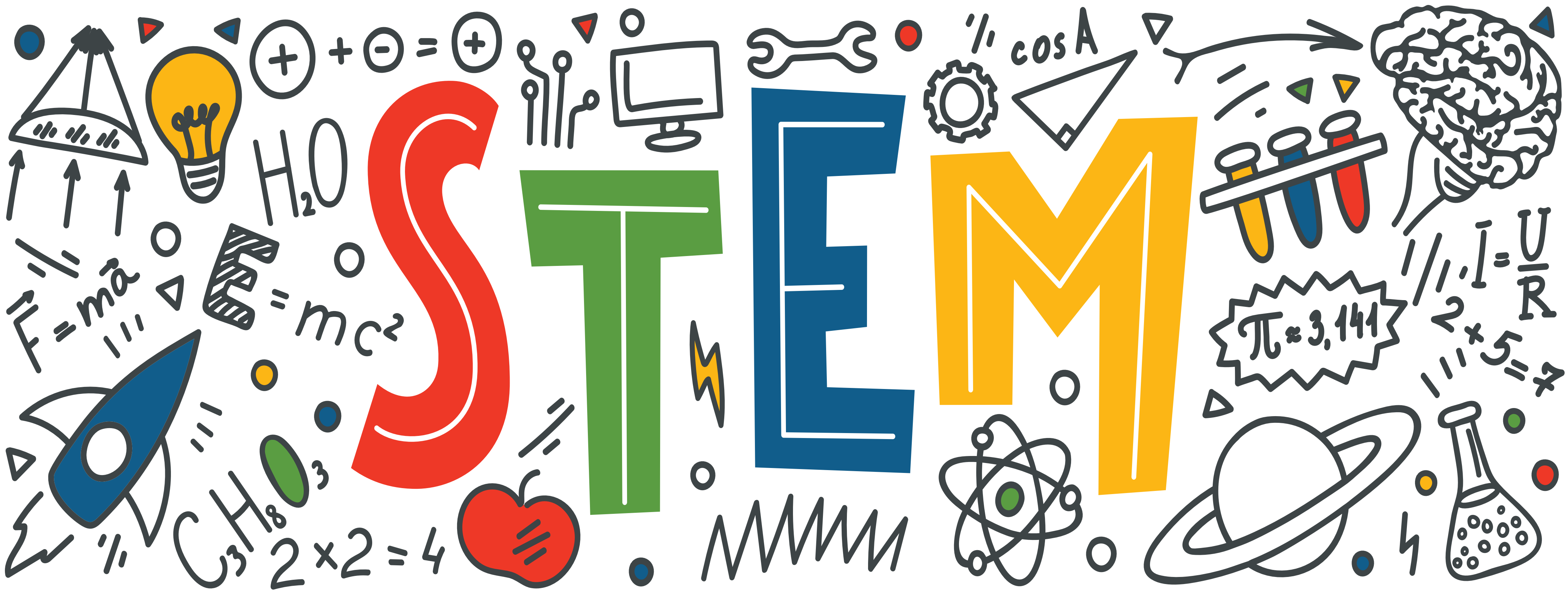

STEMaP

Simple machines in
SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS

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THE ANALYSIS OF TEACHERS AND STUDENTS' NEEDS IN SIMPLE MACHINES

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TABLE OF CONTENTS

INTRODUCTION

That of STEM (Science, Technology, Engineering, and Mathematics) educational field is a theme that has received growing attention by EU Member States over the past decade, constantly being included within EU Policy discourses on the future of European Economy. STEM education represents a critical factor in both tackling the important challenges that the EU is currently facing (climate change, energy supply, healthy aging and digitalization) and ensuring industrial development, smart, sustainable and inclusive economic for young people, as well as gender equality in learning scientific and mathematical subjects.

The urgency of investments in STEM education seems to be confirmed by EU STEM skills labor market. In fact, there is a mismatch between STEM education supply and demand, and as highlighted by EC (2014), a large majority of EU Member States are currently experiencing serious difficulties in recruitment of STEM skills.

The grounded project idea is that by means of Simple Machines and other teaching instruments, students will be allowed to practice and be acquainted with various technical fields in modern engineering with active thinking. In fact, through experiments with simple machines students will understand and master the method of experimental apparatus. They will realize what is the experiment process, understand experimental support for the theory and engineering, cultivate their cognitive ability and practical ability.

More specifically, while Simple Machines may be conceived as a powerful tool to increase the engagement of students in the learning processes by capturing their attention better than a traditional pencil-and-paper approach. As a consequence, by getting them to a deeper, empirical-driven comprehension of the core contents object of the study, they can be also conceived as a tremendous means through which gender inequalities in the study of STEM subjects can be overcome, opening up career opportunities to girls and women, enriching the EU labour market in terms of number of workers and range of STEM skills, and, ultimately, reducing the mismatch between STEM skills supply and demand and the shortage of STEM skills required by companies.

The research presented in this document was conducted during project first year of implementation with the aim of analyzing more into details these premises, and hence the needs of students about learning STEM and those of teachers in transferring knowledge and skills about STEM to their students while reducing the inequality between men and women. The research has been focused mainly on the teaching gaps.

The study is related to the 5 schools where the project is being developed (Italy, Greece, Poland, Estonia, Latvia) and has been organized in the following sections:

I. Synthetic description of STEM policies in each country, national official statistical data on STEM learning competences and benchmarking;

II. Report on quantitative and qualitative data emerged from administered questionnaires and interviews;

III. Connection between development of Simple Machines and scientific and creative learning outcomes of students.

All partners have contributed in the implementation of the research, which has been coordinated by the Prof Evgenia Koleza, University of Patras, Department of Educational Science, Greece.

The results will contribute to the achievements of project's objectives, as far as the development of the tools for teachers in order to improve learning outcomes of their students in relation to STEM is concerned. Therefore, outcomes will be used to equip teachers with the appropriate Simple Machine tools in order to arise students' interest and curiosity towards STEM, while reducing the gender gap.

1. THE STEMAP PROJECT

The three years project (2018 > 2021) was born from a felt need by the partner organisations that more has to be done in order to increase learning and teaching of scientific subjects, while reducing the generally perceived inequality between men and women, with the latter being less stimulated.
In fact, there is a process of growing disinterestedness of students towards STEM education, especially at secondary school level (Rohaan et al. 2010), a process whose causes can be traced back to different factors (EU, 2015):

- Attitude of students towards science and technology have changed, becoming more pessimistic;
- Shortages in STEM professions have not been accompanied by an increase in average wages levels, discouraging students to undertake STEM training, usually implying a consistent amount of years of study;
- Persisting gender segregation across study fields, often starting from family environment and then spreading at secondary school and university level, still hinders girls' and women's later study and career opportunities;
- The way in which STEM subjects are taught has a great influence on students' attitudes towards science, on their motivation to study and, consequently, on their achievements.

These elements give a good reason to engage in making the school teaching of science and mathematics more open to inquiry-based activities. It is on these points that the project is focused.
The project identifies Simple Machines as particularly suited to STEM education while reducing gender inequality.
By Simple Machine we intend any of various elementary mechanisms formerly considered as the elements of which all machines are composed and including the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw.

Objectives

The Project aims to:

- develop concepts and knowledge about Simple Machines, in terms of the learning about the composition and functioning of each device and its parts, and the identification of common uses for each of Simple Machines;
- develop and practice engineering problem solving skills, by using the concepts of mechanical devices to produce creative solutions to Problems, as well as by carrying out and practicing the iterative engineering design process Research <--> Simulate <--> Prototype;
- enable students to individuate and fully understand the existing connections between physical devices, mathematics, and scientific principles;
- encourage students to self-reflect on their work, activities, and hence on their learning processes;
- develop knowledge about concepts and functioning of Simple Machines among teachers, with the aim to promote the adoption of a more integrated, practice- and empirical-oriented STEM teaching methodology, especially with reference to engineering, combining theory and practice.

Results

In order to achieve project objectives, the following outcomes will be achieved by students at the end of the project:

1. increase in knowledge about concepts and principles of use of Simple Machines, as well as the increase in the ability of students to identify and describe the functioning of each of the devices, their parts, as well as the connections between the devices analysed and the corresponding Simple Machine;
2. increase in problem solving skills among students and their knowledge about both the concepts of the mechanical devices and how such concepts can be used to produce creative and innovative solutions to engineering problems;
3. increase in the ability of students to individuate or understand the connections between physical devices, mathematics, and scientific principles;
4. increase in the ability of students to self-reflect on their work, activities, and hence on their learning processes;
5. increase in the ability of students to work and design with Simple Machines to develop item concepts, as well as to engage in the engineering process, also by testing predictions through modelling and prototyping;
6. increase in the degree of confidence of students about their abilities, as well as in their motivation to study STEM subjects, especially engineering;

7. increase in the knowledge about Simple Machines of teachers, and the increase in the degree of adoption of integrated approaches to STEM teaching, especially with reference to engineering.

In line with OECD PISA, 2006 (OECD, 2006) context, learning outcomes that students will achieve will be framed in the following contexts:

- Science: Explain phenomena scientifically; Evaluate and design Scientific Enquiry; Interpret data and Evidence Scientifically;
- Mathematics: Change and relationship; Space and Shape; Quantity; Uncertainty and data;
- Technology and applied Engineering (Molina, 2006): relationship between society and science; impact of technological applications in life of individuals and organisations; investigation of efficacy and efficiency as a social value.

Hence, students will be able to make the connections between the physical devices and their governing abstract principles.
Progressive achievement of learning outcomes will be evaluated mainly, but not only, by OECD PISA questionnaires to students and teachers. The OECD PISA tool will facilitate comparison of results between schools.

Outputs

The project enables this change in students' performance through the combination of the following outputs, achieved during project's lifetime:

8. STEM Need Analysis teachers and students: the aim is to get a better understanding of the needs related to students of the secondary schools participating in the project. This phase confirms the initial assumptions of the project and represents the baseline for future project developments. Results are be then transferred to a wider population through inferential analysis.
9. Elaboration of a teacher training material: it constitutes the core and the envisaged output of STEMachines Project. It will be organized in units for teachers, to be applied during laboratories at school. Units are drawn in researched methodologies, which have the potential to ensure an inclusive approach. The specific content designed is based on the result of the Need Analysis conducted during the first year of the project and has the potential of being transferred to other contexts of education.
10. Simple Machines Games Online Educational Resource: it is the educational source for teachers to use during laboratories, with the potential of attracting students' attention through digital devices. It provides tests and games for students, designed by teachers. Students can use the games during homework and with their peers.

Being the project implemented in a European context, the mobility of teachers and students is an essential element to be enhanced in order to assure exchange of good practices, peer-learning, cultural exchange and understanding of the educational or other aspects that influence the willingness of students towards STEM subjects. This is the added value of the project which impacts finally the quality of the outputs.

Benefits and transferability of results

Developed outputs are fully transferable and adaptable to other school grades and other EU countries, not directly involved in the project. This will be assured by project educational platform and ELIOS platform, already developed through a previous Erasmus+ project, where already more than 20 European schools have been enrolled and use the existing tools for innovative teaching practices.

2. THE ANALYSIS OF TEACHERS AND STUDENTS' NEEDS IN SIMPLE MACHINES

2.1 Objectives

In order to contribute to project objectives, the Need Analysis, as project first output, stated as general objective the identification of the teaching/learning difficulties that contribute in each country to inequalities in the study of STEM subjects as well as to a pessimistic approach of students in approaching these fields.
More specifically, the research objectives are:

1. to understand the curriculum of each country on concepts behind Simple Machines, namely, weight/force, energy/work, torque; the age of the students to whom these concepts are taught and the school grade; the types as well as difficulty of the problems and questions (always about these concepts) contained in the textbooks used by your students. This objective was related to Phase 1 of the Research;
2. to understand the level of knowledge about concepts behind simple machines of the students enrolled in the secondary schools involved in the project, in order to have standardized results and obtain a comparison. This objective was related to Phase 2 of the Research;
3. to identify those processes or tools that can support students in obtaining envisaged learning outcomes in STEM through the use of Simple Machines and that should be used by teachers. This objective was related to Phase 3 of the Research.

2.2 Methodology of investigation

The investigation was conducted through a quantitative method targeting students and teachers from secondary schools, which are partners in the countries where the project is being developed (Italy, Greece, Latvia, Poland and Estonia).
The three phases allowed to obtain some conclusions which will be used for the following phases of the project, and in particular in the elaboration of training material for teachers and training tools through Simple Machines.
Therefore, the first phase was conducted through an analysis of existing curricula in each country related to the concepts behind Simple Machines, by the study of existing teaching books and the description of laboratory activities. (Annex Table 1)
The obtained results were used in the second phase, that is the administering of a questionnaire, in the form of physics and mathematics problems (Annex Table 2) that students in each partner school filled out during in class lessons. Each teacher corrected the texts of own students and analyzed the emerged results, pointing out the more relevant positive and negative aspects.
These results were compared in the third phase of the investigation, in order to identify similarities and differences, also in consideration of variables which could have an effect on the results, such as different ages of students, different curricula and so on.
The conclusions are related to the further development of the project and hence the development of the training material and how it should fit with students and teachers' needs in all involved countries.

2.3 Investigation Team

The coordinator of the investigation was the University of Patras, Department of Educational Science, Greece, who worked closely with the Liceo Redi and OpenCom issc, in Arezzo, Italy. Each partner school identified mathematics and physics teachers who supported the development of activities in own school and assured the quality of results.
The quality of emerged results was assured by the high competence in STEM of involved teachers as well as by the transdisciplinary of the other members, who contributed in the educational approach definition.

2.4 Evaluation

During project implementation, the achieved intermediate outcomes will be evaluated in order to check if assumptions are being respected and objectives are being met through the elaborated educational material and Simple Machines tools.
A repetition of investigation phase 2 at the end of project second and third years is a support in order to check the validity of the investigation results.
Results will be published on project's online educational tool.

3. PHASE 1: EDUCATIONAL SYSTEM DESCRIPTION AND INVESTIGATION OF TEACHERS' NEEDS

A1- Synthetic description of Textbooks at curriculum related to simple machines and the concepts behind them

3.1 Methodology

In the first phase of the STEMaP project the partners provided us with information about the contents of every partner country's curriculum on the concepts behind simple machines, the age of the students to whom these concepts are taught and the school grade. Every partner recorded the desired goals exactly as they are described in the official papers of his country. The results of the first part of the research are summarized in the table below.

