ELECTROMAGNETIC PROPERTIES OF MATERIALS

TEACHERS'MANUAL

ORIGINAL VERSION

MATERIALS SCIENCE PROJECT

UNIVERSITY-SCHOOL PARTNERSHIPS FOR THE DESIGN AND IMPLEMENTATION OF RESEARCH-BASED ICT-ENHANCED MODULES ON MATERIAL PROPERTIES

SPECIFIC SUPPORT ACTIONS

FP6: SCIENCE AND SOCIETY: SCIENCE AND EDUCATION

PROJECT COORDINATOR
CONSTANTINOS P. CONSTANTINOU,
LEARNING IN SCIENCE GROUP,
UNIVERSITY OF CYPRUS

PROJECT PARTNERS

ACKNOWLEDGMENT

RESEARCH FUNDING FOR THE MATERIALS SCIENCE PROJECT WAS PROVIDED BY THE EUROPEAN COMMUNITY UNDER THE SIXTH FRAMEWORK SCIENCE AND SOCIETY PROGRAMME (CONTRACT SAS6-CT-2006-042942).

ELECTROMAGNETIC PROPERTIES OF MATERIALS

Design and Development

University Team
Constantinos P. Constantinou
Michalis Livitziis
Rodothea Hadjilouca
Argyro Scholinaki
Marios Papaevripidou
Nikos Papadouris
Giannis Hadjidemetriou

School Teachers
Ioannis Karmiotis
Marios Michail
Giannakis Hadjicostis
Antonis Stylianou
Nitsa Kindini
Myrto Pouangare
Leonidas Fakiolas

Transfer, Implementation and Feedback

University Team
Roser Pintó
Digna Couso
María Isabel Hernández

School Teachers
Montserrat Armengol
Celsa Cortijo
Raül Martos
Miquel Padilla
Consol Rios
Marta Simón
Carme Sunyer
Montserrat Tortosa

Peer review and Feedback
Mathilde Vicentini, University of Roma (La Sapienza)
Roser Pinto, Autonomous University of Barcelona

Other Contributions

The following curriculum materials have served as a resource for this effort: McDermott, L. C. & the P.E.G., University Washington. (1996). Physics by Inquiry (Volume 1). USA: John Wiley & Sons, Inc.

We would like to thank Lillian McDermott and the Physics Education Group at the University of Washington for their continuing support.

CONTENTS

A: TEACHERS' GUIDE

A: TEACHERS' GUIDE

1. INTRODUCTION TO THE MODULE

In the context of the Materials Science (MS) Project, the University of Cyprus (UCY) has designed and developed a module titled "Electromagnetic Properties of Materials" (EPM). The design and development process relied on the close partnership between experienced secondary teachers and science education researchers. The main idea underlying this participative design approach was that the expertise that is distributed among the various parts of such synergies could serve to reduce the gap between research and practice and facilitate the development of effective teaching innovations that fit the needs and satisfy the constraints of the educational system.

The module that has been developed by the UCY focuses on the magnetic properties of materials and electromagnetism. Research studies that have been reported in the literature (Raduta, 2005; Tanel, 2008, Chabay, 2006) indicate that sound and functional understanding of basic concepts and ideas related to electromagnetism and magnetism does not emerge as a typical outcome of conventional science teaching and highlights the need for teaching innovations in this area. Another aspect of this topic that further illustrates its appropriateness to serve as a context for the module relates to the growing number of technological applications of electromagnetism in modern societies. Some examples include the technologies of MRI (Magnetic Resonance Imaging) in medicine, magnetic levitation in transportation and Magnetic Resonance Force Microscopy (MRFM)[1]. As discussed later, a major component of the module involves the design and construction of a model of a magnetically levitated train and this is expected to provide students with an interesting context within which to integrate the relevant concepts in a meaningful manner.

