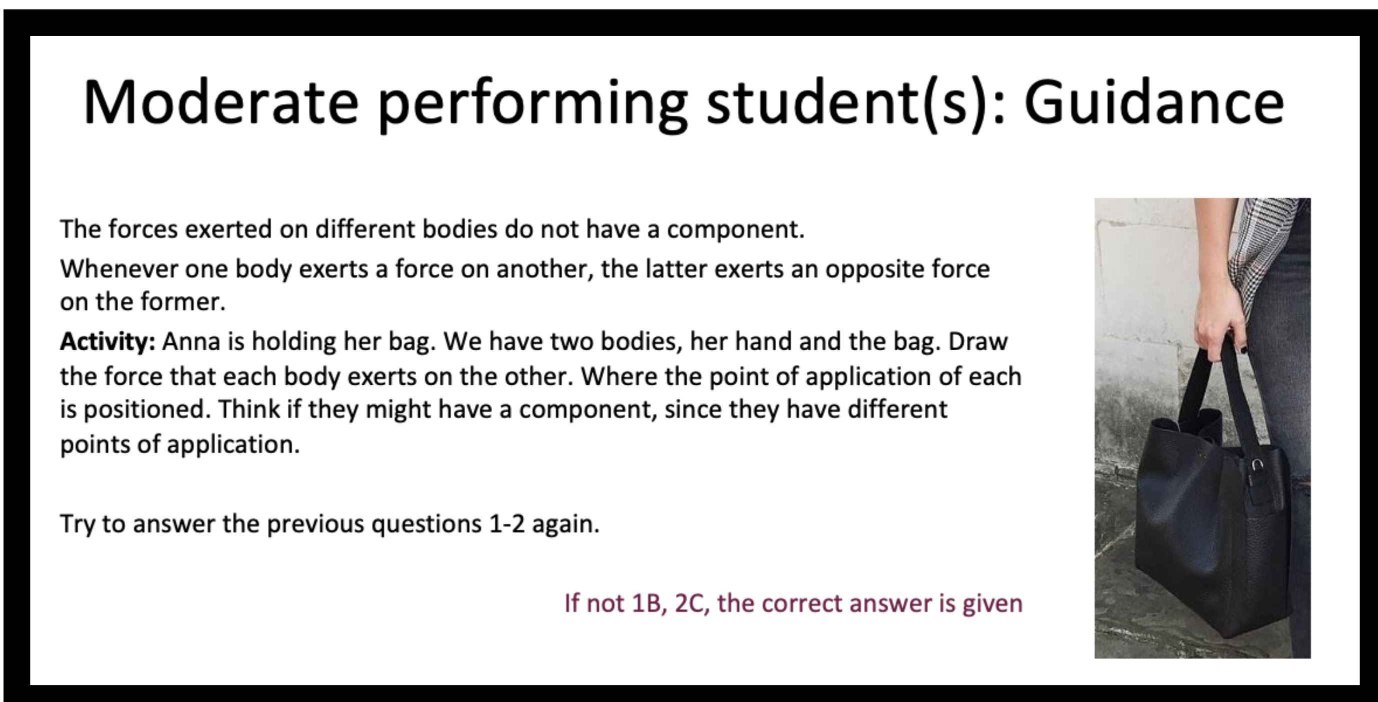
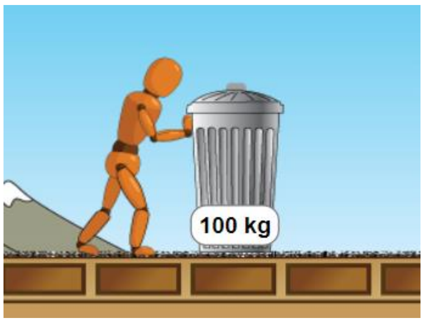


Figure 125 Guidance to students in need of moderate support

Phase 2: Hypothesis Creation

Q3. In the picture the man is pushing the trash bin with a constant force, without any movement. What forces are exerted on each of these two bodies (man - M, trash bin - B)?



A. Man: Weight W_M from the Earth, force from the ground (friction component F_M and vertical N_M), force from bin F_{BM}, . (Trash bin : Weight W_B from Earth, force from ground (friction component F_B and vertical N_B), force from man F_{MB})

B. Man exerts a force on the bin, but fails to move it, it is heavy.

C. Man: Weight W_M from the Earth,
(Bucket: Weight W_B, from Earth, force from man F_{MB})

Q4 Among the forces exerted on the two bodies (man - M, trash bin - B), which ones do you consider are mutual actions between them and what relationship connects them as vector quantities?

A. From the man to the trash bin: F_{MB} and from the bin to the man F_{BM}

$$\vec{F}_{MB} = -\vec{F}_{BM}$$

B. From the man to the trash bin : F_{MB} and from the bin to the man F_{BM}

$$F_{MB} = F_{BM}$$

C. The man pushes the trash bin, but he fails to move it

Table 29 Table indicating the students' different paths.

	Low performer	Moderate performer	High performer
Question 1	B	C	A
Question 2	C	B	A
	Guidance Go to slides 9-10	Guidance Go to slides 9-10	Next Phase

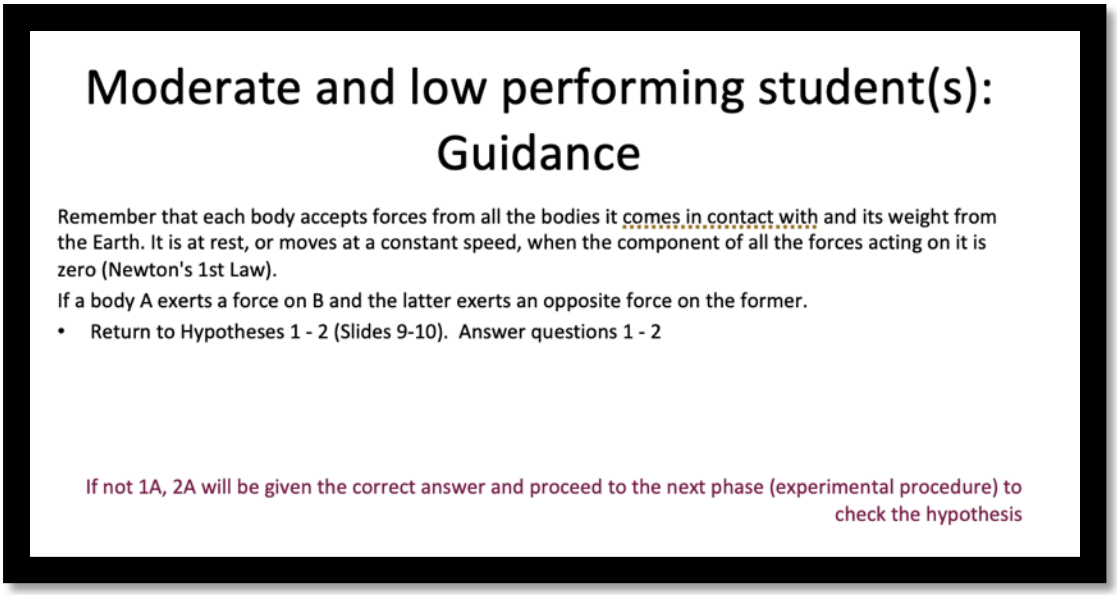


Figure 126 Guidance provided to students in need of more support.