Tasks that partners performed were:

A. Provided details about teachers to be involved in the activities of the project. More specifically: names, expertise and professional experience.

B. provided with information about:

- the contents of own country's curriculum on concepts behind Simple Machines, namely: weight/force, energy/work, torque;
- the age of the students to whom the concepts are taught and the school grade;
- the types as well as difficulty of the problems and questions (always about these concepts) contained in the textbooks used by students of own country.

The model used to articulate the information was an adaptation to the project of the Understanding By Design model, composed by 3 stages:

Stage 1: to record the desired goals exactly as they are described in the official papers of own country and then, according to own knowledge and experience, partners chose those goals that considered more important, as well as related noticed misconceptions in previous teaching years;

Stage 2: to choose, for each concept behind Simple Machines, 4 or 5 examples/problems from own textbooks of different cognitive demands that would use at the end of the teaching, to make sure that students have understood what has been taught them;

Stage 3: to elaborate a Learning Plan, according to which the right teaching material will be prepared (this is IO2 Phase of STEMaP Project)
In Stage 1 partners recorded:

ESTABLISHED GOALS: the desired goals, exactly as they were described in the official papers of own country.

TRANSFER: how these goals are transferred to students through Simple Machines. It is related to the principal fact about the physical concepts (e.g. force) that students will retain in their minds after using the simple machine (e.g. inclined plane)

MEANING: the meaning of the physical concept (e.g. force), in terms of knowledge, in the context of Physics, in general not only about the simple machines, for example, the second Law of Newton; the essential questions to ask students in classroom about the physical concept.

ACQUISITION OF KNOWLEDGE and SKILLS: knowledge and abilities related to the physical concept, that teachers referred to in the previous sections (for example the inclined plane or any other simple machine); any misconception.

In Stage 2 partners recorded:

4 or 5 examples/problems (taken from their textbooks or constructed by teachers), used at the end of the teaching of the physical concept (e.g. force), to make sure that students have acquired a deep understanding of this concept. The problems chosen by partners were of various cognitive demands/levels of difficulty. As further assistance, we sent partners detailed examples of level 1 (about concepts like power, energy, torque..) found in the curricula of various states/countries in the world. The content was indicative of the format. We did not suggest it to be used as a prototype.

All previous information concerned the **3 concept**s:

Force - Work/Energy - Torque.

In total, partners sent 3 files (approximately, each one of one page).
In order to provide the information reported in points a., b. and c., we have prepared a template (Annex 1 of the report).

3.2 OUTCOMES PER COUNTRY

A resume of emerged outcomes

In the tables bellow you can see integrated and qualitative results of our research findings. As far as Weight and Force are concerned, in all countries teaching starts at the age of 14 years for the students. In Italy the mainly focus on the mathematical aspect of vectors and secondly on experimental aspects.
In Greece mainly in the mathematical aspect and formula solution.
In Latvia they teach all Newton's laws and focus on the dynamometers. In Poland students are connecting teaching of force and weight to everyday practice, distinguishing forces, drawing vectors and calculating values. They also try to get used to symbols and represents graphically the forces. Finally, in Estonia, the most important physical sizes are approached in the field of the forces, making a reference in Pascal act, gravitational field of Earth and pressure. They also connect this knowledge to swimming and drowning.
As far as concerns Torque. Students in Italy first are learning about Torque in the age of 14 years old mainly approaching the subject of the Torque through the mathematical concept of vector analysis. Also, in Estonia students are learning Torque for the very first time at the age of 14, although not in so much mathematical depth. In the rest countries they start teaching Torque not earlier than 15 years old and not in so much depth. In Greece students are learning Torque for first time at the age of 16 years old.
As far as concerns Energy and Work. Greece, Latvia, Poland and Estonia start teaching Energy at the age of 14 years old. They teach all aspects, Work calculation, Energy calculation, Kinetic and Dynamic Energy and Energy Conservation laws. Then, at the age of 15 years old students in Greece and Latvia are introduced more in depth in the meaning of the work further conservation laws, like Bernoulli's Law and Power. After the age of 16 years old in Italy students are firstly taught about Energy and conservation laws but in depth, even for elastic energy and rotational motions.

ITALY	GREECE	LATVIA	POLAND	ESTONIA
WEIGHT/FORCE				
Students age when the concept is taught: 14 **School grade when the concept is taught: 9th**				
That there are physical quantities described by means of vectors		Concepts of force, resulting force, gravity, weight, Archimedes force, lever, incline plane, pulley, windlass (winch)	Selects the right measuring instruments (e.g. for measuring length, time, force)	The most important physical sizes - weight, strength, pressure
How to represent vector quantities by means of vectors		1st, 2nd and 3rd Newton Law	lists and distinguishes the types of actions (mechanical, gravitational, electrostatic, electrostatic).	Pascal Act
How to describe the operations between vectors graphically		Interaction of object causes and maintain motion or change the speed of motion.	Gives examples of impacts that occur in everyday life gives examples of the effects of impacts daily life observes and compares the effects of different the type of impact gives examples of forces and recognizes them	Gravity field strength on Earth surface, normal pressure
The S.I. unit of the forces		Weight is the force that object act on support or pull suspension.	Measures the value of the force by means of dynamometer	Signs of swimming, drowning and suspended

ITALY	GREECE	LATVIA	POLAND	ESTONIA
		WEIGHT/FORCE		
The dimensional formula of force		A dynamometer is used to measure the force.	Determines the characteristics of the resultant force of two forces acting along the same line and force balancing another force	
How a spring works		Lever is in balance if multiplication of force and shoulder on both sides of support is equal.	Uses symbols of length, mass, time, force and their symbols units in the SI System	
The behavior of a spring through Hooke's law			Recalculates multiples and submultiples (pre- and post-multiples): micro, mili-, cent-); recalculates time units (second, minute, hour) estimates the order of magnitude of the expected measurement result, e.g. lengths, forces	
How to use Hooke's law			Performs a schematic drawing illustrating the measurement, e.g. lengths, forces	
How to calculate the weight of a body			Explains for what purpose the measurement is repeated several times, and then calculates the average of the results obtained, calculates the average value of several measurement results (e.g. length, time, force)	

ITALY	GREECE	LATVIA	POLAND	ESTONIA
WEIGHT/FORCE				
The effects of weight force on bodies			Describes the course and outcome of the experiment, using in the language of physics, explains the role of the instruments used and makes a schematic drawing showing the use of the experimental system in the study of e.g. interactions of bodies	
How to calculate the normal force acting on a body			Represents the force graphically (draws the force vector)	
How to calculate the static friction force on a body in stillness			Distinguishes between scalar (numerical) and vectorialvalues-and gives relevant examples	
What are the binding forces acting on a body			Analyses the results, draws a conclusion from the results achieved observations and measurements	
The equilibrium conditions on a sloping plane.			Finds graphically the resultant of two forces acting along the same straight line and a force balancing another force	

ITALY	GREECE	LATVIA	POLAND	ESTONIA
WEIGHT/FORCE				
The effects of weight force on bodies			Describes the course and outcome of the experiment, using in the language of physics, explains the role of the instruments used and makes a schematic drawing showing the use of the experimental system in the study of e.g. interactions of bodies	
How to calculate the normal force acting on a body			Represents the force graphically (draws the force vector)	
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What are the binding forces acting on a body			Analyses the results, draws a conclusion from the results achieved observations and measurements	
The equilibrium conditions on a sloping plane.			Finds graphically the resultant of two forces acting along the same straight line and a force balancing another force	

ITALY	GREECE	LATVIA	POLAND	ESTONIA
WEIGHT/FORCE				
The relationship between the balance of a material point and the forces applied to it			In a given coordinate system (described and graduated) draw a diagram of the force value dependence gravity acting on spring-loaded suspensions	
Students age when the concept is taught: 15 School grade when the concept is taught: 10				
The kinematic characteristics of the rectilinear, circular and parabolic motion	That laws are the same all over the world	Types of forces		
The conditions under which a system is inertial	To design an experiment	Acceleration, which the object has gained, always is directed the same direction as resulting force;		
The principles of dynamics	To solve mathematical equations	1st, 2nd and 3rd Newton Law		

ITALY	GREECE	LATVIA	POLAND	ESTONIA
WEIGHT/FORCE				
The significance of different modeling assumptions, and how they affect the calculations in a particular problem	To use mathematics in real life problems	Sliding friction force is directly proportional to surface of object reaction force and acting contrary to the direction of movement		
How to calculate the dynamic frictional force between two surfaces in relative motion	To measure forces	Hook Law		
The friction effects of the fluid medium	To calculate the acceleration if they know the forces and the mass	Mechanical stress - elasticity force acting on the area unit of cross-section of the sample along the body axis.		
	That total force is zero when the body is steal or moves with stable velocity			
	To add vectors			

ITALY	GREECE	LATVIA	POLAND	ESTONIA
		WEIGHT/FORCE		
	To analyze a force in two perpendicular axes			
	That mass and weight are different quantities			
	That weight depends on the place			
Students age when the concept is taught: 16 School grade when the concept is taught: 11				
Key terms---				
The superposition principle, and the differences between 1D and 2D and 3D systems of reference.				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
WEIGHT/FORCE				
The formulas of resistance force in a medium, of the normal force, of the elastic force, of the static and dynamic frictional force between two surfaces in relative motion and of the centripetal force.				
The differences between external forces and internal forces in a system.				
The principles of dynamics.				
The conditions of free fall of a body.				
The harmonic oscillator.				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
		TORQUE		
Students age when the concept is taught: 14 **School grade when the concept is taught: 9**				
What is the vector (cross) product				That the force-bearing effect is characterized by the product of force and its shoulder
What is the moment of a force applied to a rigid body with respect to a point				Gold rule of mechanics
The S.I. unit of the moment of a force				Energy Conservation Act
The dimensional formula of moment of a force				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
TORQUE				
The definition of torque				
The definition of couple				
The vector form of the torque of a force				
What is a couple of forces				
The torque concepts necessary for solving static problem				
The equilibrium conditions of a hanging body and a supported body				
What is the center of mass and the center of gravity of a body				
What is a lever				
How do levers work				
The levers used in everyday life				
The levers that our body use				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
		TORQUE		
The classes of levers				
Students age when the concept is taught: 15 **School grade when the concept is taught: 10**				
	To calculate torques and the net torque	Force moment - multiplication of force applied to the object and shoulder of force.		
	To use mathematics and physics to study every day phenomena	The object is in equilibrium if the sum of all the moments in relation to the axis of rotation is equal to zero.		
	How they can lift a man without be injured			
Students age when the concept is taught: 16 **School grade when the concept is taught: 11**				
Key terms---				
The relationships between angular and linear dimensions in circular motion.				
The concept of rigid body				
That an unbalanced torque causes a rotation of a rigid body				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
TORQUE				
That mass isn't enough to describe dynamic properties of a rigid body while moment of inertia is the correct quantity needed, and how to calculate it in some symmetrical situations.				
The S.I. unit of the moment of inertia and the dimensional formula of moment of inertia				
The first and the second principle of dynamics for rotations				
The angular momentum (units etc)				
The law of conservation of angular momentum				
The motion of rolling without slipping				
The ratio (comparison) of load/resistance force to the effort force is called the mechanical advantage.				
The difference between quantitatively mechanical advantage of pulleys and systems of pulleys				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
ENERGY/WORK				
Students age when the concept is taught: 14 **School grade when the concept is taught: 9**				
		Concepts: mechanical work, power, energy, potential and kinetic energy.	Uses the concept of energy and gives examples of its various forms	work, energy and power as physical sizes
		The work done depends on the amount of force that works on the object and on the length of the road that he is doing.	Distinguishes work in the physical sense from work in everyday language, indicates examples of performing mechanical work in the environment	Energy Conservation Act
		Power is the work done in the certain time.	Uses the notion of kinetic energy, indicates examples of bodies having kinetic energy, distinguishes kinetic energy from other forms of energy	
		Above the height of the support (h), the lifted body has potential energy.	Gives examples of energy conversion (transformation and transmission)	
		All moving objects have kinetic energy.	Solves simple calculation tasks concerning mechanical work and power, distinguishes between data and searched values, calculates multiples and submultiples (prefixes: mili-, cent, kilo-, mega-), estimates the order of magnitude of the expected result and, on this basis, evaluates the result of the calculation	

ITALY	GREECE	LATVIA	POLAND	ESTONIA
ENERGY/WORK				
		Energy does not disappear; it just turns from one kind to another.	Applies the principle of mechanical energy conservation to describe its transformations, e.g. by analysing energy transformations during a free fall of the body.	
Students age when the concept is taught: 15 **School grade when the concept is taught: 10**				
	The meaning of the work	Energy describes the body's ability to do the work.		
	That energy always exists	Work done is equal to body energy change.		
	Energy can change, transfer from one body to another and transform into another kind.	If in the straight directional motion there is applied a constant force to the object directed towards the displacement, then the work done is equal to the multiplication of this force and the path.		
	That friction transforms the energy into thermal.	The potential energy of an object raised in the gravitational field is directly proportional to the object's mass and height at which it is raised.		
	To calculate the work of a force, the kinetic and potential energy and solve problems using them.	The potential energy of a flexible deformed object is directly proportional to the square of the extension.		
	That energy remains stable but less useful	The Law of Energy Conservation.		