The design of the module sought to combine two different teaching approaches, namely *guided inquiry* and *technological design*. The aim was to design curriculum materials that promote conceptual understanding, reasoning skills and epistemological awareness about certain aspects of the Nature of Science (NOS), in an integrated manner. The structure of the module allows students to operate in a semi-autonomous environment that relies on their interaction and collaboration. Thus, the learning environment is expected to help students develop important social skills, such as cooperation, responsibility and cognitive reflection.

The module is divided in six sections, as follows:

- Investigation with Magnets
- Magnetic Interactions at a distance
- A Model for Magnetic Materials
- Investigation with Electromagnets
- Technology Project: Design and Construction of a Magnetic Levitation train
- Science & Technology: Linkages between Science & Technology

The whole module revolves around the design and development of a model of a magnetically levitated (maglev) train. It begins by presenting the problem of transportation in Cyprus and asks the students to design a train model based on advanced technologies. Immediately afterwards, students are exposed, in a structured manner, to fundamental ideas about Magnetism. Specifically, the activity sequence seeks to gradually help students develop core ideas of magnetism and electromagnetism, e.g. magnetic interactions, magnetic field, electromagnets' function, etc. In Unit 1, the aim is to help students understand some basic ideas of magnetism, such as magnetic interactions, magnetic poles and strength of magnets. Unit 2 seeks to help students understand the abstract idea of the magnetic field and rely on this representational model (construct) to account for (situations involving magnetic) interactions at a distance. The objective of Unit 3 is to help students create a conceptual model for magnetic domains that could be used to account for a range of observations, such as magnetic interactions, strength of magnets, magnetization and demagnetization, etc. Unit 4 covers basic ideas on electromagnetism. It includes specifically designed

1. *Researchers from IBM have recently demonstrated the ability of this technology to depict the structure of a virus (4nm)*

activities that prepare students for the development of the train model; these activities cover the properties of electromagnets (e.g. strength, polarity, etc.) and motion using electromagnetic forces. Unit 5 engages students in the design and development of their train models. The project provides an opportunity for students to apply the concepts they are expected to acquire throughout the first four units to solve a relevant technological problem (design a magnetically levitated train). In addition to this, it is expected to acquaint students with the opportunity to experience the connections between science and technology. Unit 6 is devoted to the elaboration of the connection and the differences between science and technology. Towards this end students are systematically engaged in explicit epistemological discourse in the context of relevant narratives drawn from the history of science. In addition to this, an explicit attempt is made to help students make connections between these discussions and the various activities they had been engaged with, in the previous units of the module.

2. CONNECTION OF THIS MODULE TO OTHER MODULES IN THE MATERIALS SCIENCE PROJECT

Materials Science Project was initiated as an answer to the escalating problems observed in science education. The different educational systems across the European Community have to address very similar problems. Some of the most important problems relate to a) the continuously decreasing number of students that wish to continue their studies in science and b) the tendency of traditional teaching approaches to give emphasis to factual content and rote memorisation instead of functional conceptual understanding. This approach is in contrast to EU plans for sustainable growth and wider participation of the general public into decision making processes regarding complex socio-scientific issues.

One of the main aims of the project includes the development of teaching/learning modules (each partner has to develop a module on a different topic) that (a) embody innovative teaching designs reflecting our current understanding with respect to learning in science and (b) seek to help students emerge with functional conceptual understanding with respect to topics falling under materials science and appreciate aspects of the nature of science.

The modules were the outcome of a close partnership between experienced science education researchers and science teachers. Each of the modules focuses on a different aspect of the broad area of "Materials Science". The topic of "Materials Science" was selected due to their increasing number of technological applications in modern societies, on the hand, and the lack of teaching innovations in this field, on the other hand. Materials Science is an interdisciplinary subject that provides several opportunities for curriculum development that connects fundamental scientific ideas with the real world through the applications of the materials. The main instructional approach used in all the modules is inquiry. In inquiry-oriented learning materials, students are guided, amongst others, to make observations, design and carry out investigations and develop models with predictive and explanatory capability. In addition to this, inquiry-based learning environments might serve to help students acquire knowledge and skills that are essential for living and working in the “information society”. Each partner has used different strategies to capture and convey the inquiry method. Some of the most common teaching strategies that have been embedded in the various modules include conceptual modelling, elicit-confront-resolve, predict-observe-explain, etc.