Phase 3: Experimentation, testing of hypotheses

Students are invited to get acquainted with the PhET simulation and use it to validate their hypotheses

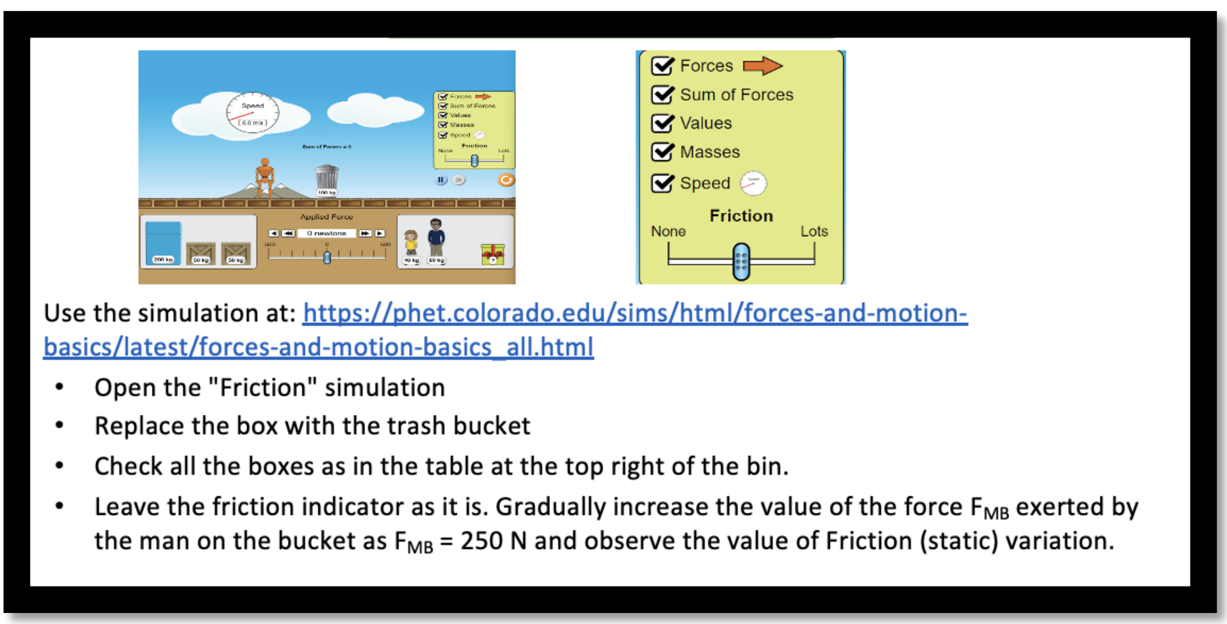


Figure 127 Introduction to the Forces and Motion virtual simulation

New questions are presented inviting students to reflect on the results of their simulations:

Answer the questions below by watching the evolution of simulation:

Q5. The man exerts a varying force on the bucket FMB and FTOTAL=0 (Sum of Forces = 0 for each value of FMB). The man and the trash bin are in a state of equilibrium. Why is the man in balance?

A. Three forces are exerted, and their component is zero: W_M from the Earth, F_M (the friction) from the ground and F_{BM} from the trash bin

B. W_M from the Earth

C. W_M from the Earth and N_M (vertical force from the ground) have a component of zero. F_{BM} from the trash bin and F_M (the friction) from the ground have a component of zero.

Answer the questions below by watching the evolution of simulation:

Q6. Which pairs of opposing forces (Action - Reaction) do you think are exerted during the interaction of the bodies with the bucket when the man pushes the bucket with a varying force and the bucket balances?

A. Trash bin - Man: F_{MB} from the man to the bin and F_{BM} from the bin to the man ($F_{MB} = F_{BM}$)

B. Trash bin - Man: F_{MB} from the man to the bin and F_{BM} from the bin to the man ($\vec{F}_{MB} = -\vec{F}_{BM}$),

6. Man – ground: Friction F_{GM} from the ground to the man and F'_{GM} from the man to the ground ($\vec{F}_{GM} = -\vec{F}'_{GM}$) and vertical force N_{GM} from the ground to the man and from the man to the ground N'_{GM} ($\vec{N}_{GM} = -\vec{N}'_{GM}$).

Trash bin - ground: Friction F_B from the ground to the bin και F'_B from the bin to the ground ($\overrightarrow{F_B} = -\overrightarrow{F'}_B$)(and a vertical force from the ground to the bin N and from the bin to the ground N' ($\vec{N} = -\vec{N}$).

Bin - Earth: W_B from Earth to the bin, from the bin to the centre of the Earth W'_B ($\overrightarrow{W_B} = -\overrightarrow{W'}_B$)

C. Trash bin - Man: : F_{MB} from the man to the bin and F_{BM} from the bin to the man ($F_{MB} = F_{BM}$),

Trash bin - ground: Friction F_B from the ground to the bin, Bin - Earth: W_B from Earth to the bin

Different paths will be suggested for the students according to their answers as can be seen in table below

Table 30 Table indicating the students' different paths.

	Low performer	Moderate performer	High performer
Question 1	B	A	C
Question 2	A	C	B
	Guidance/Activity Repeat the experiment, answer the questions (Slides 14-15)	Guidance/Activity Repeat the experiment, answer the questions (Slides 14-15)	Next Phase

Guidance is provided to the students according to their needs and competence level

Moderate performing students: Guidance / Activity

- Remember that each body receives forces from the bodies it comes into contact with or interacts with from a distance.
- Activity: Draw on a piece of paper the forces on each body separately, if it helps you understand the motion of each body (man, bucket).
- Apply Newton's 1st Law to the interactions of bodies.
- Repeat the experimental procedure.
- Answer questions 1-2 (slides 14-15) about Newton's 3rd law

If not 1C, 2B, the correct answer will be given with more explanation and move on to the next phase to understand and apply Newton's 3rd Law.

Low performing students: Guidance / Activity

Remember that:

Each body receives forces from the bodies it comes into contact with or interacts with from a distance.

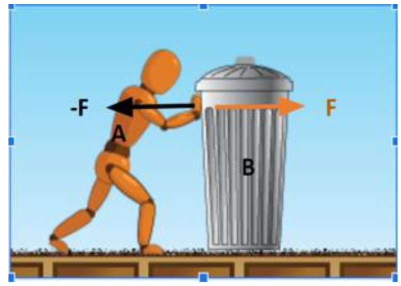
According to Newton's 1st Law: if no forces are applied to a body, or forces whose component is equal to zero are applied, then the body either remains stationary or moves smoothly in a straight line.