ITALY	GREECE	LATVIA	POLAND	ESTONIA
		ENERGY/WORK		
		Bernoulli Law.		
		The power of the mechanism is equal to the work done per unit time.		
		Utility factor - the ratio of the work used by the mechanism to the work done.		
		The power impulse is a multiplication of force and its duration.		
Students age when the concept is taught: 16 **School grade when the concept is taught: 11**				
The definitions of work, kinetic energy, potential energy, and power.				
The dependence of kinetic energy on speed.				
The kinetic energy theorem				
How to calculate work for a constant force and for a non-constant force.				
The link between conservative forces and potential energy.				
that potential energy is as a property of the system formed by interacting bodies.				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
ENERGY/WORK				
The relation between work with kinetic energy, gravitational potential and elastic potential energy and the conservation energy theorem.				
That the elastic potential energy of a spring is connected with a non-permanent deformation and it is the energy of the spring- mass system.				
The link between power and speed.				
The energy conservation theorem in rotational motions.				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
		WEIGHT/FORCE		
Students age when the concept is taught: 14 **School grade when the concept is taught: 9th**				
That there are physical quantities described by means of vectors		Concepts of force, resulting force, gravity, weight, Archimedes force, lever, incline plane, pulley, windlass (winch)	Selects the right measuring instruments (e.g. for measuring length, time, force)	The most important physical sizes - weight, strength, pressure
How to represent vector quantities by means of vectors		1st, 2nd and 3rd Newton Law	lists and distinguishes the types of actions (mechanical, gravitational, electrostatic, electrostatic).	Pascal Act
How to describe the operations between vectors graphically				
How to describe the operations between vectors graphically		Interaction of object causes and maintain motion or change the speed of motion.	Gives examples of impacts that occur in everyday life gives examples of the effects of impacts daily life observes and compares the effects of different the type of impact gives examples of forces and recognizes them	Gravity field strength on Earth surface, normal pressure
The S.I. unit of the forces		Weight is the force that object act on support or pull suspension.	Measures the value of the force by means of dynamometer	Signs of swimming, drowning and suspended
The dimensional formula of force		A dynamometer is used to measure the force.	Determines the characteristics of the resultant force of two forces acting along the same line and force balancing another force	

ITALY	GREECE	LATVIA	POLAND	ESTONIA
WEIGHT/FORCE				
How a spring works		Lever is in balance if multiplication of force and shoulder on both sides of support is equal.	Uses symbols of length, mass, time, force and their symbols units in the SI System	
The behavior of a spring through Hooke's law			Recalculates multiples and submultiples (pre- and post-multiples): micro, mili-, cent-); recalculates time units (second, minute, hour) estimates the order of magnitude of the expected measurement result, e.g. lengths, forces	
How to use Hooke's law			Performs a schematic drawing illustrating the measurement, e.g. lengths, forces	
How to calculate the weight of a body			Explains for what purpose the measurement is repeated several times, and then calculates the average of the results obtained, calculates the average value of several measurement results (e.g. length, time, force)	
The effects of weight force on bodies			Describes the course and outcome of the experiment, using in the language of physics, explains the role of the instruments used and makes a schematic drawing showing the use of the experimental system in the study of e.g. interactions of bodies	

ITALY	GREECE	LATVIA	POLAND	ESTONIA
		WEIGHT/FORCE		
How to calculate the normal force acting on a body			Represents the force graphically (draws the force vector)	
How to calculate the static friction force on a body in stillness			Distinguishes between scalar (numerical) and vectoral values- and gives relevant examples	
What are the binding forces acting on a body			Analyses the results, draws a conclusion from the results achieved observations and measurements	
The equilibrium conditions on a sloping plane.			Finds graphically the resultant of two forces acting along the same straight line and a force balancing another force	
The relationship between the balance of a material point and the forces applied to it			In a given coordinate system (described and graduated) draw a diagram of the force value dependence gravity acting on spring-loaded suspensions	
Students age when the concept is taught: 15 **School grade when the concept is taught: 10**				
The kinematic characteristics of the rectilinear, circular and parabolic motion	That laws are the same all over the world	Types of forces		

ITALY	GREECE	LATVIA	POLAND	ESTONIA
WEIGHT/FORCE				
The conditions under which a system is inertial	To design an experiment	Acceleration, which the object has gained, always is directed the same direction as resulting force;		
The principles of dynamics	To solve mathematical equations	1st, 2nd and 3rd Newton Law		
The significance of different modeling assumptions, and how they affect the calculations in a particular problem	To use mathematics in real life problems	Sliding friction force is directly proportional to surface of object reaction force and acting contrary to the direction of movement		
How to calculate the dynamic frictional force between two surfaces in relative motion	To measure forces	Hook Law		
The friction effects of the fluid medium	To calculate the acceleration if they know the forces and the mass	Mechanical stress - elasticity force acting on the area unit of cross-section of the sample along the body axis.		
	That total force is zero when the body is steal or moves with stable velocity			
	To add vectors			
	To analyze a force in two perpendicular axes			
	That mass and weight are different quantities			
	That weight depends on the place			

ITALY	GREECE	LATVIA	POLAND	ESTONIA
WEIGHT/FORCE				
Students age when the concept is taught: 16 **School grade when the concept is taught: 11**				
Key terms---				
The superposition principle, and the differences between 1D and 2D and 3D systems of reference.				
The formulas of resistance force in a medium, of the normal force, of the elastic force, of the static and dynamic frictional force between two surfaces in relative motion and of the centripetal force.				
The differences between external forces and internal forces in a system.				
The principles of dynamics.				
The conditions of free fall of a body.				
The harmonic oscillator.				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
TORQUE				
Students age when the concept is taught: 14 **School grade when the concept is taught: 9**				
What is the vector (cross) product				That the force-bearing effect is characterized by the product of force and its shoulder
What is the moment of a force applied to a rigid body with respect to a point				Gold rule of mechanics
The S.I. unit of the moment of a force				Energy Conservation Act
The dimensional formula of moment of a force				
The definition of torque				
The definition of couple				
The vector form of the torque of a force				
What is a couple of forces				
The torque concepts necessary for solving static problem				
The equilibrium conditions of a hanging body and a supported body				
What is the center of mass and the center of gravity of a body				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
		TORQUE		
What is a lever				
How do levers work				
The levers used in everyday life				
The levers that our body use				
The classes of levers				
Students age when the concept is taught: 15 **School grade when the concept is taught: 10**				
	To calculate torques and the net torque	Force moment - multiplication of force applied to the object and shoulder of force.		
	To use mathematics and physics to study every day phenomena	The object is in equilibrium if the sum of all the moments in relation to the axis of rotation is equal to zero.		
	How they can lift a man without be injured			
Students age when the concept is taught: 16 School grade when the concept is taught: 11				
Key terms---				
The relationships between angular and linear dimensions in circular motion.				
The concept of rigid body				
That an unbalanced torque causes a rotation of a rigid body				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
TORQUE				
That mass isn't enough to describe dynamic properties of a rigid body while moment of inertia is the correct quantity needed, and how to calculate it in some symmetrical situations.				
The S.I. unit of the moment of inertia and the dimensional formula of moment of inertia				
The first and the second principle of dynamics for rotations				
The angular momentum (units etc)				
The law of conservation of angular momentum				
The motion of rolling without slipping				
The ratio (comparison) of load/resistance force to the effort force is called the mechanical advantage.				
The difference between quantitatively mechanical advantage of pulleys and systems of pulleys				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
ENERGY/WORK				
Students age when the concept is taught: 14 **School grade when the concept is taught: 9**				
		Concepts: mechanical work, power, energy, potential and kinetic energy.	Uses the concept of energy and gives examples of its various forms	work, energy and power as physical sizes
		The work done depends on the amount of force that works on the object and on the length of the road that he is doing.	Distinguishes work in the physical sense from work in everyday language, indicates examples of performing mechanical work in the environment	Energy Conservation Act
		Power is the work done in the certain time.	Uses the notion of kinetic energy, indicates examples of bodies having kinetic energy, distinguishes kinetic energy from other forms of energy	
		Above the height of the support (h), the lifted body has potential energy.	Gives examples of energy conversion (transformation and transmission)	
		All moving objects have kinetic energy.	Solves simple calculation tasks concerning mechanical work and power, distinguishes between data and searched values, calculates multiples and submultiples (prefixes: mili-, cent, kilo-, mega-), estimates the order of magnitude of the expected result and, on this basis, evaluates the result of the calculation	

ITALY	GREECE	LATVIA	POLAND	ESTONIA
ENERGY/WORK				
		Energy does not disappear; it just turns from one kind to another.	Applies the principle of mechanical energy conservation to describe its transformations, e.g. by analysing energy transformations during a free fall of the body.	
Students age when the concept is taught: 15 **School grade when the concept is taught: 10**				
	The meaning of the work	Energy describes the body's ability to do the work.		
	That energy always exists	Work done is equal to body energy change.		
	Energy can change, transfer from one body to another and transform into another kind.	If in the straight directional motion there is applied a constant force to the object directed towards the displacement, then the work done is equal to the multiplication of this force and the path.		
	That friction transforms the energy into thermal.	The potential energy of an object raised in the gravitational field is directly proportional to the object's mass and height at which it is raised.		
	To calculate the work of a force, the kinetic and potential energy and solve problems using them.	The potential energy of a flexible deformed object is directly proportional to the square of the extension.		

ITALY	GREECE	LATVIA	POLAND	ESTONIA
		ENERGY/WORK		
	That energy remains stable but less useful	The Law of Energy Conservation.		
		Bernoulli Law.		
		The power of the mechanism is equal to the work done per unit time.		
		Utility factor - the ratio of the work used by the mechanism to the work done.		
		The power impulse is a multiplication of force and its duration.		
Students age when the concept is taught: 16 **School grade when the concept is taught: 11**				
The definitions of work, kinetic energy, potential energy, and power.				
The dependence of kinetic energy on speed.				
The kinetic energy theorem				
How to calculate work for a constant force and for a non-constant force.				
The link between conservative forces and potential energy.				

ITALY	GREECE	LATVIA	POLAND	ESTONIA
ENERGY/WORK				
that potential energy is as a property of the system formed by interacting bodies.				
The relation between work with kinetic energy, gravitational potential and elastic potential energy and the conservation energy theorem.				
That the elastic potential energy of a spring is connected with a non-permanent deformation and it is the energy of the spring- mass system.				
The link between power and speed.				
The energy conservation theorem in rotational motions.				

4. PHASE 2: QUANTITATIVE INVESTIGATION OF STUDENTS

A2- Quantitative data emerged from administered questionnaires (students)

4.1 Methodology

Construction of Questionnaires

There are topics in science that many students all over the world find difficult. Often students may hold ideas about a concept or a phenomenon that would be considered to be 'wrong' but this does not necessarily stop students getting answers to questions correctly. However, it does make it difficult for them to do well in examinations. It will also be difficult for students to progress if they continue to hold these ideas. Over the years, as a result of research, people have built up a list of common misunderstandings for many topics.

When students try to make sense of a new situation, they draw on everyday experience and on ideas that have worked well for them before. Some of these ideas as 'not scientific' or 'not the accepted explanation'. But as long as these ideas are able to predict what will happen, then students will use them. These 'misunderstandings' are not like equations or definitions that have been learnt incorrectly. Misunderstandings can be the result of explanations that students have been given by other people or that the student has constructed for themselves. Alternatively, these explanations were appropriate for younger ages but are no longer relevant for more complex ideas and topics. There is often a lot of 'common sense' appeal about these ideas, but the problem is that using them is going to be unhelpful in work in secondary school science. These ideas can act as a barrier to understanding the accepted models of science.

Many students face problems to understand that the state of inertia of physical bodies is characterized with a constant velocity (that is not necessarily zero), that no external cause, and more specifically no interaction, is needed to maintain such a state, that no physical body can act on itself but an interaction takes place between at least two bodies. It is difficult for them to realize that the concept of force represents agent-object interaction. A force of particular characteristics is associated with a particular kind of interaction. They face difficulties to understand that two objects exert simultaneous forces on one another. The two exchanged forces are equal and opposite, irrespective of the physical or kinematical properties of either body. Concepts as velocity and acceleration are also difficult for students. They face difficulties concerning facts as two objects that occupy the same position at a given time do not have necessarily the same velocity at this time but two objects may have the same acceleration when they move with different velocities

Many students may confuse energy with fuel, and they may describe energy as being 'used up' in various situations. They may correctly predict that a ball released on a u-shaped track should not reach any higher than the height from which it was released, but will say this was because 'all the energy has been used up'. It is very important for them to understand that energy is conserved and can only be converted from one form to another. Some other common misunderstandings about energy are: Objects only have energy when they are moving, Energy is often lost in energy transfers, Energy is a substance, Force is the same as energy, Force is the same as work…

Teachers need to support students to undertake conceptual change and restructure of what has been previously learned.

In this initial questionnaire the focus is on weight, mass, friction, forces, work and energy which are difficult concepts for students (and some adults) to understand properly (Driver et al, 1994; Bates & Galloway, 2016; Afif, Nugraha, & Samsudin, 2017). This research also is focusing on Simple machines and how they work. It is important for the students to understand the fundamentals of their function and be able to recognize simple machines and their applications in everyday life.

In order to test the initial conceptions of students, two tests were created. The items of the Tests were concerning problems aiming at making students think on situations involving the concepts of **mass**, **weight**, **force**, **work**, **energy** as well as simple machines. Students' answers assist in designing teaching on simple machines (e.g. inclined planes, pulleys etc), so even students' potential mistakes are very important.

Administration of Questionnaires (Test A and Test B)

The Tests A and B were given to the students that will participate in the summer school and will work next year in the Laboratories with the simple machines.
Information about the curriculum of each country was taken under consideration.
Time needed for the completion of the Tests was:

- 2 hours for TEST A and 1,5 hours for TEST B (+10' its allowed)
- The tests were given in the same week, but not necessarily the same day.

- Mobiles were not allowed.
- Depending on the school-time organization, the Tests were given during classes or during afterschool activities.

Data collection:

Teachers provided an excel file with all the questions in the column and the answers in rows.