Thus, common elements of all the modules are:

- to address basic topics of physics through the study of materials and their applications.
- to introduce innovative science instructional methods into primary and secondary school curricula as a means to support science learning as a process of inquiry.
- to introduce students to science as a cultural enterprise.
- to feed students’ motivation and interest towards science and inquiry.

3. BACKGROUND INFORMATION

[A considerable amount of the information that appears on the section below was retrieved from Wikipedia, accessed Nov 07, 2008, http://en.wikipedia.org/wiki/Magnetism]

3.1. MAGNETS

A *magnet* (from Greek "*Magnesian* stone") is a material or object that produces a magnetic field. This magnetic field is responsible for the most notable property of a magnet: a force applied on other ferromagnetic materials and attracts or repels other magnets.

A *permanent magnet* is one that stays magnetized, such as a magnet used to hold notes on a refrigerator door. Materials which can be magnetized, which are also the ones that are strongly attracted to a magnet, are called ferromagnetic. These include iron, nickel, cobalt, some rare earth metals and some of their alloys, and some naturally occurring minerals such as lodestone. Permanent magnets are made from "hard" ferromagnetic materials which are designed to stay magnetized, while "soft" ferromagnetic materials like soft iron are attracted to a magnet but don’t tend to stay magnetized.

Although *ferromagnetic materials* are the only ones strongly attracted to a magnet to be commonly considered "magnetic", all other substances respond weakly to a magnetic field, by one of several other types of magnetism. Paramagnetic materials, such as aluminum and oxygen are weakly attracted to a magnet. Diamagnetic materials, such as carbon and water, which include all substances not having another type of magnetism, are weakly repelled by a magnet.

Ferromagnetic and ferrimagnetic materials are the ones normally thought of as ’magnetic’; they are attracted to a magnet strongly enough that the attraction can be felt. These materials are the only ones that can retain magnetization and become magnets; a common example is the refrigerator magnet. Ferrimagnetic materials, which include ferrites and the oldest magnetic materials magnetite and lodestone, are similar but weaker than ferromagnetics. The difference between ferro- and ferrimagnetic materials is related to their microscopic structure.

Paramagnetic substances such as platinum, aluminum, and oxygen are weakly attracted to a magnet. This effect is hundreds of thousands of times weaker than ferromagnetic materials attraction, so it can only be detected by using sensitive instruments, or using extremely strong magnets. Magnetic ferrofluids, although they are made of tiny ferromagnetic particles suspended in liquid, are sometimes considered paramagnetic since they can't be magnetized.

Diamagnetic means repelled by both poles. Compared to paramagnetic and ferromagnetic substances, diamagnetic substances such as carbon, copper, water, and plastic are even more weakly repelled by a magnet. The permeability of diamagnetic materials is less than the permeability of a vacuum. All substances not possessing one of the other types of magnetism are diamagnetic; this includes most substances. Although force on a diamagnetic object from an ordinary magnet is far too weak to be felt, using extremely strong superconducting magnets diamagnetic objects such as pieces of lead and even frogs can be levitated so they float in midair. Superconductors repel magnetic fields from their interior and are strongly diamagnetic.

The *magnetic field* is called a field because it has a value at every point in space. The magnetic field (at a given point) is specified by two properties: (1) its direction, which is along the orientation of a compass needle; and (2) its magnitude (also called strength), which is proportional to how strong is the interaction.