- Activity: Draw on a piece of paper the forces on each body separately, if it helps you understand the motion of each body (man, bucket).
- Repeat the experimental procedure.
- Answer questions 1-2 (slides 14-15) about Newton's 3rd law

If not 1C, 2B, the correct answer will be given with more explanation and move on to the next phase to understand and apply Newton's 3rd Law.

Phase 4: Analysis

To support the analysis of the acquired data, students are invited to answer a couple of questions.

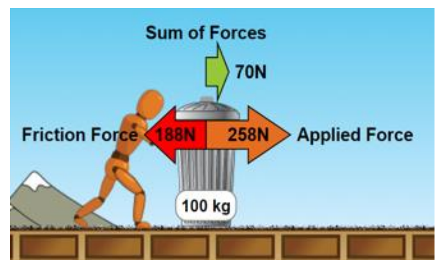


Q7. According to Newton's 3rd law, when a body A exerts force F on a body B and B exerts force -F on A. Therefore

A. In the interaction between two bodies, forces occur in pairs and have no component.

B. In the interaction between two bodies, forces occur in pairs and have a magnitude of zero.

C. When two bodies interact, the forces have no component, but cause acceleration of the same magnitude and opposite direction in each body.



Q8. When F_{MB} = 258 N and F_B = 188 N, what is the force F_{BM} exerted by the bin on the man?

A. 258 N (the same as the F_{MB} exerted by the man on the bin, but in the opposite direction)

B. $F_{BM} = m_m \times a$

C. $F_{BM} = W_M$

According to their answer the next steps are defined

Table 31 Table indicating the students' different paths.

	Low performer	Moderate performer	High performer
Question 1	B	C	A
Question 2	C	B	A
	Information / Activity	Information / Activity	Next Phase

Support to students is provided according to their competence profile:

Moderate performing students: Guidance / Activity

According to Newton's 3rd law, when a body A exerts a force $\vec{F}$ on a body B (Action) and B exerts on A a force - $\vec{F}$ ′(Reaction).

Try to answer the question below again (there was one at the beginning of the scenario):

3. A truck collides with a small car. The small car is deformed more than the truck because

A. The truck exerts more force on the small car than this on the truck.

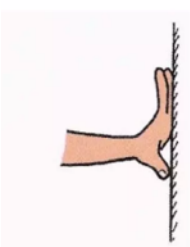
B. Only the truck exerts a force on the small car because it is larger.

C. The truck exerts a force on the small car equal to the force that this exerts on the truck. The deformation is greater because of its materials and its fabrication.

Answer questions 1 - 2 (Slide 19)

If not 1A, 2A, the correct answers will be given with more explanation and move on to the next phase

Low performing students: Guidance / Activity



All three of Newton's laws apply to interactions between bodies. According to Newton's 3rd law, when a body A exerts a force $\vec{F}$ on a body B (Action) and B exerts on A a force - $\vec{F}$ (Reaction).

Answer the question below again (there was one at the beginning of the scenario):

3. When you push a wall what forces are exerted on the bodies here and where is each force exerted from?

A. The hand exerts a force on the wall and the wall exerts an equal and opposite force on the hand. Their component is zero.

B. The hand exerts a force on the wall and the wall exerts an equal and opposite force on the hand. They have no component.

C. The hand pushes the wall.

Answer questions 1 - 2 (Slide 19)

If not 1A, 2A, the correct answers will be given with more explanation and move on to the next phase

Phase 5: Reflection

Towards the end of the activity, a few more demanding questions are presented to the students:

Q9. An egg accidentally falls to the floor. Why does it break?

A. The floor exerts more force on the egg than the egg exerts on the floor

B. The floor exerts a force on the egg (action) and the egg exerts an opposite force (reaction) on the floor. The egg breaks because of the construction of its wall.

C. It is natural to break. It always does.

Q10. A runner starts: What forces are exerted on her body and by which body(s)?

A. From her own body

B. The component of the forces from the Earth (W_R) and the ground (N_R, F)

C. From the Earth (W_R) and the air (Resistance)

Q11. The force moving her body is a reaction to which force, if the effect of air is considered negligible?

A. Friction is to the left (action), her own body exerts an opposite force (reaction) and moves forward

B. The reaction to its weight is the moving force

C. The runner exerts force F on the ground to the left (action) and the ground exerts friction F to the right (reaction), which moves her. The vertical forces have a component of zero.

Table 32 Table indicating the students' different paths.

	Low performer	Moderate performer	High performer
Question 1	C	A	B
Question 2	A	C	B
Question 3	A or B	A or B	C
	Guidance / Activity	Guidance /Activity	More In-depth Question

Moderate performing students: Guidance / Activity

Remember that each body receives forces from the bodies it comes into contact with or interacts with from a distance.

The runner accepts forces (If it helps you, try to draw them on paper):

A. From the Earth (Weight/distance), from the ground (Friction and vertical force) and from the air (considered negligible). (High performer)

B. From the ground and from the air. (Moderate performer)

C. From the ground (Low performer)

PHASE 5 - *In-depth study for high performing students, after teaching all three of Newton's laws and free fall*

Q12. Why do apples fall to Earth while the moon orbits around the Earth? Can the same laws apply on Earth and in the sky?

(Koumaras, P., Paths of Thought in the World of Physics, p. 75, 2015)

A. The motions of the apples and the moon cannot be correlated, the apples make a free fall, the moon approximately circular. On Earth and in the sky cannot the same laws apply.

B. The same laws apply on Earth and in the sky. The Earth exerts on all bodies an attractive force towards its centre. Apples that do not have an initial velocity are free-falling. The moon, which has acquired a proper horizontal velocity of 1.022 m/s (could be considered an initial velocity), makes a "horizontal" shot and never hits the ground, but moves (roughly) in a circular orbit. Circular motion around the earth would also be made by the apple if it were thrown with a horizontal velocity of 8 km/s
C. The Earth exerts a force on the apples (their weight) and they fall in a linear, uniformly accelerated motion (free fall). It also exerts force on the Moon and causes it to go in a circular motion around itself. So, the same laws do not apply on Earth and in the sky.

Moderate or Low performing student(s): Information

A body that accepts a force has a uniformly accelerating motion.
To all bodies, terrestrial and celestial, the Earth exerts an attractive force. If they have no initial velocity, they move toward its centre in a linear uniformly accelerating motion, like apples from an apple tree...
If they have a horizontal initial velocity, they make a horizontal shot and fall to the Earth, tracing a curved path. But if they have the right initial horizontal velocity they continue to move around the Earth.
For example, if we throw an apple at 8 km/s tangentially to the surface of the Earth, it will return to the same point on the other side in 5000 s (Why?)
The moon moves at 1.022 m/s

5.9. Seasons Explored: Embarking on Earth's Annual Journey

The scenario starts with the engagement phase where the students are invited to recall basic knowledge about the seasons.

ENGAGEMENT

Students are oriented to recall basic knowledge about the seasons as they know them in Europe – how many, their characteristics, their order. Students are expected to have this knowledge, so the questions are intended to have them interpret the pictures, using their knowledge.