As it was difficult to provide the complete answers (in English) in rows, answers were codified as follow:

Codes:

- 0 for no answer
- 1 for absurd error
- 2 for error/common misconception
- 3 for correct without justification
- 4 for correct with justification

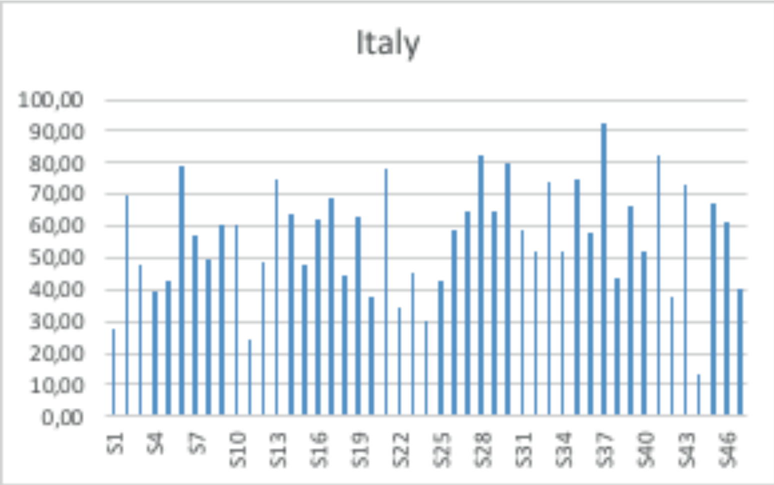
4.2 Results of questionnaires

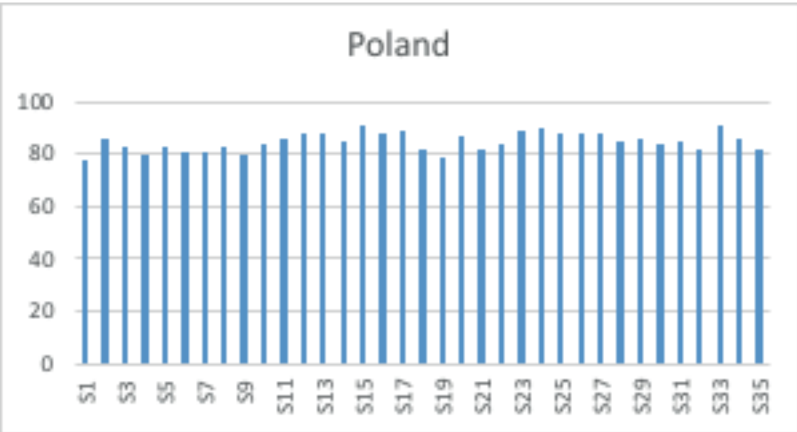
Introduction on the presentation of results

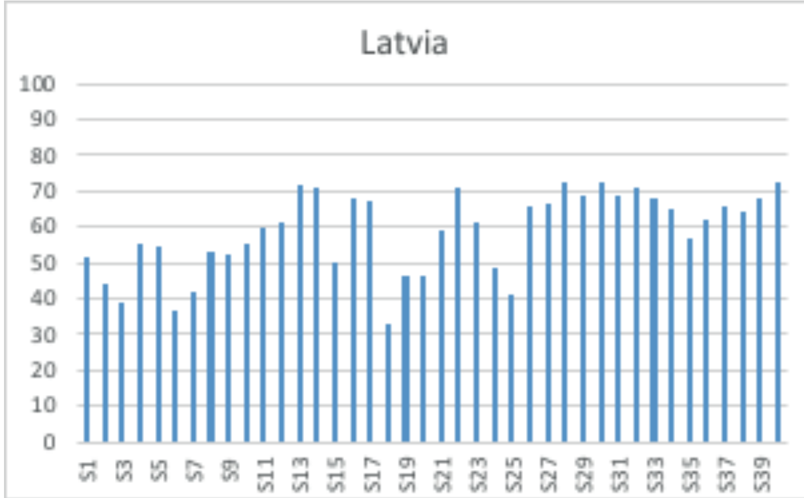
As we have already said, the partners corrected the questionnaire using the same code, but they corrected the "false and true" and the multiple choice questions using slightly different codes, so it was necessary to normalize the scores of a questionnaire results in the comparison of each country. We show the results of test A and B among students of each country and we made a comparison between the results of test A and test B. We calculated the difficulty index for all the questions and the discrimination index for some questions. For some harder questions (difficulty index <0,4) we investigated possible incorrected formulations of the question, the required knowledge and skills, the opportunities of the students to acquire the knowledge and skills necessary to answer it.

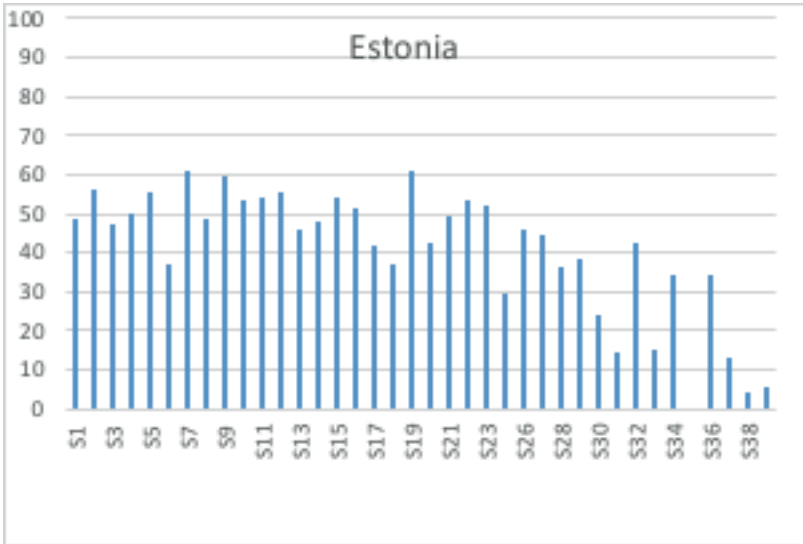
Analysis of the results of the A and B tests among the students of each partner country

The partners corrected the tests using the following codes: 0 for no answer, 1 for absurd error, 2 for error/common misconception, 3 for correct answer without justification, 4 for correct answer with justification. However, for True and false questions (test A question1) no justification is required and different countries corrected them following different codes: Italy: 0 for no answer or error, 1 for each correct answer; Poland: 0 for no answer or error, 4 for each correct answer; Estonia: 3 for each correct answer; 2 for error; 0 for no answer ; Greece : 3 for each correct answer, 1 for error, 0 for no answer and Latvia: 0 for no answer, 1 for error, 4 for each correct answer. As regards multiple choice questions, where no justification is required (Test A - questions: 5, 13, 15 and Test B - questions: 10 and 11), different countries followed different codes as well. In Italy: 0 for no answer or error, 4 for each correct answer; in Greece 3 for each correct answer, 1 for error, 0 for no answer; in Latvia: 4 for each correct answer, 1 for error, 0 for no answer; in Estonia and In Poland they asked for a justification even in multiple replies and used the general code (0 for no answer, 1 for absurd error, 2 for error/common misconception, 3 for correct without justification, 4 for correct with justification). The maximum score for each partner country - in the case the test is completely correct - , was the following: Italy 139, Poland and Latvia 184, Greece 164 and Estonia 169. Therefore, it was necessary to normalize the scores. In the following histograms we can see the results for each country where 100 corresponds to the maximum value, all the answers corrected, in all the countries. "Si" represents the student of the school of the country indicated in the histogram. In Italy, 47 students attending "F. Redi " upper secondary school in Arezzo had the questionnaire, in Poland 35 students attending Szkola Podstawowa im. Powstancow Wielkopolskich w Jankowie Przygodzkim, in Latvia, 40 students attending "Liepaja Raina Secondary School Nr. 6", in Greece,44 students attending "EPAL of Korydallos" secondary school, , in Estonia 39 students attending Kärdla Põhikool.









The average score of test A and B for Liceo Redi (Italy) was 57/100, for Poland was 85/100, for Latvia was 59/100, for Greece was 47/100, but 3 students had only test A, for Estonia was 42/100, but 14 students had only one part of the tests (9 students had only part A and 5 students had only part B).

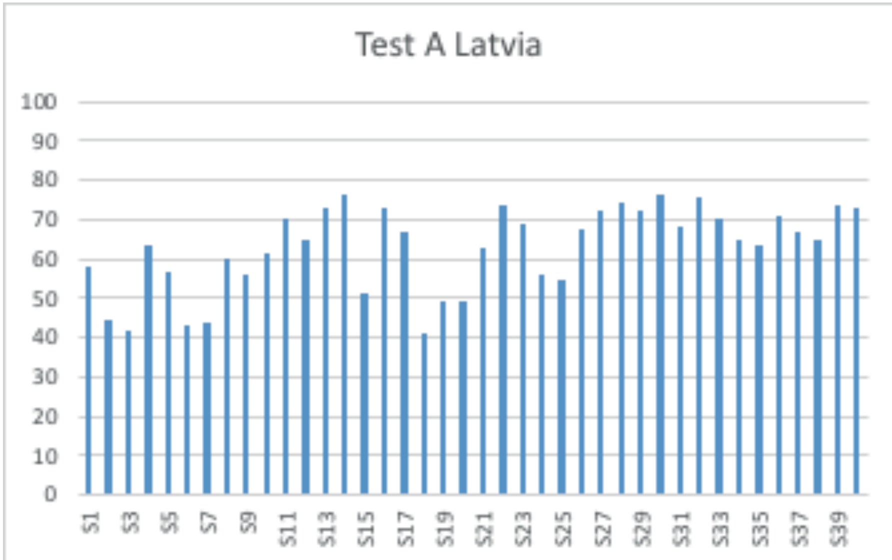
Analysis of the results of test A among students of each country

In the following histograms we can briefly see the results of test A for each country where 100 corresponds to the maximum value, all the answers corrected, in each country.

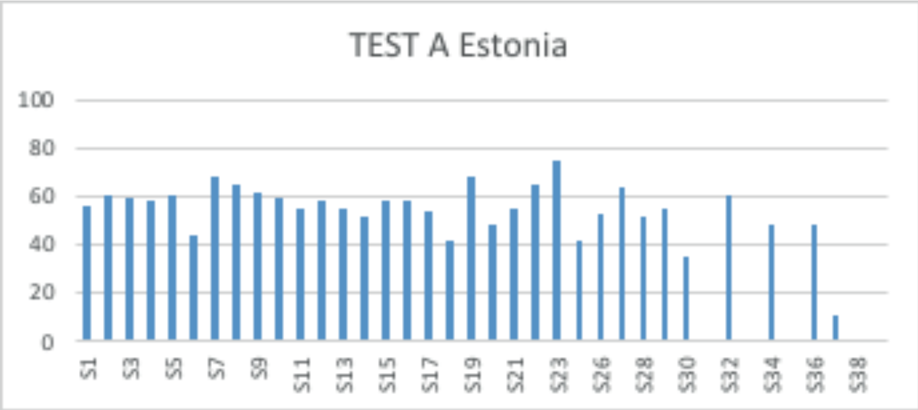
Average point from test A for Italy was 62/100.

Average point from test A for Poland was very high 87/100.

Average point from test A for Poland was 49/100.



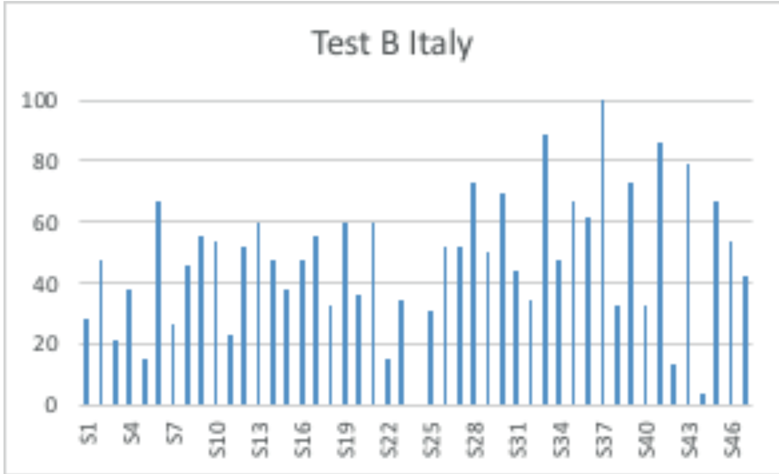
Average point from test A for Italy was 63/100.



Average point of test A for Estonia was 57/100 considering only the 33 students that had the test A. Two questions from test A - question 16 and question 17 - were not evaluated by the testers correctors.

Analysis of the results of test B among students of each country

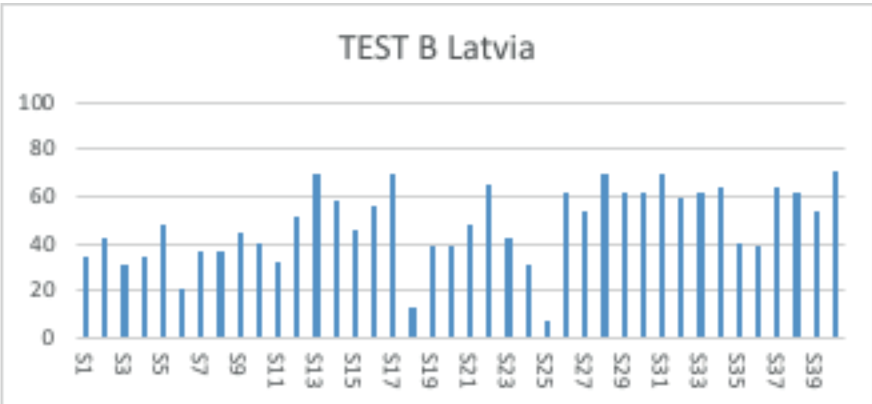
In the following histograms we can briefly see the results of test B for each country where 100 corresponds to the maximum value, all the answers corrected, in each country.



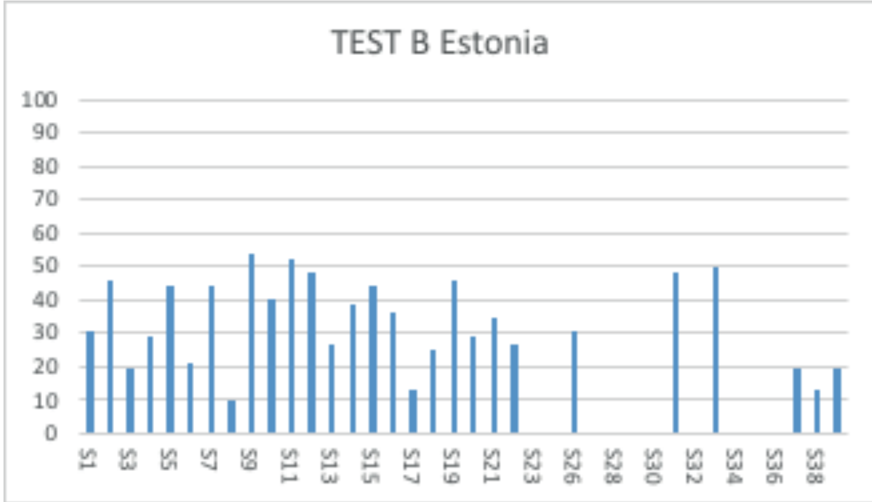
Average point from test B for Italy was 47/100.