A *magnetic field* is a vector field which can exert a magnetic force on moving electric charges and on magnetic dipoles (such as permanent magnets). When placed in a magnetic field, magnetic dipoles tend to align their axes parallel to the magnetic field. Magnetic fields are created by electric currents, magnetic dipoles, and changing electric fields. Magnetic fields also have their own energy, with an energy density proportional to the square of the field intensity.

Magnetic field is a relativistic part of electric field. When electric field is seen by an observer moving with some velocity v (or vice versa) then Lorentz transformations of space and time from one reference frame to another result in the origin of cross product of electric field E and velocity of motion v. This cross product vxE is what we call magnetic field.

The strength and direction of the magnetic field due to an object varies from position to position. Mapping out this magnetic field is simple in principle. First, measure the strength and direction of the magnetic field at a large number of points. Then, mark each location with an arrow (called a vector) pointing in the direction of the magnetic field with a length proportional to the strength of the magnetic field. This is a valid and useful way of marking out and visualizing the magnetic field of an object. It has the unfortunate consequence, though, of cluttering up a graph even when using a small number of points. An alternative method of visualizing the magnetic field is to use "magnetic field lines".

These field lines provide us with a way to depict or draw the magnetic field (or any other vector field). Technically, field lines are a set of lines through space whose direction at any point is the direction of the local magnetic field, and whose density is proportional to the magnitude of the local magnetic field. Note that when a magnetic field is depicted with field lines, it is not meant to imply that the field is only nonzero along the drawn-in field lines. Rather, the field is typically smooth and continuous everywhere, and can be estimated at any point (whether on a field line or not) by looking at the direction and density of the field lines nearby. The choice of which field lines to draw in such a depiction is arbitrary, apart from the requirement that they be spaced out so that their density approximates the magnitude of the local field. The level of detail at which the magnetic field is depicted can be increased by increasing the number of lines.

Even when it appears that a magnetic field has an end (such as when it leaves near a north pole or enters near a south pole of a magnet) in reality it does not. In the case of the permanent magnet the field lines complete the loop inside the magnet traveling from the south to the north pole. (To see that this must be true imagine placing a compass inside the magnet. The north pole of the compass will point toward the north pole of the magnet).

Field lines are also a good tool for visualizing magnetic forces. When dealing with magnetic fields in ferromagnetic substances like iron, and in plasmas, the magnetic forces can be understood by imagining that the field lines exert a tension, (like a rubber band) along their length, and a pressure perpendicular to their length on neighboring field lines. The ’unlike’ poles of magnets attract because they are linked by many field lines, while ’like’ poles repel because the field lines between them don’t meet, but run parallel, pushing on each other.

A magnet’s *magnetic moment* (also called magnetic dipole moment, and usually denoted μ) is a vector that characterizes the magnet’s overall magnetic properties. For a bar magnet, the direction of the magnetic moment points from the magnet’s south pole to its north pole and the magnitude relates to how strong and how far apart these poles are.

A magnet both produces its own magnetic field and it responds to magnetic fields. The strength of the magnetic field it produces at any given point is proportional to the magnitude of its magnetic moment. In addition, when the magnet is put into an "external" magnetic field produced by a different source, it is subject to a torque tending to orient the magnetic moment parallel to the field. The amount of this torque is proportional both to the magnetic moment and the "external" field. A magnet may also be subject to a force driving it in one direction or another, according to the positions and orientations of the magnet and source. If the field is uniform in space the magnet is subject to no net force, although it is subject to a torque.

The *magnetization* of a magnetized material is the local value of its magnetic moment per unit volume, usually denoted M. It is a vector field, rather than just a vector (like the magnetic moment), because different areas in a magnet can be magnetized with different directions and strengths (for example, due to domains, see below).

Although for many purposes it is convenient to think of a magnet as having distinct north and south magnetic poles, the concept of poles should not be taken literally: it is merely a way of referring to the two different ends of a magnet. The magnet does not have distinct "north" or "south" particles on opposing sides. (No magnetic monopole has yet been observed.) If a bar magnet is broken in half, in an attempt to separate the north and south poles, the result will be two bar magnets, each of them with both a north and a south pole.