Figure 128 Seasons (Image from Freepik)

Q1: What do you think this picture is representing:

a) A nice park outside the city
b) Possible weather changes
c) Annual season cycle

For teachers

Answers:

a) *Needs guidance to be more attentive to the picture and interpret what it is representing*
b) *Noticed the changes but needs to go a step further and interpret the seasons*
c) *The best answer*

<u>For the students that answered a) a new question is presented:</u>

Q1 PATH a)

Q'1a: Look more carefully to the picture.

Although it seems to be a nice park, the picture is trying to illustrate something else. See how the weather and the trees change sequentially. Could it be because:

a) The weather changes everyday
b) Each image represents a season
c) The picture represents the annual season cycle: summer, fall, winter, spring

For teachers

Answers:

a) *The student isn't paying much attention to the picture. Needs to be instructed*
b) *The student has already understood the idea of the different images, but hasn't noticed the sequential aspect*
c) *The student has got it*

Students receive some guidance according to their answers:

Q'1a PATH a):

The weather can change a lot from day to day, but usually not as much as depicted in the picture. Also, trees won't change their aspect on a daily basis.

This picture is representing the sequence of the seasons: summer, fall, winter and spring.

Q'1a PATH a):

Yes, each image is a different season. The sequence of the images represents the annual season cycle: summer, fall, winter, spring.

Q'1a PATH c):

Well done, you understood the complete meaning of the picture!

For students that answered b) a new question is presented

Q1 PATH b:

Q'1b: Look more carefully to the picture.

Yes, the weather changes in each image, but the picture is trying to illustrate something more. See how the weather and the trees change sequentially. Could it be because:

a) The weather is changing everyday
b) Each image represents a season
c) The picture represents the annual season cycle: summer, fall, winter, spring

For teachers

Answers:

a) *The student is only focusing on the weather. Needs to be instructed*
b) *Already understood the idea of the different images, but hasn't noticed the sequential aspect*
c) *The student has got it*

Students receive some guidance according to their answers:

Q'1b PATH a):

The weather can change a lot from day to day, but not as much as depicted in the picture. Also, trees won't change their aspect on a daily basis.

This picture is representing the sequence of the seasons: summer, fall, winter and spring.

Q'1b PATH b):

Yes, each image is a different season. The sequence of the images represents the annual season cycle: summer, fall, winter, spring.

Q'1b PATH c):

Well done, you understood the complete meaning of the picture!

For students that answered c:

Well done, you understood the meaning of the picture!

The Engagement phase continues with new questions to all students (Q2 and Q3)

Q2: This picture represents the apparent sun path across the sky at different times of the year and each path corresponds to the first day of a season. Paths A, B and C correspond to the first day of which season?

a) A – Fall and Spring; B- Summer; C- Winter
b) A – Summer; B- Fall and Spring; C- Winter
c) A – Winter; B- Summer; C- Fall and Spring

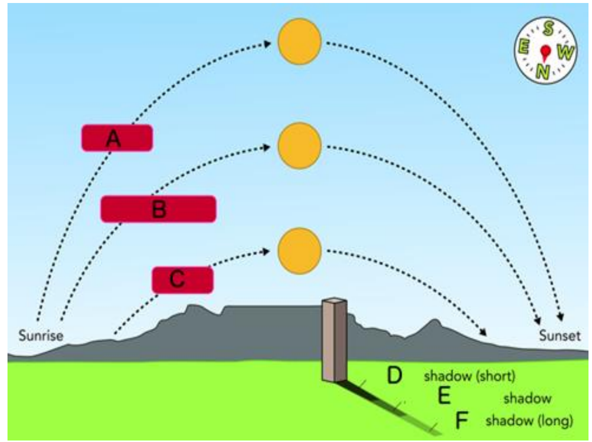


Figure 129 The apparent path of the Sun (http://www.mstworkbooks.co.za/natural-sciences/gr7/gr7-eb-01.html)

For teachers

Answers:

a) and c) need guidance – both are equally wrong

b) Is the correct answer

For students that answered a) a new question is presented:

Q2 PATH a) and c):

Q'2 ac: Path A takes the sun higher in the sky and it is a longer path, meaning that there are more daylight hours. In contrast, path C is shorter and consequently days are shorter. With this in mind, paths A, B and C correspond to the first day of which season?

a) A – Fall and Spring; B- Summer; C- Winter
b) A – Summer; B- Fall and Spring; C- Winter
c) A – Winter; B- Summer; C- Fall and Spring

For teachers

Answers:

a) and c) need to be instructed

b) Is the correct answer

Students receive some guidance according to their answers:

Q'2 ac PATH a) and c):

During the summer, the sun rises higher, takes a longer path in the sky, and there is more daylight hours. So label A is Summer.

During the winter, the sun is lower in the sky and there are less daylight hours. Label C is Winter.

Label B is Fall and Spring.

Q'2 ac PATH b)

Exactly! Well done!

For students that answered b) a new question is presented:

Q2 PATH b):

Q'2 b: Knowing that this picture is from a south-facing perspective, do you think it is illustrating the situation in

a) the northern hemisphere
b) the southern hemisphere
c) in both hemispheres

For teachers
Answers:
a) Is the correct answer
b) and c) need to be instructed

Students receive some guidance according to their answers:

Q'2b PATH b) and c):
In the northern hemisphere, above the tropic of Cancer, the sun is always towards south, as the compass is showing. So this picture is illustrating the situation in the northern hemisphere.
Q'2b PATH a):
Yes, you are right! The compass shows that the sun is towards the south, so it has to be in the northern hemisphere.

A new question is presented to all students:
Q3: Let's look again at the picture. Now consider the shadows at noon - which position do you think is responsible for shadow D?

a) A
b) B
c) C

For teachers
Answers:
b) and c) need guidance to pay more attention to the picture and interpret what it is representing
a) Is the correct answer

For students that answered b) or c) new question is presented:

Q3 Path b) and c):
Q'3 bc: Picture **A** shows how the angle of light incident on an object changes the length of its shadow. Now, look again at picture (**B**) - which position do you think is responsible for shadow D?

a) A
b) B
c) C

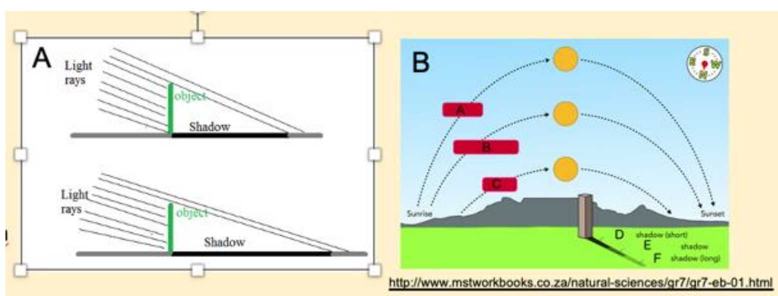


Figure 130 Illustration A and B

For teachers
Answers:
b) and c) students need an explanation
a) is the correct answer

Students receive some guidance according to their answers:

Q'3bc PATH b) and c):
Picture **A** illustrates that a light incident with a shallower angle on an object produces a larger shadow of the object. Think about how your shadow is much larger on sunset than at noon! So the season that gives you a shorter shadow at noon is Summer, path A in the picture!
Q'3bc PATH a):
Yes! During Summer, the Sun is higher in the sky at noon so the shadow is shorter.