Average point from test B for Poland was 78/100.

Average point of test B for Greece was 20/100. In the average, we did not take into consideration the three students that didn't do test B.



Average point from test A for Latvia was 48/100.



Average point of test B for Estonia was 32/100. In the average, we did not take into consideration the nine students that didn't have test B.

Comparison between test A e Test B results

In the following table the results of test A and test B in short, where 100 corresponds to the maximum value, all the answers corrected, in each test and in each country:

Country	TEST A	TEST B
Italy	62/100	47/100
Poland	87/100	78/100
Greece	48/100	20/100
Latvia	63/100	48/100
Estonia	53/100	31/100

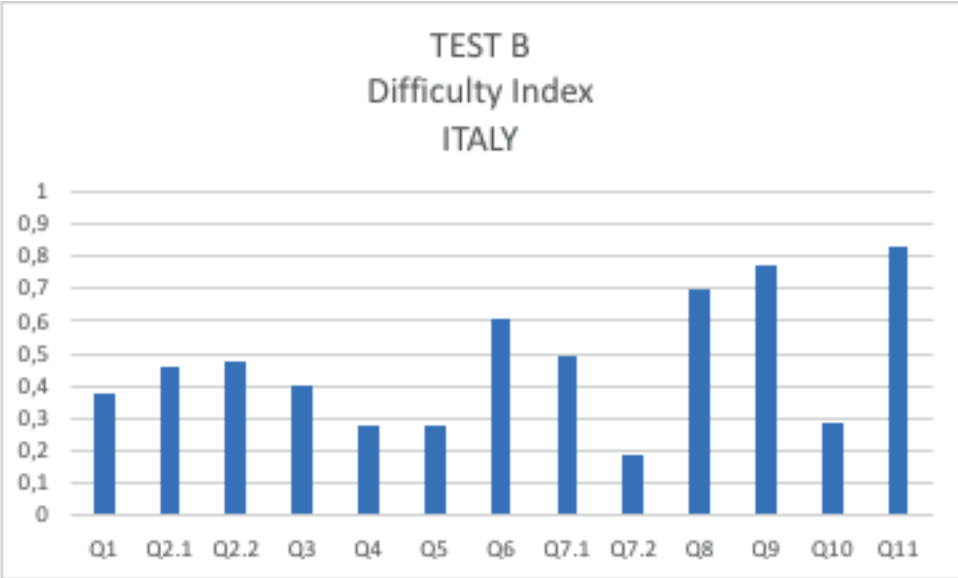
We can see that the test B was more difficult for students in all the countries. It was very difficult for students who have not faced the study of simple machines in their curriculum as in Greece. Therefore, test B was made after test A and the students were, perhaps, tired and less motivated.

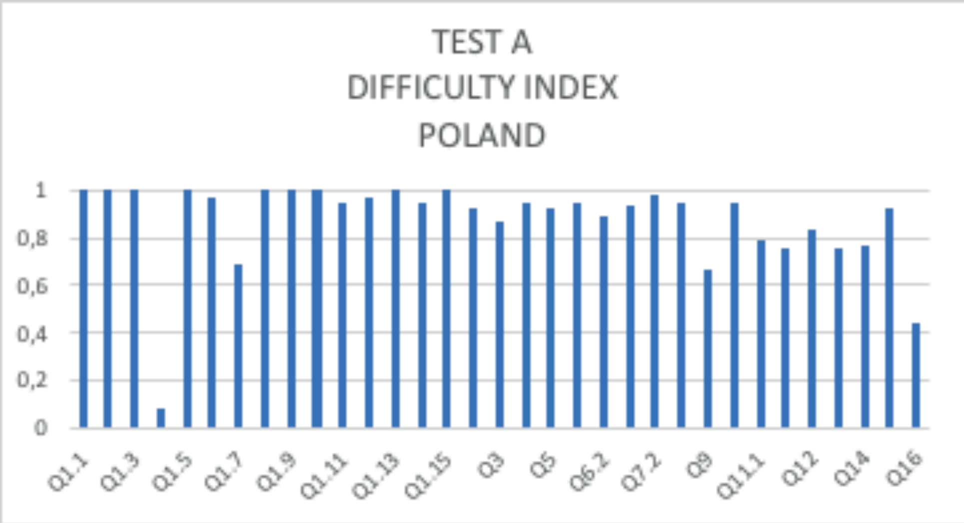
Analysis of the results of single questions among students of each country

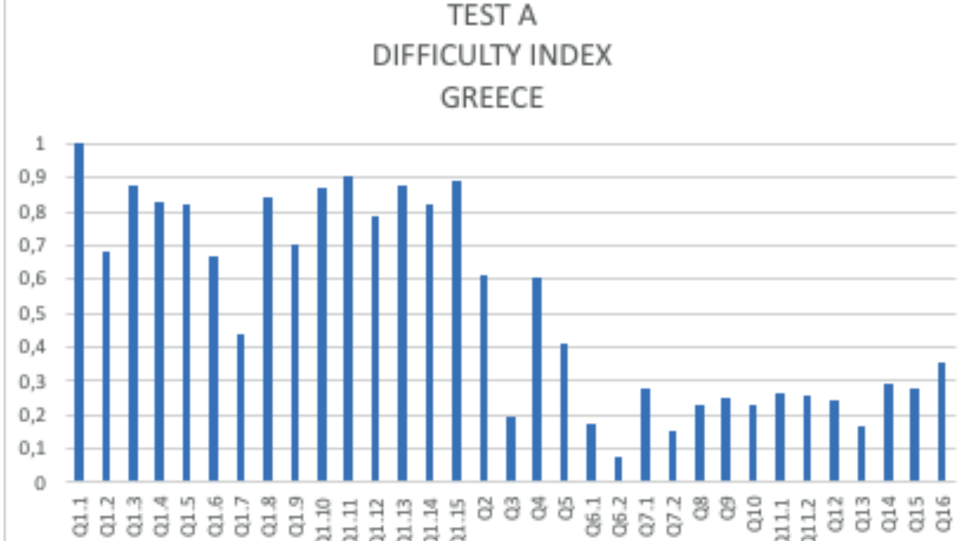
We calculated the difficulty index for every question and the discrimination index for some questions.
The difficulty index is the total score obtained by the students in each single question divided by the maximum total score obtainable

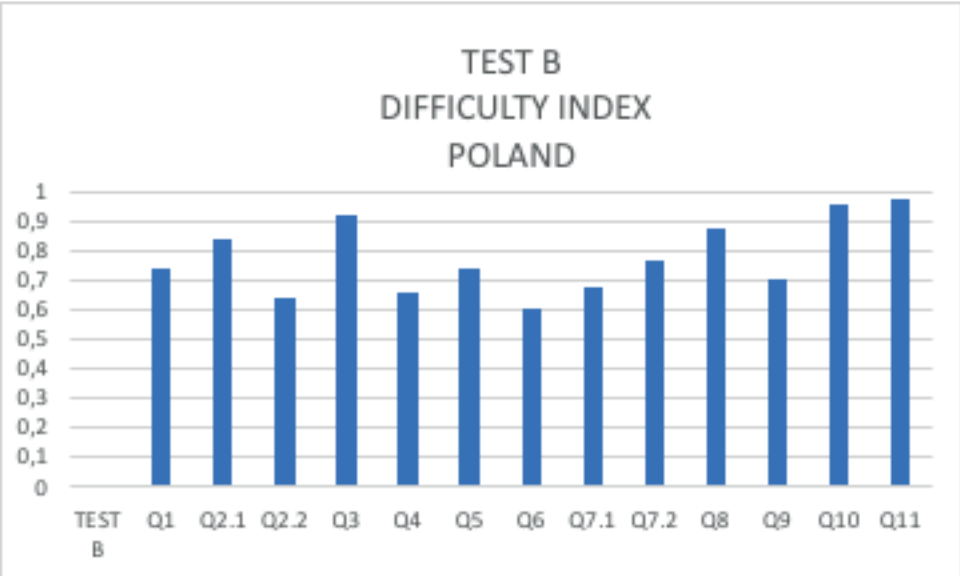
difficulty index = (P1+P2+P3+.........+PN) ÷ (M * N)

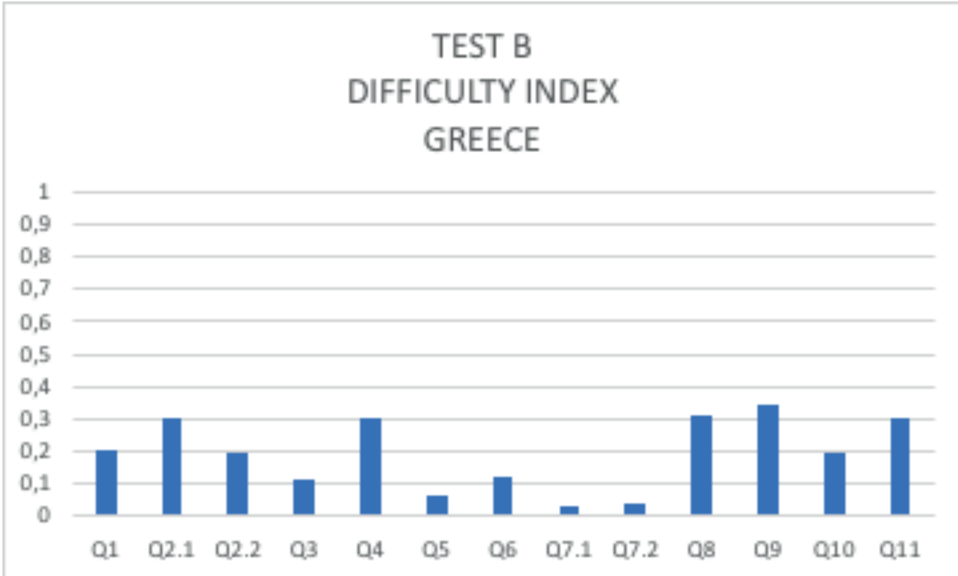
Where Pi with 1<i<N is the score obtained by the student i in the question, N is the total number of students, M is the maximum score obtainable in a question, generally M=4. The difficulty index will be a value between 0 and 1, with harder questions resulting in values closer to 0 and easier questions resulting in values closer to 1. The difficulty index might be called more properly, easiness index: high value of the difficulty index corresponds to easy question; low value of the difficulty index corresponds to difficult question.
In the following histograms we can see the difficulty index for each question of test A and B for each country.

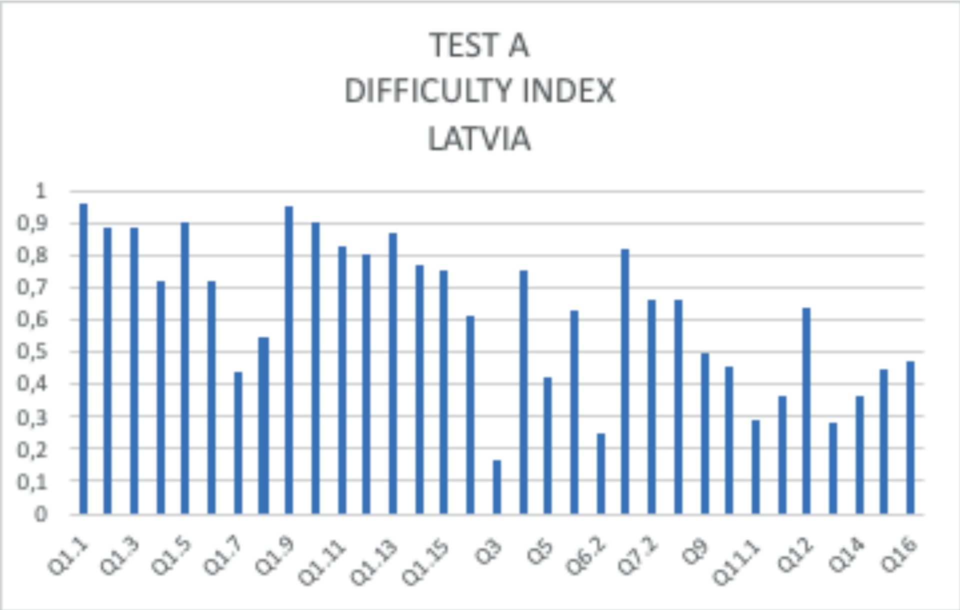


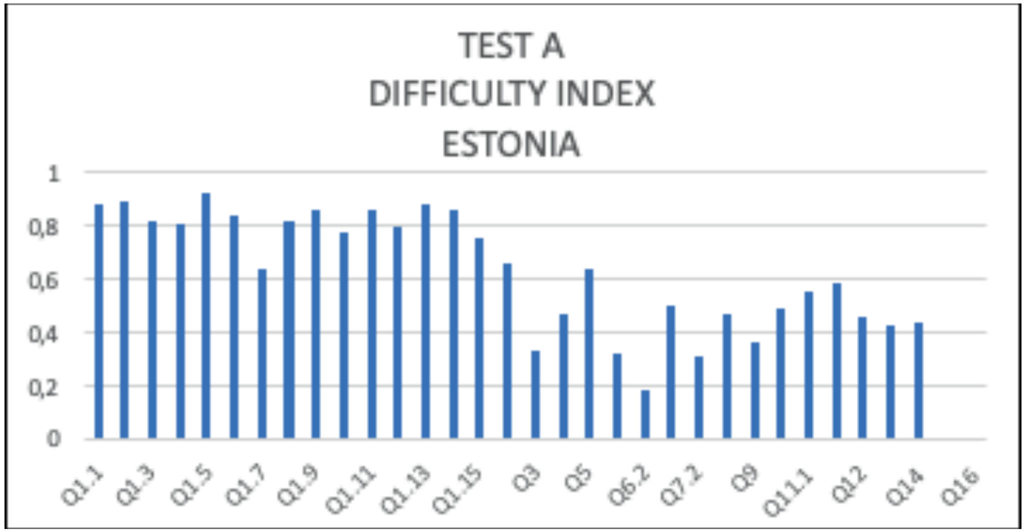

TEST A
DIFFICULTY INDEX
POLAND
1
0,8
0,6
0,4
0,2
0
Q1.1
Q1.3
Q1.5
Q1.7
Q1.9
Q1.11
Q1.13
Q1.15
Q3
Q5
Q6.2
Q7.2
Q9
Q11.1
Q12
Q14
Q16