Gilbert model: The magnetic pole approach is used by professional magneticians to design permanent magnets. In this approach, the pole surfaces of a permanent magnet are imagined to be covered with ’magnetic charge’, little ’north pole’ particles on the north pole and ’south poles’ on the south pole, that are the source of the magnetic field lines. If the magnetic pole distribution is known, then outside the magnet the pole model gives the magnetic field. In the interior of the magnet this model fails to give the correct field. This pole model is also called the "Gilbert model" of a magnetic dipole.

Ampère model: Another model is the "Ampère model", where all magnetization is due to the effect of microscopic, or atomic, circular "bound currents", also called "Ampèrian currents" throughout the material. For a uniformly magnetized cylindrical bar magnet, the net effect of the microscopic bound currents is to make the magnet behave as if there is a macroscopic sheet of electric current flowing around the surface, with local flow direction normal to the cylinder axis. The right-hand rule tells which direction the current flows. The Ampere model gives the exact magnetic field both inside and outside the magnet. It is usually difficult to calculate the Amperian currents on the surface of a magnet, whereas it is often easier to find the effective poles for the same magnet.

The magnetic moment of atoms in a ferromagnetic material cause them to behave like tiny permanent magnets. They stick together and align themselves into small regions of more or less uniform alignment called magnetic domains or Weiss domains. Magnetic domains can be observed with a magnetic force microscope to reveal magnetic domain boundaries that resemble white lines in the sketch. There are many scientific experiments that can physically show magnetic fields.

When a domain contains too many molecules, it becomes unstable and divides into two domains aligned in opposite directions so that they stick together more stably as shown below (fig.1).

When exposed to a magnetic field, the domain boundaries move so that the domains aligned with the magnetic field grow and dominate the structure as shown at the left. When the magnetizing field is removed, the domains may not return to an

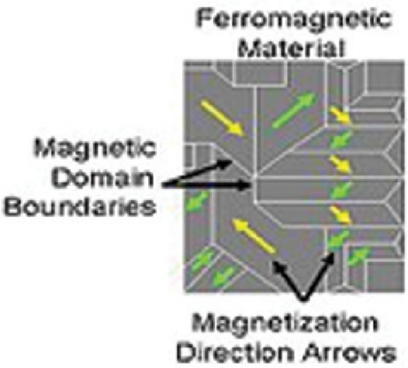


FIGURE 1: MAGNETIC DOMAINS IN A FERROMAGNETIC MATERIAL

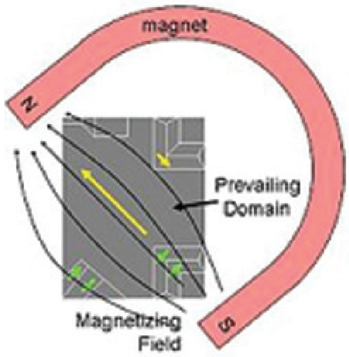


FIGURE 2: EFFECT OF A MAGNET ON THE DOMAINS

unmagnetized state. This results in the ferromagnetic material being magnetized, forming a permanent magnet (fig. 2).

When magnetized strongly enough that the prevailing domain overruns all others to result in only one single domain, the material is magnetically saturated. When a magnetized ferromagnetic material is heated to the Curie point temperature, the molecules are agitated to the point that the magnetic domains lose the organization and the magnetic properties they cause cease. When the material is cooled, the domains alignment structure spontaneously returns, in a manner roughly analogous to how a liquid can freeze into a crystalline solid.