<u>For students that answered a) a different question is presented:</u>

Q3 Path a):
Q'3 a: Yes! During the first day of Summer, which is Path A, the Sun is higher in the sky at noon, and so the shadow is shorter.
What would happen if you were in a place with a higher latitude, i.e., nearer the North pole? Would the shadow be longer or shorter? Use the picture to help you figure it out.

a) Longer
b) Shorter
c) Equal

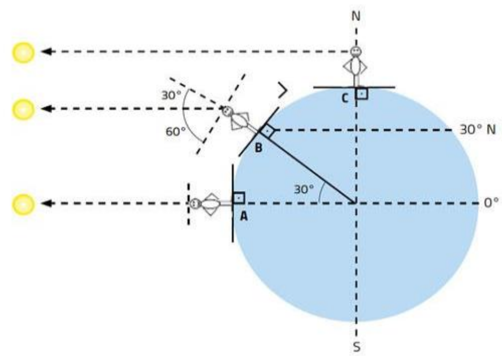


Figure 131 Different possible paths of the Sun

For teachers
Answers:
b) and c) need explanation
a) Is the correct answer

Students receive some guidance according to their answers:

Q'3a PATH b) and c):
The picture illustrates how the incident angle of the sunlight varies with latitude. The nearer you are to the North pole, the shallower is the angle of the incident sunlight – with the extreme situation at the pole, when the sunlight is parallel to the horizon! At the equator, the sun will be exactly above your head, so the shadow disappears!
Q'3a PATH a):
You are right, the shadow will be longer because the sunlight will strike at a shallower angle.

After this initial engagement phase students are invited to make **their hypothesis.**

Q4: Do you think that the fact that the sun is higher in the sky in summer makes this season warmer than others? To answer this question, you are going to do an experiment.
Look at the picture illustrating the light rays hitting the ground at different angles. What do you think happens?

a) If the light strikes the ground more directly (closer to perpendicular), its energy is concentrated in a smaller area and consequently, it will heat more that place than if the light strikes at more glancing angles.

b) If the light strikes at more glancing angles (closer to horizontal), its energy is greater than if the light strikes more directly because it will spread out in a bigger area. Consequently, it will heat more than if the light strikes more directly.
c) Regardless of the angle of incidence of the light, the ground will heat up in the same way because the energy of the light is the same.

Figure 132 Illustration of the light rays hitting the ground

For teachers

Answers:

These are all acceptable hypotheses - now they will test them!

a) *is the hypothesis that will be verified*
b) *is the hypothesis that doesn't have a good explanation*
c) *is the hypothesis that shows that the student isn't thinking about energy per area*

This is your hypothesis - write it down in your notebook! Now you will test it through an experiment and see if it verifies or not.

Students are now entering the **EXPERIMENT phase**

Q5:

It's lab time! You will design an experiment to test your hypothesis with the equipment you see in the picture. The independent variables of your experiment are: the height of the lamp, the angle of incidence of the light, the intensity of the lamp, the time the light was hitting the thermometer. And you have one independent variable, the temperature of the surface stroke by the light, which you measure.

How will you handle the variables when conducting the experiment?

a) I'll fix all independent variables except the angle of incidence of the light, which I will vary at least three times and read the temperature of the surface hit by the light. Afterwards, I'll change the height of the lamp and repeat the procedure.
b) I'll fix all independent variables except the angle of incidence of the light, which I will vary at least three times and read the temperature of the surface hit by the light.

Figure 133 Illustration for the first experiment

c) I'll fix all variables and read the temperature of the surface hit by the light. Then I'll change the height of the lamp, the intensity and the angle of incidence of the light and read the temperature of the surface hit by the light. I'll do this a couple of times.

For teachers
Answers:

a) *This is the best design. Fixes all the variables except one and takes several measurements; then repeats for another height to see if the same effect is also there.*
b) *It is not a bad design, but doesn't test for another situation, e.g., different height or different intensity, which would reinforce the result.*
c) *The design fails because it is changing several variables at each experiment.*

For students that answered c) :

Q5 Path c):
Q5'c: You are planning to change the height of the lamp, the intensity and the angle of incidence of the light at each experiment. If the temperature changes from one experiment to another, which variable will be responsible for the effect?

a) I won't know.
b) All of them.
c) The angle of incidence because it is the one I want to verify.

For teachers
Answers:

a) *It is the correct answer.*
b) *The student has to understand that, even if all the variables contribute to the change in temperature, it is not possible to know the effect of each variable and compare to the hypothesis.*
c) *The student has to understand that changing all variables makes it impossible to know the effect of an individual variable.*

Students receive some guidance according to their answers:

Q'5 PATH b) and c):
Well, maybe all of them contribute, or only one - you can't identify the effect of each variable if you are changing all of them each time!
Q'5 PATH a):
Exactly, allowing multiple variables to change creates a tangle of causal relationships and makes it harder to trace which change is having which effect.
So, let's try again!
(It goes back to the previous question)

Students are invited to prepare their experiments

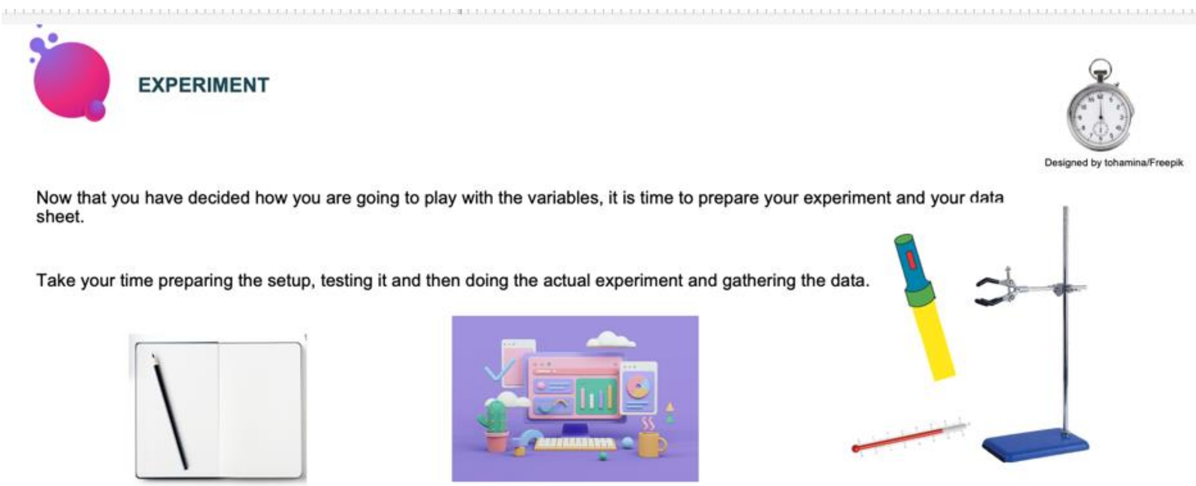


Figure 134 Students experiment

For teachers

Students should work in groups. Teachers can supervise the students as they carry out the experiment but shouldn't interfere too much – just give useful hints!