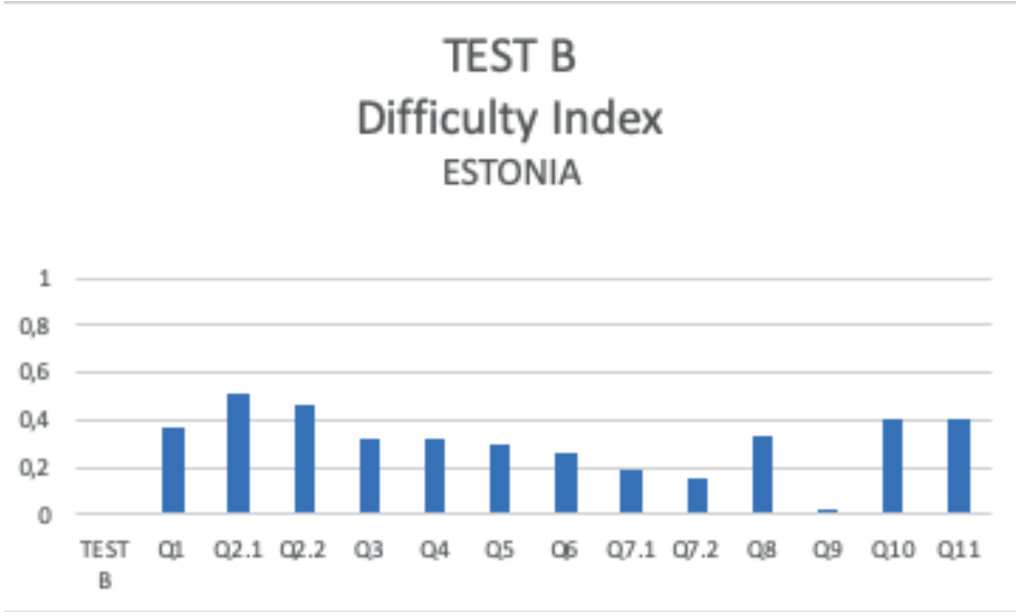

TEST A
DIFFICULTY INDEX
GREECE
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Q1.1
Q1.2
Q1.3
Q1.4
Q1.5
Q1.6
Q1.7
Q1.8
Q1.9
Q2
Q3
Q4
Q5
Q6.1
Q6.2
Q7.1
Q7.2
Q8
Q9
Q10
Q12
Q13
Q14
Q15
Q16


TEST B
DIFFICULTY INDEX
POLAND
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
TEST B
Q1
Q2.1
Q2.2
Q3
Q4
Q5
Q6
Q7.1
Q7.2
Q8
Q9
Q10
Q11


TEST B
DIFFICULTY INDEX
GREECE
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Q1
Q2.1
Q2.2
Q3
Q4
Q5
Q6
Q7.1
Q7.2
Q8
Q9
Q10
Q11







About the discrimination index, there are several different formulas that calculate item discrimination, but the one most commonly used is called "the point-biserial correlation", which compares a test taker's score on an individual item with their score on the test overall. We considered the 13 students with the highest score and the 13 students with the lowest score; we subtracted the number of students in the lower-scoring group who answered the question correctly (lc) from the number of students in the higher-scoring group who answered the question correctly (hc). Then, we divided the resulting number by the number of students of each group (t=13)

Item discrimination = (hc – lc)/ t

If the item discrimination is less or equal to 0 the item is not a good measure of mastery and the item fails to distinguish the skill measured by the test, if the item discrimination is greater or equal to 0,3 the Item is effective. For highly discriminating questions, students who answered correctly are those who have done well the rest of the test. It is also true that the students who answered very incorrectly discriminating questions tend to do poorly the rest of the test as well. About the True-False questions (Test A Q1) we have generally high values for the difficulty index, our students found easy the T-F questions except for the seventh question (Q1.7) :

Gravity on the earth is different depending on the country True False

This question has a low difficulty index in almost all the countries (0,28 in Italy, 0,44 in Latvia and in Greece, 0,55 in Estonia). I think that it is due to the bad formulation of the question. The students did not understand the question. Better "Gravity on the Earth is different depending on the place". In Poland the difficulty index of this question is 0,69, a low value in comparison to the difficulty index of the other T-F questions.
We can note that the Poland students found very hard the question Q1.3:

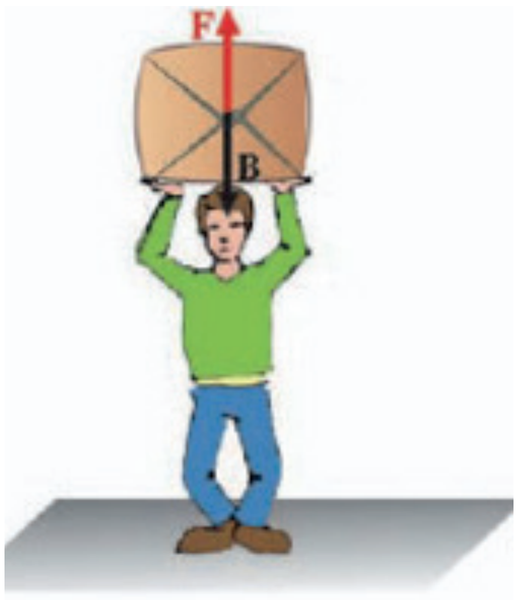
Weight is a force True False

Only three students answered correctly this question. The other students did not answer, but our students generally distinguish the difference between mass and weight, can calculate the weight of a body, can describe the relation between force and mass and the connection between weight and gravitational attractive force, and know the effects of weight force on bodies.

Question 12 Test A

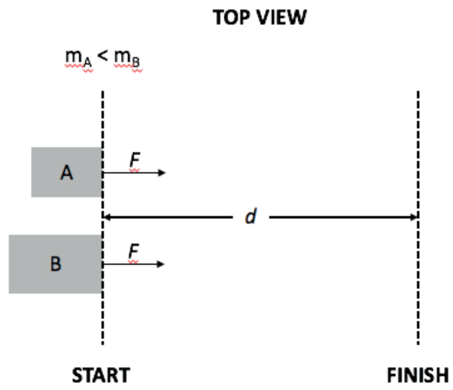
George is holding the box and he is tired. How much is the work he produces?

This question has a low difficulty index in Italy (0,41), in Greece (0,24), in Estonia (0,46). The concept of work in physics is not simple: often students confuse "work" with "to do force" or "work" with "muscle fatigue". Furthermore, there is confusion in their answers between height and displacement. This question has a good discrimination index, about 0,5 in all the three countries.



Question 13 Test A

Two blocks are initialy at rest on a frictionless horizontal surface. The mass m_a of block A is less than mas$_b$ of block B. You apply the same constany force F and pull the blocks through the same distance d along a straight line as shown below (forece F is applied for the entire distance d).



Wich one of the following statements correctly compares the kinetic energies of the blocks after you pull the same distance d?

a. The kinetic energies of blocks are indentical
b. The kinetic energy is greater for the smaller mass block because it achieves a larger speed.
c. The kinetc energy is greater for the larger mass block because of its large mass.
d. Non enough information, need to know the actual mass of both blocks to compare the kinetc energies.
e. Non t enough information, need to know the actual magnitude of force F to compare the kinetic energies.

This question has a very low difficulty index in almost all the countries (0,13 in Italy and in Greece, 0,28 in Latvia, 0,43 in Estonia, in Poland all the students answered correctly). In Italy about forty percent of the students chose option b (less mass more acceleration and more velocity) and about the forty percent chose option C (more mass more kinetic energy). Which hypothetical difficulties students could meet in answering to this question? Do not students know the work-kinetic energy theorem and how it works? Which are the opportunities of the students to acquire the knowledge and the skills necessary to answer this question? There were several opportunities in almost all the curricula of the different countries, but this question was very difficult for our students.

Question 16 (17) Test A

Look at the picture below. On each object? find ALL the sources of the forces (pushes & pull) and draw in arrows to show the direction (1) of the forces and (2) the direction in wich the object moves by using a larger or another arrow. It is particularly interesting the analysis of the pictures at the end of test A, these were some students' solutions.

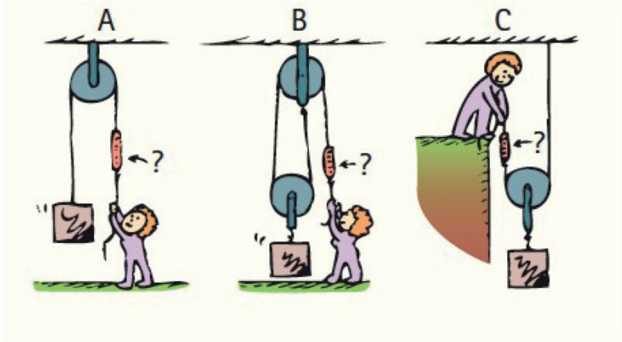
Weight force often does not appear, forces appear everywhere instead, even in a confused way and launched bodies maintain the initial thrust. This question was very difficult for our students, the table shows the index of difficulty of this question in the partner countries.

Country	Difficulty Index
Italy	0,17
Poland	0,44
Greece	0,36
Latvia	0,39

For our students was very difficult to find and draw the forces on the objects, to apply the action-reaction law and to recognize forces and their sources in real life systems.

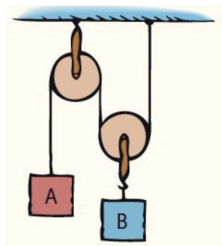
Question 4 and 5 Test B

4. Rank the scale reading from highest to lowest. (Ignore friction).



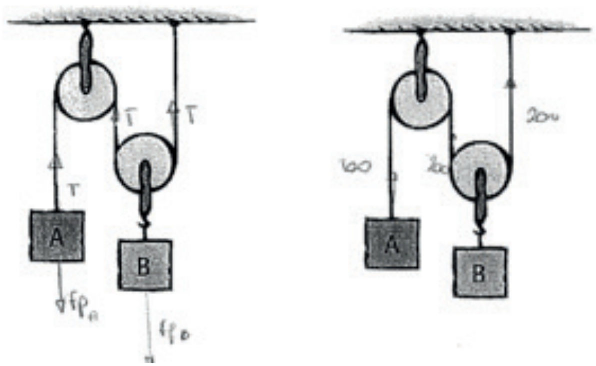
A, B=C

5. In the pulley system shown, blok A has a mass of 10 kg and is suspended precariously at rest. Assume that the pulleys and strings are massless and ther is no friction. Non friction means that the tension in one part of the supporting string is the same as at any part.
Discuss why tha mass of blok B is 20 kg.



Country	Q4 Difficulty Index	Q5 Difficulty Index
Italy	0,28	0,28
Poland	0,66	0,74
Greece	0,28	0,06
Latvia	0,68	0,30
Estonia	0,24	0,23

Our students do not know how pulleys work and how we can use pulleys together to reduce the amount of force needed to lift a load. In Figure there are some examples of free-body diagrams in which some rope tension is missing. It is interesting to note that the tension on the wires is always missing on the same side, from the fixed pulley side (the tension is only a support to the weight).

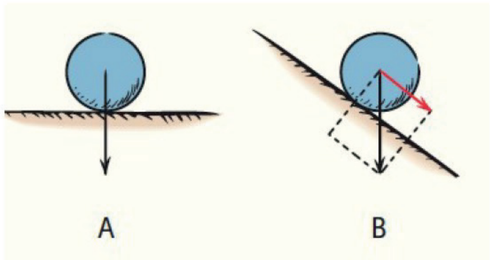


Question 7a and 7b Test B (Q7.1 and Q7.2)

7. No work is done by gravity on a bowling ball that is resting or moving on a bowling alley because the force of gravity on the ball acts perpendicular to the surface, but on an incline, the force of gravity hasa vector component parallel to the alley, as in B. How does this component account for:

a. the acceleration of the ball and **a=gsinΘ**

b. the work done on the ball to change its kinetik energy? **ΔK=mgh**



Country	Q7a (Q7.1) Difficulty Index	Q7b (Q7.2) Difficulty Index
Italy	0,49	0,19
Poland	0,68	0,77
Greece	0,03	0,04
Latvia	0,25	0,20
Estonia	0,18	0,16

This shows that our students have problems with the study of the motion in an inclined plane, with the decomposition of the forces and again with the calculation of the work and the variation of the kinetic energy and with the use of the kinetic energy theorem.

5. PHASE 3: INVESTIGATION RESULTS: CONNECTION BETWEEN DEVELOPMENT OF SIMPLE MACHINES AND SCIENTIFIC AND CREATIVE LEARNING OUTCOMES OF STUDENTS

Our students can distinguish the difference between mass and weight, can calculate the weight of a body, can describe the relation between force and mass and know the connection between weight and gravitational attractive force. Generally, they are not able to find and draw the forces acting on a body, to recognize contact forces as adaptable forces, to apply the action-reaction law, to describe graphically operations between vectors and to recognize forces and their sources in real life systems in. It is generally difficult, for our students, to understand that work in physics is different from muscle fatigue, to realize that to have mechanical work there must be a displacement, to describe how the mechanical work depends on the angle that the force forms with the displacement, to apply the kinetic energy theorem, and finally to realize that work is an “energy in motion” and it increases or decreases the mechanical energy of a system.

Often Simple machines are not present or are marginally present in school curricula and the students have serious difficulties to describe what is a pulley and how it works, to describe what is the mechanical advantage in simple machines, to understand the difference between mechanical advantage of pulleys and systems of pulleys and finally to understand that the function of simple machines is explained by the Newton’s laws and the laws of mechanical energy. Not all the students have realized that in a simple machine what is gained in strength is lost in displacement.

6. CONCLUSIONS FOR THE ELABORATION OF TEACHERS’ MATERIAL

Resume of the state of the art

First of all, we must take seriously under consideration the fact that different subjects are taught in different ages in each country. Each country’s educational system is focused into different subjects and accordingly into different extend. For instance, in many countries mechanics of solid body is being taught in the very beginning of the High school while in other countries e.g. in Greece is being taught in the last class of High School. According to this, the depth of the analysis is different from country to country. Especially in Italy, Physics are holistically approached beginning from the first class of junior high school.