Ferromagnetic materials can be magnetized in the following ways:

- Heating the object above its Curie temperature, allowing it to cool in a magnetic field and hammering it as it cools. This is the most effective method, and is similar to the industrial processes used to create permanent magnets.
- Placing the item in an external magnetic field will result in the item retaining some of the magnetism on removal. Vibration has been shown to increase the effect. Ferrous materials aligned with the earth's magnetic field, which are subject to vibration (e.g. frame of a conveyor), have been shown to acquire significant residual magnetism. A magnetic field much stronger than the earth's can be generated inside a solenoid by passing direct current through it.
- Stroking - An existing magnet is moved from one end of the item to the other repeatedly in the same direction.

Magnetized materials can be *demagnetized* in the following ways:

- Heating a magnet past its Curie temperature - the molecular motion destroys the alignment of the magnetic domains. This always removes all magnetization.
- Hammering or jarring - the mechanical disturbance tends to randomize the magnetic domains. Will leave some residual magnetization.
- Placing the magnet in an alternating magnetic field, such as that generated by a solenoid with an alternating current through it, and then either slowly drawing the magnet out or slowly decreasing the magnetic field to zero. This is the principle used in commercial demagnetizers to demagnetize tools and erase credit cards and hard disks, and degaussing coils used to demagnetize CRTs (Cathode Ray Tubes).

An *electromagnet* is a type of magnet in which the magnetic field is produced by the flow of electric current. The magnetic field disappears when the current ceases. A wire with an electric current passing through it generates a magnetic field around it. The strength of the generated magnetic field is proportional to the amount of current.

In order to concentrate the magnetic field generated by a wire, it is commonly wound into a coil, where many turns of wire sit side by side forming what is known as a solenoid. When electric current flows through the wire, a magnetic field is generated. It is concentrated near (and especially inside) the coil, and its field lines are very similar to those for a bar magnet. The orientation of this effective magnet is determined via the right hand rule. The magnetic moment and the magnetic field of the electromagnet are proportional to the number of loops of wire per length, to the cross-section of each loop, and to the current passing through the wire (fig.3).

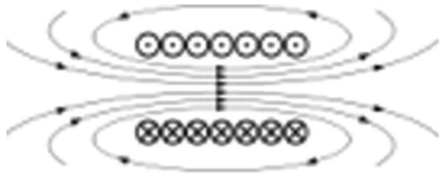


FIGURE 3: MAGNETIC FIELD PRODUCED BY A SOLENOID (THE CROSSES ARE WIRES IN WHICH CURRENT IS MOVING INTO THE PAGE; THE DOTS ARE WIRES IN WHICH CURRENT IS MOVING UP OUT OF THE PAGE)

Much stronger magnetic fields can be produced if a "core" of ferromagnetic material, such as soft iron, is placed inside the coil. The core magnifies the magnetic field to thousands of times the strength of the field of the coil alone. This is called a ferromagnetic-core or iron-core electromagnet.

As a current is passed through the coil, small magnetic regions within the core material, called magnetic domains, align with the applied field, causing the magnetic field strength to become saturated; a further increase in current will only cause a relatively minor increase in the magnetic field. In some materials, some of the domains may realign themselves. In this case, part of the original magnetic field will persist even after power is removed, causing the core to behave as a permanent magnet. This phenomenon, called remanent magnetism, is due to the hysteresis of the material. Applying a decreasing AC current to the coil, removing the core and hitting it, or heating it above its Curie point will reorient the domains, causing the residual field to weaken or disappear.

If the coil of wire is wrapped around a material with no special magnetic properties (e.g., cardboard), it will tend to generate a very weak field. However, if it is wrapped around a "soft" ferromagnetic material, such as an iron nail, then the net field produced can result in a several hundred- to thousand fold increase of field strength.

The direction of the magnetic field through a coil of wire can be found from the right-hand rule. If the fingers of the right hand are curled around the coil in the direction of current flow (conventional current, flow of positive charge) through the windings, the thumb points in the direction of the field inside the coil. The side of the magnet that the field lines emerge from is defined to be the *north pole*.

The main advantage of an electromagnet over a permanent magnet is that the magnetic field can be rapidly manipulated over a wide range by controlling the amount of electric current. However, a continuous supply of electrical energy is required to maintain the field.