Students are now invited to **analyse the data and reach the first conclusions**

A new question is presented to all students in support for this phase

Q6:

Well done! You've completed the first experiment and obtained your own data. Now comes a very important part: analysing the data and checking whether your initial hypothesis has been verified or not.
Recall your hypothesis – you should have written it down in your notebook.
Do you verify your hypothesis?

a) Yes.
b) No.
c) I can't conclude.

For teachers

Answers:

These are all acceptable answers – it depends on the data and on their analysis.

a) *Go to Q'6a*
b) *Go to Q'6b*
c) *Go to Q'6c*

For students that answered a) :

Q'6a:

So, your hypothesis has been verified?

a) Yes, I verify that if the light strikes the ground more directly (closer to perpendicular), it will heat up the area more than if the light strikes at more glancing angles.
b) Yes, I verify that if the light strikes at more glancing angles (closer to horizontal), its energy is greater than if the light strikes more directly because it will spread out in a bigger area. Consequently, it will heat more than if the light strikes more directly.
c) Yes, I verify that regardless of the angle of incidence of the light, the ground will heat up in the same way because the energy of the light is the same.

For teachers

Answers:

a) *This is the hypothesis that should be verified, the experiment gave the expected result.*
b) *This shouldn't be verified so either the experiment wasn't correctly done, or the analysis is incorrect.*
c) *This shouldn't be verified so either the experiment wasn't correctly done, or the analysis is incorrect.*

Students receive some guidance according to their answers:

Q'6a PATH b) and c):

Something didn't go well either during your experiment or during your analysis. Go through your work and try to find what went wrong. If you can't discover it, your teacher can help you.

Q'6a PATH a):

Well done, you have verified your hypothesis! In fact, if the light strikes the ground more directly (closer to perpendicular), it will heat up the area more than if the light strikes at more glancing angles. That is because the energy is concentrated in a smaller area and consequently, the amount of energy per area is greater than for glancing angles.

For students that answered b) :

Q'6b:

So, your hypothesis hasn't been verified?

a) Yes, I didn't verify that if the light strikes at more glancing angles (closer to horizontal), it will heat up more than if the light strikes more directly.
b) Yes, I didn't verify that if the light strikes the ground more directly (closer to perpendicular), it will heat up the area more than if the light strikes at more glancing angles.
c) Yes, I didn't verify that regardless of the angle of incidence of the light, the ground will heat up in the same way because the energy of the light is the same.
d) Yes, I didn't verify that regardless of the angle of incidence of the light, the ground will heat up in the same way because the energy of the light is the same.

For teachers

Answers:

a) *This hypothesis shouldn't be verified, so the experiment gave the expected result.*
b) *This shouldn't be verified so either the experiment wasn't correctly done, or the analysis is incorrect.*
c) *This shouldn't be verified so either the experiment wasn't correctly done, or the analysis is incorrect.*
d) *This hypothesis shouldn't be verified*

Students receive some guidance according to their answers:

Q'6b PATH b) and c):
Something didn't go well either during your experiment or during your analysis. Go through your work and find what went on. If you can't discover it, your teacher will help you.
Q'6b PATH a) and d):
Well done, you have verified that, contrary to what you expected, if the light strikes the ground more directly (closer to perpendicular), it will heat up the area more than if the light strikes at more glancing angles! That is because the energy is concentrated in a smaller area and consequently, the amount of energy per area is greater than for glancing angles.

For students that answered c) :

Q'6c:
So, you can't conclude if your hypothesis has been verified or not.
Something didn't go well either during your experiment or during your analysis. Go through your work and try to find what went wrong. If you can't discover it, your teacher can help you.

Students are invited to **reflect** on their journeys:

Q7:
Now we can go back to our question: do you think that the fact that the sun is higher in the sky in summer makes this season warmer than others?
a) Yes
b) No

For teachers
Answers:
a) *It is the correct answer.*
b) *The student didn't understand the conclusions of the experiment. Needs more guidance.*

Q7 PATH b):
From the previous experiment we know that when the sunlight strikes the ground more directly (closer to perpendicular), it will heat it up more than when the sunlight strikes at more glancing angles. So we can conclude that the fact that the sun is higher in the sky in summer contributes to making this season warmer than others. Of course, there can be more factors contributing to making summer the warmest season.
Q7 PATH a):
It seems that you understood the conclusions of your experiment, well done!
Q8:
And speaking of seasons, can you explain what causes the different seasons on Earth?
a) The tilt of the Earth's axis as it orbits the Sun.
b) The distance between the Earth and the Sun changes throughout the year.
c) The Earth's rotation causes different parts of the world to have different seasons.

For teachers

Answers:

a) *This is the correct answer.*
b) *Although it is a true statement, it doesn’t cause the seasons.*
c) *Completely incorrect*

Q8 Path c:

The Earth’s rotation is responsible for day and night on Earth. Between day and night, are there different seasons? No, so the Earth’s rotation doesn’t cause seasons. Then, what causes?

a) The tilt of the Earth's axis as it orbits the Sun.
b) The distance between the Earth and the Sun changes throughout the year.

For teachers

The student is back to the same question but doesn’t have option c)

Answers:

a) *This is the correct answer.*
b) *Although it is a true statement, it doesn’t cause the seasons.*

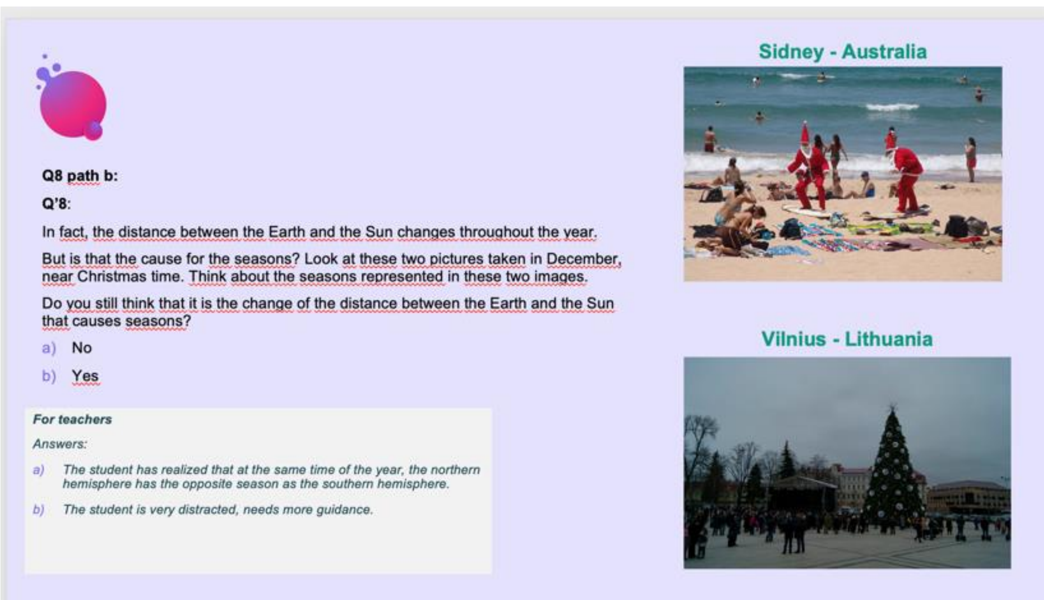


Figure 135 Question for students on path b

Q’8b path b:

The pictures show that at the end of December, around Christmas time, it is Winter in the Northern Hemisphere and Summer in the Southern Hemisphere.