On the other hand, teaching of Weight and Force in all countries starts at the students’ age of 14 years old. In Italy, teachers mainly focus on the mathematical aspect of vectors and secondly on experimental aspects, while in Greece teachers mainly focus on the mathematical aspect and formula solution.

In Latvia all Newton’s laws are taught to 14 years old students focusing on the dynamometers. In Poland students are connecting teaching of force and weight to everyday practice, distinguishing forces, drawing vectors and calculating values. They also try to get used to symbols and represents graphically the forces. Finally, in Estonia, the most important physical sizes are approached in the field of the forces, making a reference in Pascal act, gravitational field of Earth and pressure. They also connect this knowledge to swimming and drowning.

As far as Torque is concerned, students in Italy start learning about Torque at the age of 14 years old mainly approaching the subject of the Torque through the mathematical concept of vector analysis. Also, in Estonia students are learning Torque for the very first time at the age of 14, although not in so much mathematical depth. In the other countries, they start teaching Torque not earlier than 15 years old and not in so much depth. In Greece students are learning Torque for first time at the age of 16 years old.

As far as Energy and Work are concerned, Greece, Latvia, Poland and Estonia start teaching Energy at the age of 14 years old. They teach all aspects, Work calculation, Energy calculation, Kinetic and Dynamic Energy and Energy Conservation laws. Then, at the age of 15 years old, students in Greece and Latvia are introduced more in depth in the meaning of the work further conservation laws, like Bernoulli’s Law and Power. After the age of 16 years old, in Italy students are firstly taught about Energy and conservation laws but in depth, even for elastic energy and rotational motions.

Main conclusions

All these statements are leading us into the conclusion that we must compose well defined worksheets, with inquiry-based steps in order for students to discover by their own the physics laws. We need some very well-structured laboratory exercises in order students to set an experiment, collect experimental data, proceed into mathematical processes and extract their own conclusions. While different countries are following different ways of educational approach, we must support the STEM philosophy in the way of triggering students to further discover new knowledge.

In our future work we suggest focusing on specific physics laws (e.g. force, energy, torque) and compose inquiry-based worksheets with strong experimental part. These worksheets will encourage students to discover into different extend the related physics laws. One of the most ambitious challenges is to let students to choose between four different correct options, defining the one which is most suitable for their knowledge depth. The deepest the understating of a principle the most relevant the answer will be.

7. ANNEXES (TABLE A1 AND QUESTIONNAIRES A2)

Table A1

IO1 - STEM NEED ANALYSIS TEACHERS AND STUDENTS
IO1-A1 Synthetic description of Textbooks at curriculum related to simple machines and the concepts behind them
IO1-A1-2 Return of data about Countries Curricula on simple machines and methodologies used to teach on simple machines
Delivery date to partners:
Due date:
Means of delivery:
Partner Organisation filling this document:
Teacher’s name and surname:
Actual Delivery Date:

For each stage (1 and 2) please create one table for each of the followinf simple machine concept

weight/force (NECESSARY FOR THE INCLINED PLANE), energy/work, torque (NECESSARY FOR THE LEVER &PULLEY)

Students age when the concept is taught:
School grade when the concept is taught:

<table>
<tr><th colspan="3">Stage 1 – Desired Results
TABLE 1 weight/force</th></tr>
<tr><td>As from Official Papers of your Country
As they appear in the National Curriculum Documents</td><td colspan="2">From THE ESTABLISHED GOALS, according to your knowledge and experience, you choose those, WHICH YOU, yourself, CONSIDER MORE IMPORTANT, as well as related MISCONCEPTIONS you have noticed in your previous teaching years.</td></tr>
<tr><td>Established Goals
What Content Standards, Program and/or Mission related goal(s) will this unit address?
The Enduring understandings and learning goals of the lesson, unit, or course</td><td colspan="2">Transfer
What kind of long-term, independent accomplishments are desired?
Refers to how students will transfer the knowledge gained from lessons, units, or course and apply it outside the context of the course</td></tr>
<tr><td rowspan="7"></td><td colspan="2">Students will be able to independently use their learning to
-</td></tr>
<tr><th colspan="2">Meaning</th></tr>
<tr><td>Understandings
What specifically do you want students to understand?
What inferences should they make?
Refers to the bid ideas and specific understandings students will have when they complete lessons, units, or course</td><td>Essential questions
What thought-provoking questions will foster enquiry, meaning making and transfer?
Refers to the provocative questions that foster inquiry, understanding and transfer of learning. These questions typically frame the lessons, units, or course and are often revisited. If students attain the established goals they should be able to answer the essential question(s)</td></tr>
<tr><td>Students will understand that…
-</td><td>Students will keep considering…
-</td></tr>
<tr><th colspan="2">Acquisition of Knowledge & skills</th></tr>
<tr><td>What facts and basic concepts should students know and be able to recall?
Refers to the key knowledge students will acquire from the lesson, unit, or course.</td><td>What discrete skills and process should students be able to use?
Refers to the key skills students will acquire from the lesson, unit, or course.</td></tr>
<tr><td>Students will know…
-</td><td>Students will be skilled at…
-</td></tr>
</table>

Students age when the concept is taught:
School grade when the concept is taught:

<table>
<tr><th colspan="3">Stage 1 – Desired Results
TABLE 2 energy/work</th></tr>
<tr><td>As from Official Papers of your Country
As they appear in the National Curriculum Documents</td><td colspan="2">From THE ESTABLISHED GOALS, according to your knowledge and experience, you choose those, WHICH YOU, yourself, CONSIDER MORE IMPORTANT, as well as related MISCONCEPTIONS you have noticed in your previous teaching years.</td></tr>
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Refers to how students will transfer the knowledge gained from lessons, units, or course and apply it outside the context of the course.</td></tr>
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Refers to the key skills students will acquire from the lesson, unit, or course.</td></tr>
<tr><td>Students will know…
-</td><td>Students will be skilled at…
-</td></tr>
</table>

Students age when the concept is taught:
School grade when the concept is taught:

<table>
<tr><th colspan="3">Stage 1 – Desired Results
TABLE 3 torque</th></tr>
<tr><td>As from Official Papers of your Country
As they appear in the National Curriculum Documents</td><td colspan="2">From THE ESTABLISHED GOALS, according to your knowledge and experience, you choose those, WHICH YOU, yourself, CONSIDER MORE IMPORTANT, as well as related MISCONCEPTIONS you have noticed in your previous teaching years.</td></tr>
<tr><td>Established Goals
What Content Standards, Program and/or Mission related goal(s) will this unit address?
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What kind of long-term, independent accomplishments are desired?
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<tr><td rowspan="7"></td><td colspan="2">Students will be able to independently use their learning to…
-</td></tr>
<tr><td colspan="2">Meaning</td></tr>
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What specifically do you want students to understand?
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Refers to the key skills students will acquire from the lesson, unit, or course.</td></tr>
<tr><td>Students will know…
-</td><td>Students will be skilled at…
-</td></tr>
</table>

Stage 2 –Evidence and Assessment TABLE 1 weight/force
Choose, for each concept, 4 or 5 examples/problems from your textbooks of different cognitive demands as we explain in the document we have sent you

Stage 2 –Evidence and Assessment TABLE 2 energy/work
Choose, for each concept, 4 or 5 examples/problems from your textbooks of different cognitive demands as we explain in the document we have sent you

Stage 2 –Evidence and Assessment TABLE 3 torque
Choose, for each concept, 4 or 5 examples/problems from your textbooks of different cognitive demands as we explain in the document we have sent you

Table A1

Questions for TEST A

Concepts: Weight, Mass and Forces
Objectives:
We want to test if students are able to:

- distinguish the difference between mass and weight
- describe the relation between force and masse
- describe the connection between weight and gravitational attractive force
- calculate the weight of a body
- recognize the effects of weight force on bodies

Questions:

1.

	True	False	
1	T	F	*In science weigth means the same as mas.*
2	T	F	*Weight and mass are forces.*
3	T	F	*Weight is a force.*
4	T	F	*An object with one kilogram mass weighs one kilogram*
5	T	F	*The kilogram is a unit of mass.*
6	T	F	*Sometimes the distinction between mass and weight is unimportant*
7	T	F	*Gravity of Earth is different depending on the country.*
8	T	F	*The weight of an object is directly porportional to its mass.*
9	T	F	*The weight is 10 times greater than the mass.*
10	T	F	*It's easy to undestrand the difference between mass and weight comparing the same object on different planet.*
11	T	F	*On the Moon gravity is stronger than on Earth.*
12	T	F	*The mass of an object is the same on the Moon as on Earth.*
13	T	F	*The weight of an object the same on the Moon as on Earth.*
14	T	F	*We can know the weight of a mass using Newton's second law.*
15	T	F	*On Earth the weight of a 5 kg mass is 37 N.*

2.
At a certain point in the journey of a spaceship towards the Moon, the attraction force of the Earth has the same magnitude as that of the Moon, in the same line of action, but in the opposite direction. We can state that at that point the astronaut:

- has weight equal to zero
- has a mass equal to zero
- has mass and weight both equal to zero
- has the same mass and the same weight it had on Earth
- Justify your statement.

Concepts: Friction and Normal force
Objectives:
We want to test if students are able to:

- apply the action-reaction law
- identify and draw the normal force acting on a body
- recognize contact forces as adaptable forces
- realize forces as vectors on different objects
- describe operations between vectors graphically

3.
A block of mass M sits on a plane that is inclined at an angle θ (Draw a diagram). Assume that the friction force is large enough to keep the block at rest. What are the horizontal components of the friction and normal force acting on the block?

Concepts: Work and Energy
Objectives:
We want to test if students are able to:

- understand that work in physics is different from muscle fatigue
- realize that to have mechanical work there must be a displacement
- describe how the mechanical work depends on the angle that the force for-

ms with the displacement

- prove that in some situations the mechanical energy is conserved
- express the definitions of work, kinetic energy, and potential energy
- realize that the kinetic energy theorem comes from laws of motion
- Work is an "energy in motion" and it increases or decreases the mechanical energy of a system (positive or negative work).
- explain why systems evolve towards points of stable equilibrium in which the potential energy is minimal
- interpret laws that relate work with kinetic energy, gravitational potential and elastic potential
- describe the dependence of kinetic energy on speed
- apply the kinetic energy theorem
- describe the link between conservative forces and potential energy
- explain the relation between work with kinetic energy, gravitational potential and elastic potential energy and the conservation energy theorem.

4.
Which requires more work: lifting a 50-kg sack a vertical distance of 2 m or lifting a 25-kg sack a vertical distance of 4 m?

5.
You drop a ball from a high tower and it falls freely under the influence of the gravitational force. Which one of the following statements is true?

- The kinetic energy of the ball increases by equal amounts in equal times.
- The kinetic energy of the ball increases by equal amounts over equal distances.
- There is zero work done on the ball by the gravitational force as it falls.
- The work done on the ball by the gravitational force is negative as it falls.
- (The total mechanical energy of the ball decreases as it falls.

6.
A person holds a book out of the second floor window of a building, and at a certain moment he drops it.

- *How much work is produced on the book by the person, while holding it out of the window?*
- *How much work is produced by the force of gravity, during the time interval in which the book falls?*

7.
A car is raised a certain distance in a service-station lift and therefore has potential energy relative to the floor.
If it were raised twice as high, how much more potential energy would it have?

Two cars are raised to the same elevation on service station lifts. If one car is twice as massive as the other, compare their gains of potential energy.

8.
When the speed of a moving car is doubled, how much more kinetic energy does it have?

9.
An apple hanging from a limb has potential energy because of its height. If it falls, what becomes of this energy just before it hits the ground? When it hits the ground?
What about his kinetic energy when it hits the ground?

10.
Belly-flop Bernie dives from atop a tall flagpole into a swimming pool below. His potential energy at the top is 10,000 J (relative to the surface of the pool). What is his kinetic energy when his potential energy is reduced to 1000 J?

11
Can something have energy without having momentum? Explain.
Can something have momentum without having energy? Explain.

12.
George is holding the box and he is tired. How much is the work he produces?

13.
Two blocks are initially at rest on a frictionless horizontal surface. The mass mA of block A is less than the mass mB of block B. You apply the same constant force F and pull the blocks through the same distance d along a straight line as shown below (force F is applied for the entire distance d).

Which one of the following statements correctly compares the kinetic energies of the blocks after you pull them the same distance d?

a. The kinetic energies of both blocks are identical.

b. The kinetic energy is greater for the smaller mass block because it achieves a larger speed.

c. The kinetic energy is greater for the larger mass block because of its larger mass.

d. Not enough information, need to know the actual mass of both blocks to compare the kinetic energies.

e. Not enough information, need to know the actual magnitude of force F to compare the kinetic energies.

15.
The roller coaster ride starts from rest at point A.
Rank these quantities from greatest to least at each point:
a. Speed
b. KE (Kinetic Energy)
c. PE (Potential Energy)

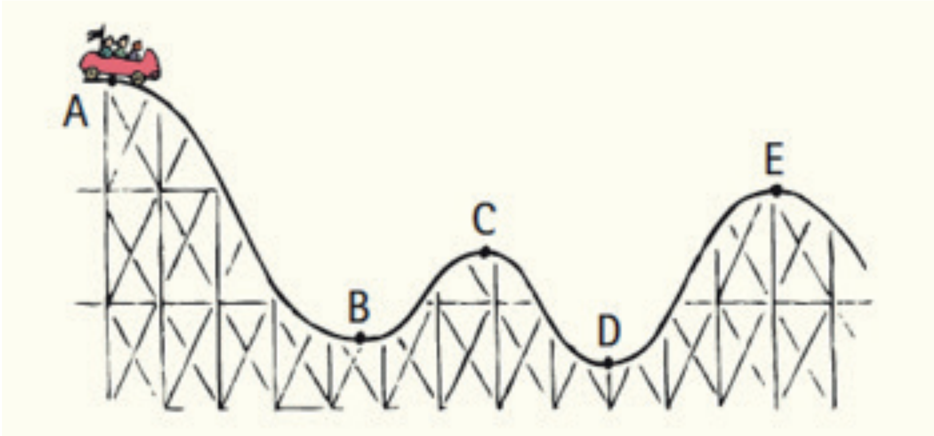
Point A:

Point B:

Point C:

Point D:

Point E:



16.
You lift a suitcase from the floor to a table. In addition to the weight of the suitcase, select all of the following factors that determine the work done by the gravitational force on the suitcase.