Uses for electromagnets include particle accelerators, electric motors, junkyard cranes, and magnetic resonance imaging machines. Some applications involve configurations more than a simple magnetic dipole, for example quadrupole and sextupole magnets are used to focus particle beams.

Earth's magnetic field: A compass placed anywhere on Earth will turn so that the "north pole" of the magnet inside the compass points roughly north, toward Earth's north geographic pole in northern Canada. This is the traditional definition of the "north pole" of a magnet, although other equivalent definitions are also possible. A confusion that arises from this definition is that if Earth itself is considered a magnet, the south pole of that magnet would be the one nearer the north geographic pole, and vice-versa. The north magnetic pole of a magnet is so named not because of the polarity of the field there but because of the geographical direction that points when it rotates freely.

The figure below is a sketch of Earth's magnetic field represented by field lines. The magnetic field at any given point does not point straight toward (or away) from the poles and has a significant up/down component for most locations. (In addition, there is an East/West component as Earth's magnetic poles do not coincide exactly with Earth's geographic poles.) The magnetic field is as if there was a magnet deep in Earth's interior (fig.4).

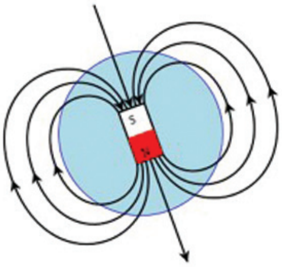


FIGURE 4: A SKETCH OF EARTH'S MAGNETIC FIELD REPRESENTING THE SOURCE OF EARTH'S MAGNETIC FIELD AS A MAGNET

The Earth's field is closely approximated by the field of a dipole positioned near the centre of the Earth. A dipole defines an axis. The two positions where the axis of the dipole that best fit the Earth's field intersects the Earth's surface are called the North and South magnetic poles. If the Earth's field were perfectly dipolar, the geographic and magnetic poles would coincide. However, there are significant non-dipolar terms which cause the position of the two types of poles to be in different places.

The locations of the magnetic poles are not static; they wander as much as 15 km every year (Dr. David P. Stern, emeritus Goddard Space Flight Center, NASA). The pole position is usually not the one indicated on many charts. The Geomagnetic Pole positions are usually not close to the position that commercial cartographers place "Magnetic Poles." "Geomagnetic Dipole Poles", "IGRF Model Dip Poles", and "Magnetic Dip Poles" are variously used to denote the magnetic poles.

The Earth's field changes in strength and position. The two poles wander independently of each other and are not at directly opposite positions on the globe. Currently the magnetic north pole is further away from the geographic south pole than the magnetic north pole is from the geographic south pole.

Earth's magnetic field is probably due to a dynamo that produces electric currents in the outer liquid part of its core. Earth's magnetic field is not constant: Its strength and the location of its poles vary. The poles even periodically reverse direction, in a process called geomagnetic reversal.

3.2. MAGNETIC LEVITATION (MAGLEV) TRAINS

3.2.1. HISTORY OF MAGLEV TRAINS

Magnetic levitation, maglev, or magnetic suspension is a method by which an object is suspended above another object with no support other than magnetic fields. The electromagnetic force is used to counteract the effects of the gravitational force.

Magnetic levitation transport, or maglev, is a form of transportation that suspends and propels vehicles (especially trains) via electromagnetic force. This method can be faster than wheeled mass transit systems, potentially reaching velocities comparable to turboprop and jet aircraft (900km/h, 559 mph). The maximum speed of a maglev train (fig. 5) that has been reported so far is 581km/h (361 mph) (Japan, 2003).

FIGURE 5: MAGLEV TRAIN

In Britain, Eric Laithwaite developed a functional maglev train; his maglev had one mile of track and was thoroughly tested, but his research was cut off in 1973 due to lack of funding. In the 1970s, Germany and Japan also began research and after some failures both nations developed mature technologies in the 1990s. However, superconductor related costs remain a barrier to widespread acceptance.