If the change of distance between the Earth and the Sun throughout the year is the cause of seasons, then how can you have different seasons around Earth at the same time?

What causes seasons has to explain why the two hemispheres have opposite seasons.

Q'8b path a:
Well done, you noticed that at the same time of the year the two hemispheres have opposite seasons making it meaningless to think that the change of distance between the Earth and the Sun throughout the year is the cause of seasons.

For teachers
In both cases the students are ready to proceed to investigate how the tilt of the Earth's axis can cause the seasons.

Students are invited to make a new hypotheses:

Q9:
We shall now investigate how the tilt of the Earth's axis might cause the seasons.
What do you think?

a) The tilt of the Earth's axis causes different parts of the Earth to receive sunlight at different angles throughout the year, leading to the changing seasons.
b) The tilt of the Earth's axis makes one hemisphere closer to the Sun than the other at different times of the year, causing the seasons to change.
c) Seasons change because Earth's tilt itself changes.

For teachers
Answers:
These are all hypotheses - now they will test them!

a) *is the hypothesis that will be verified*
b) *is a hypothesis that has some reasoning behind it, but the actual calculations will show that it doesn't really affect the seasons*
c) *is a hypothesis that shows that the student thinks the tilt angle changes throughout the year*

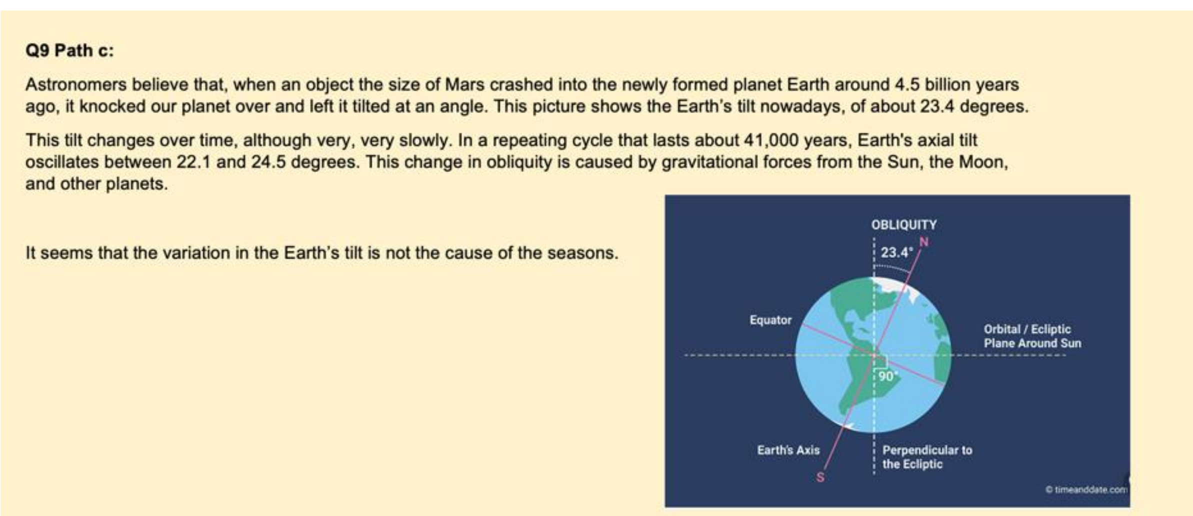


Figure 136 Support for students who chose path c

For students who chose path b):

Q9 Path b:
It is true that the tilt of the Earth's axis makes one hemisphere closer to the Sun than the other at different times of the year.
But will that difference in distance be able to account for the seasons?
Consider the following:
Earth's average radius: 6371 km
Sun-Earth average distance: 149 000 000 km
Calculate Earth's average radius
Sun-Earth average distance
Surprised?
So, the answer is no. The Earth is so small compared to the distance between the Sun and the Earth that the difference between the hemisphere that is closer to the Sun and the other hemisphere doesn't count for the seasons.

Students are now invited to interact with a virtual experiment:

Let's investigate the hypothesis:
The tilt of the Earth's axis causes different parts of the Earth to receive sunlight at different angles throughout the year, leading to the changing seasons.
You will use the simulator https://astro.unl.edu/naap/motion1/animations/seasons_ecliptic.html
Start by exploring the simulator as you like. When you feel you understand what is does, start designing your experiment.
Keep in mind the hypothesis you want to verify!

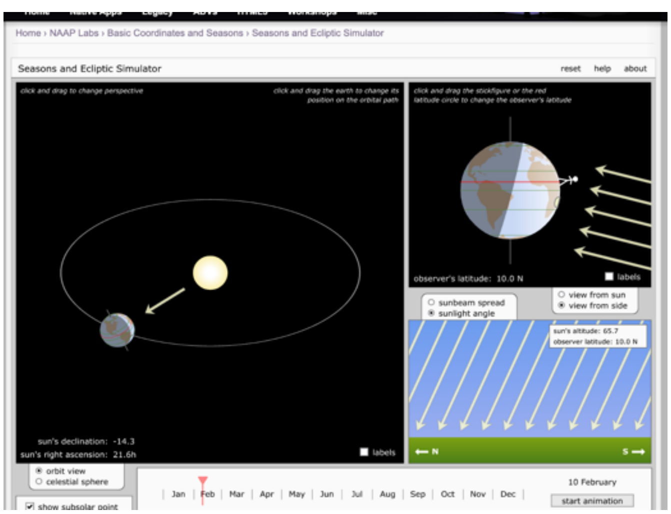


Figure 137 Seasons and eclipses simulator

For teachers
Students can form small groups.
They will explore the simulator and design their experiment.

Q10:
Your variables are:

a) Independent variables: date, observer's latitude. Dependent variables: sunlight angle (or sun's altitude), sunbeam spread
b) Independent variables: sunlight angle (or sun's altitude), sunbeam spread. Dependent variables: date, observer's latitude
c) Independent variables: date, observer's latitude, sunlight angle (or sun's altitude), sunbeam spread. Dependent variables: none.

For teachers
Answers:
a) The student understood the variables of the simulation.
b) The student doesn't know the difference between independent and dependent variables.
c) The student doesn't distinguish options from variables.