1. Whether you lift it directly up to the table or along a longer path
2. Whether you lift it quickly or slowly
3. The height of the table above the floo

a. 8 1) only

b. (3) only

c. (1) and (3) only

d. (2) and (3) only

e. (1), (2) and (3)

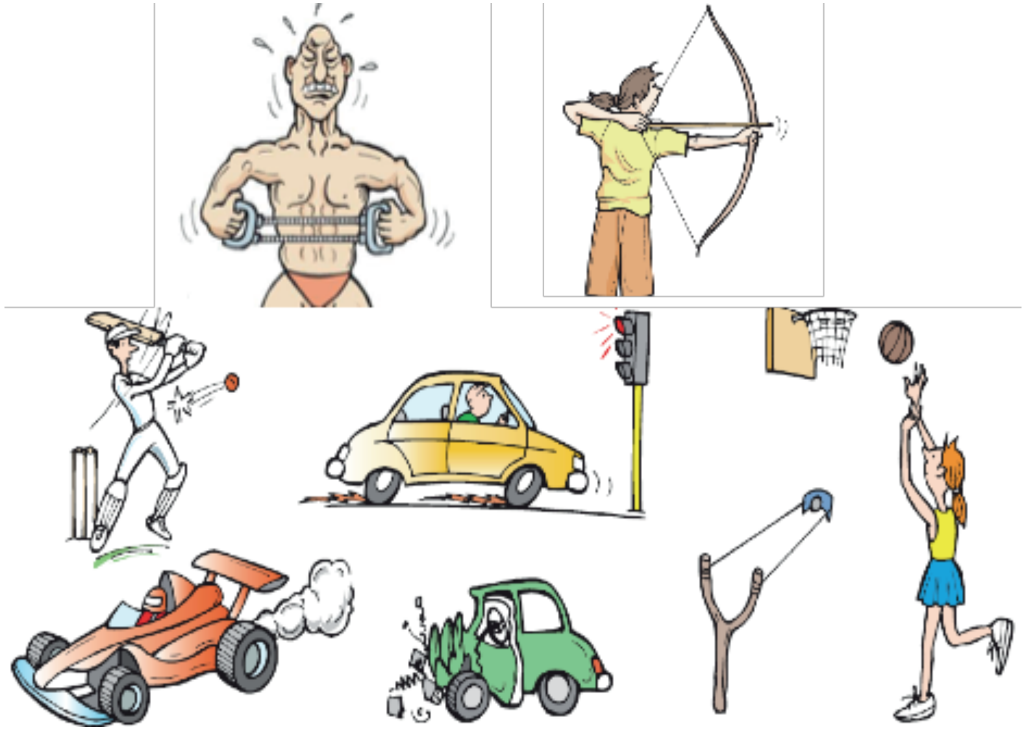
Concepts: Forces and applications in real life
Objectives:
Students would be able to:

- • find and draw the forces (all kind) on objects
- • apply the action-reaction law
- • explain the source of each force on an object

- realize forces as vectors on different objects
- describe operations between vectors graphically
- apply the 2nd Newton's law
- recognize forces and their sources in systems in real life

17.

Look at the pictures below. On each picture find ALL the sources of the forces (pushes & pulls) and draw in arrows to show the direction (1) of the forces and (2) the direction in which the object moves by using a larger or another arrow.



Questions for TEST B

The following questions aim to introduce students to simple machines and their function and not to discuss in details the laws of Physics that govern and explain them.

Concepts: Simple machines – Levels and Pulleys

Objectives:

We want to test if students are able to:

- identify different simple machines; lever, inclined plane, pulley
- describe what is a lever and how it works
- evaluate the balance conditions in a lever
- describe what is a pulley and how it works
- understand that the function of simple machines is explained by the Newton's laws and the laws of mechanical energy
- describe what is the mechanical advantage in simple machines
- understand the difference between mechanical advantage of pulleys and sy-stems of pulleys
- understand that pulleys are levers and they can change the orientation of a needed force or even decrease it
- recognize simple machines in objects and tools in real life

Questions:

1.

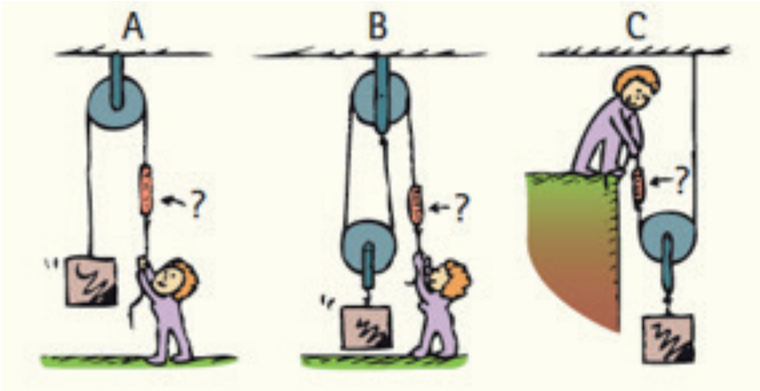
How do pulleys and inclined planes reduce the amount of force needed to do work?

2.

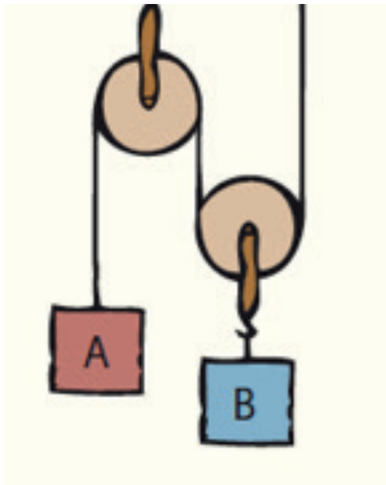
Can a machine multiply input force?
Input energy?

3.
A force of 50 N is applied to the end of a lever, which is moved a certain distance. If the other end of the lever moves one-third as far, how much force, can it exert?

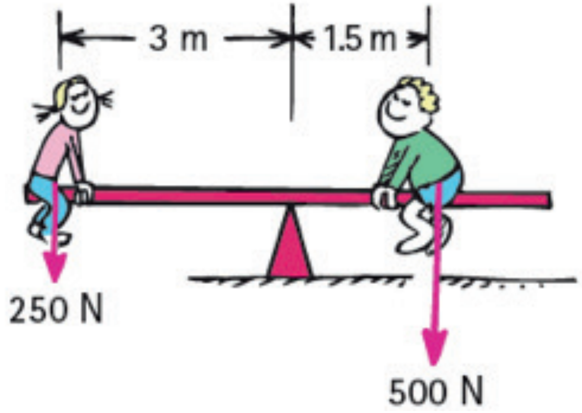
4.
Rank the scale readings from highest to lowest. (Ignore friction.)



5
In the pulley system shown, block A has a mass of 10 kg and is suspended precariously at rest. Assume that the pulleys and string are massless and there is no friction. No friction means that the tension in one part of the supporting string is the same as at any other part.
Discuss why the mass of block B is 20 kg.



8.
Consider the balanced seesaw in the figure. Suppose the girl on the left suddenly gains 50 N, such as by being handed a bag of apples. Where should she sit in order to be in balance, assuming the heavier boy does not move?



11.
A simple machine helps us get more work done by using less:
(a) gravity (b) heat (c) fuel (d) effort.

Concepts: Simple machines – inclined plane
Objectives:
We want to test if students are able to:
- describe the application of the Newton's laws and the laws of mechanical energy on an inclined plane
- describe what is the mechanical advantage of an inclined plane
- recognize applications of the inclined plane in real life

6.
Why can we exert less force to push a barrel in the upward direction on an inclined plane, rather than lifting it vertically?

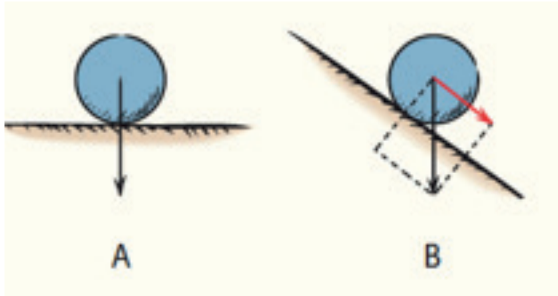
7.

No work is done by gravity on a bowling ball that is resting or moving on a bowling alley because the force of gravity on the ball acts perpendicular to the surface.

But on an incline, the force of gravity has a vector component parallel to the alley, as in B. How does this component account for

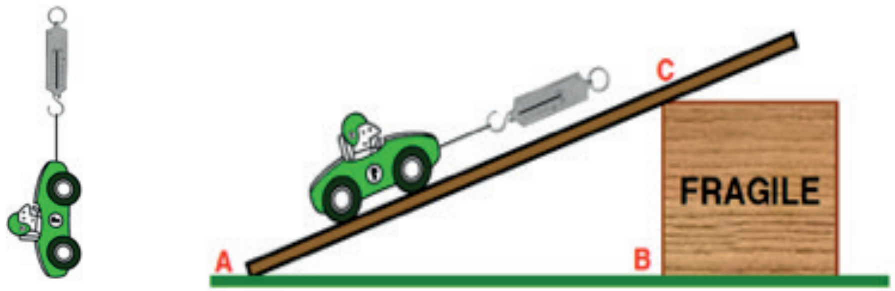
(a) the acceleration of the ball and

(b) the work done on the ball to change its kinetic energy?



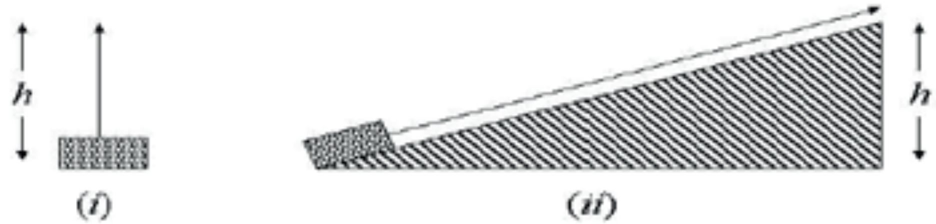
9.

A car is kept stationary on a ramp by means of a rope attached to a dynamometer. The same car is suspended vertically by a dynamometer. In which of the two cases is the indication of the dynamometer greater? Explain by analyzing all the forces exercised in the car in both cases.



10.

You want to lift a heavy block through a height h by attaching a string of negligible mass to it and pulling so that it moves at a constant velocity. You have the choice of lifting it either by pulling the string vertically upward or along a frictionless inclined plane (see Figure).



Which one of the following statements is true?

(a) The magnitude of the tension force in the string is smaller in case (i) than in case(ii).

(b) The magnitude of the tension force in the string is the same in both cases.

(c) The work done on the block by the tension force is the same in both cases.

(d) The work done on the block by the tension force is smaller in case (ii) than in case (i).

(e) The work done on the block by the gravitational force is smaller in case (ii) than in case (i).

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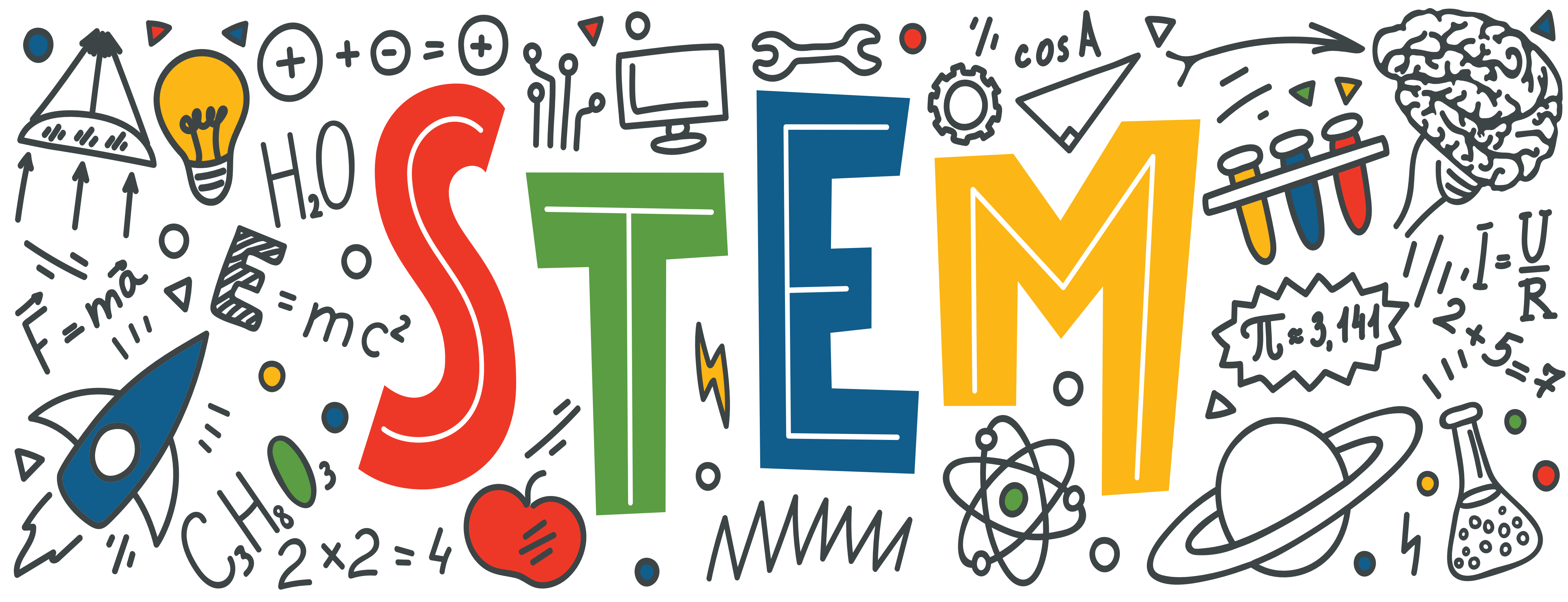

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