For student who chose path b and c:

Q10 path b) and c):
An independent variable is the cause of a phenomenon, its value is independent of other variables – you can control. A dependent variable is the effect, and its value depends on changes in the independent variable(s).
Now that you know better the difference between independent and dependent variable, what are the variables in the simulator?

a) Independent variables: date, observer's latitude. Dependent variables: sunlight angle (or sun's altitude), sunbeam spread
b) Independent variables: data. Dependent variables: sunlight angle (or sun's altitude)
c) Independent variables: date, observer's latitude, celestial sphere, view from sun, view from side. Dependent variables: sunlight angle (or sun's altitude), sunbeam spread.

For teachers
Answers:
a) The student understood the variables of the simulation.
b) The student is only considering a subset of the variables.
c) The student doesn't distinguish options from variables.

Support to students:

Q10 PATH b):
You are forgetting some other variables: the observer's latitude (independent variable) and the sunbeam spread (dependent variable)
Q10 PATH c):
Visual options are not variables - they are just there to help you visualize what is happening. So, view from sun and view from side aren't variables.

Q10 PATH a):
It seems that you understood correctly the variables of the simulation!

Students are then invited to perform the experiment:

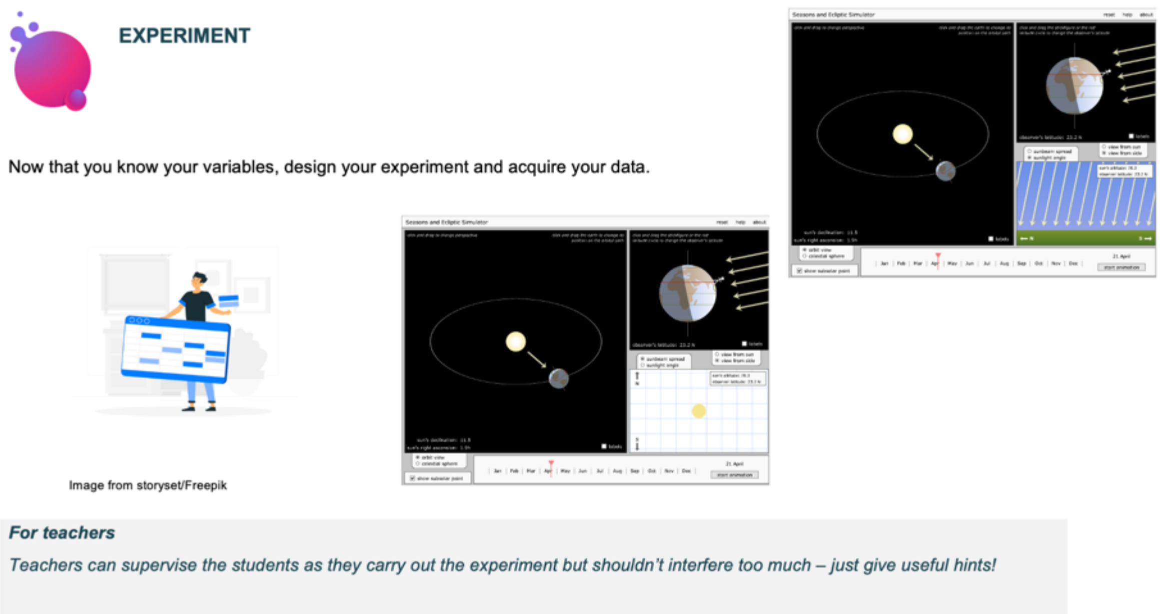


Figure 138 Students are invited to use the virtual simulation

Q11:
Which of the following are true from your data analysis?
For a fixed location in the Northern Hemisphere,

a) the sunlight angle is more horizontal in December and more vertical in June
b) the sunbeam spreads more in December and less in June
c) in September, there is a day when the night line is parallel to the Earth's axis.

For teachers
All answers are true. The teacher can promote a discussion of each of these statements.

Q12:
Students prepared a model to study the Earth's movement around the Sun and the seasons: a lamp was the Sun, and 4 Earths, at different locations around the Sun, simulated its orbital movement. The students set up the model as you see in the image. But then someone said: we aren't going to be able to understand the seasons with the model as it is. What did they do wrong?

a) The four Earth's axes are pointing to different locations in the sky and have different tilt angles.
b) The four Earth's tilt angles are different.
c) They needed more Earths to complete the orbit.

Figure 139 A model to support the discussion phase

For teachers

Answers:

a) *Is correct*
b) *Is incomplete*
c) *Is wrong*

Support for students who chose path c:

Q12 PATH c):

More Earths could help complete the orbit, but it isn't necessary to understand the seasons. What the students were forgetting had to do with the tilt of the Earth's axis and where is should point to.
The Earth's tilt doesn't change throughout the year, so all axes should have the same inclination.
Now let's see where the axes should be pointing to.

For teachers

*The students proceed to **Q12 Path b)***

Support for students who chose path b:

Q12 PATH b):

Q'12 b

All axes should have the same inclination since the Earth's tilt doesn't change throughout the year. But should all axes point to the same location?
If you are in the northern hemisphere, you must have heard of the Polar Star.
Why is this star so famous?

a) It points to the North
b) It belongs to the constellation Little Dipper
c) It is the brightest star in the sky

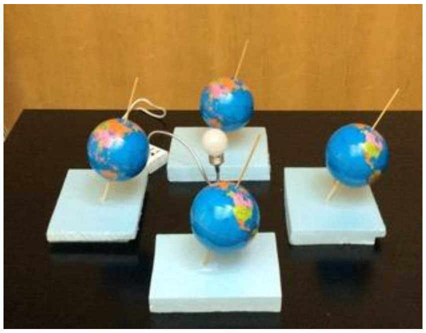


Figure 140 Earth with all axes with the same inclination

For teachers

Answers:

a) *Is correct*
b) *Is correct but it isn't why it is famous*
c) *Is wrong*

Q'12 b PATH a) b) and c):

The Polar Star, or Polaris, isn't the brightest star of the northern hemisphere, but it is the brightest star of the Little Dipper. What makes it famous is the fact that it always stays in roughly the same place in the sky.

a) It's called Polaris because if you drew an imaginary line from the South Pole through the Earth, and out the North Pole, into space, that line would point very close to Polaris. That is why it is also called the North Star since it points to the North.

b) While the Earth is in its journey around the Sun, its axis has to be pointing always to the Polar Star.
c) That's why all the earths in the student's model should be parallel, pointing to the same direction.

For teachers

Answers:

a) Is correct
b) Is correct but it isn't why it is famous
c) Is wrong

For students selecting a)

Q12 PATH a):

Q'12 a

Exactly, all axes should have the same inclination since the Earth's tilt doesn't change throughout the year and should point to the same location in the sky.

Where should it point to?

a) The Polar Star
b) North
c) The Big Dipper

For teachers

Answers:

a) Is correct
b) Is not very precise, but shows some understanding
c) Is wrong

Steps for students according to their choices

Q12'a PATH b) and c):

Go to the previous slide

Q12'a PATH a):

Great answer!

For teachers

To finalize, teachers can

- *promote a discussion of the findings,*
- *ask for a report on the activity*
- *have students prepare a hands-on activity*