The first commercial Maglev was opened in 1984 in Birmingham, England. It covered some 600 meters between its airport and rail hub, and operated at 42 km/h (26 mph) until it was eventually closed in 1995 due to reliability and design problems.

The best-known high-speed maglev currently operating commercially is the IOS (initial operating segment) demonstration line of the German built Transrapid train in Shanghai, China that transports people 30 km (18.6 miles) to the airport in just 7 minutes 20 seconds, achieving a top velocity of 431 km/h (268 mph), averaging 250 km/h (150 mph).

Other commercially operating lines exist in Japan, such as the Linimo line; while there have been maglev projects/proposals worldwide (United Kingdom, Japan, Venezuela, China, India, United States, Spain and Germany) that are being studied for feasibility. In Japan at the Yamanashi test track, current maglev train technology is mature, but costs and problems remain a barrier to development.

3.2.2. MAGLEV TECHNOLOGY

Although most people are unfamiliar with maglev technology, its basic principles are relatively simple and can be easily understood. Compared to many of the equipment we are already using in our existing transport systems, the hardware employed in maglev systems is not as complex and is less subject to stress during operation. For example, airplanes are much more complex than maglev vehicles. Airplanes have highly stressed, high temperature jet engines, many miles of electrical wiring and hydraulic lines, complex control systems and so on. In contrast, maglev vehicles based on superconducting magnets operate with simple coils of superconducting wire and compact cryogenic coolers. Maglev hardware is commercially available and highly reliable with a very large margin of safety.

Because all the operational implementations of maglev technology cannot share the existing train infrastructure, maglev trains must be designed from scratch. That is why the term maglev refers not only to the vehicles, but to the railway system as well, as it is specifically designed for magnetic levitation and propulsion.

There are two primary types of maglev technology:

- Electromagnetic suspension (EMS) uses the attractive force of a magnet beneath a rail to lift the train up. The train levitates above the steel rail while electromagnets, attached to the train, are oriented toward the rail from below. The electromagnets use feedback control to maintain the train at a constant distance from the track, at approximately 15 millimeters (0.6 in).
- Electrodynamic suspension (EDS) uses a repulsive force between two magnetic fields to push the train away from the rail (fig. 6). Both the rail and the train exert a magnetic field, and the train is levitated by the repulsive force between these magnetic fields. The magnetic field in the train is produced by either electromagnets or by an array of permanent magnets. The repulsive force in the track is created by an induced magnetic field in wires or other conducting strips in the track.

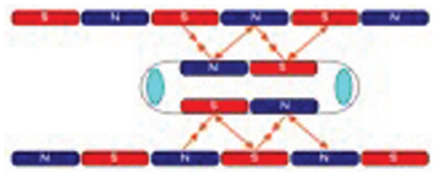


FIGURE 6: ELECTRODYNAMIC SUSPENSION

3.2.3. EXAMPLE OF A MAGNETIC LEVITATION TRAIN: JR-MAGLEV TRAIN

The Japanese JR-Maglev is the fastest non-conventional train in the world, having achieved 581 km/h (361 mph) on a magnetic-levitation track. Like all magnetic levitation trains, it makes use of a levitation system, a guide system and a driving system.

The JR-Maglev uses an Electrodynamic Suspension (EDS) system (fig. 7). Moving magnetic fields create a reactive force in a conductor because of the magnetic field induction effect. This force holds up the train. The maglev trains have superconducting magnetic coils, and the guide ways contain levitation coils. When the trains run at high speed, the levitation coils on the guide way produce reactive forces in response to the approach of the superconducting magnetic coils onboard the trains.

EDS needs support wheels which are employed in low speed running, because it cannot produce a large levitation force at “low” speeds (150km/h or less in JR-Maglev). However, once the train reaches a certain speed, the wheels retract and the train is floating.

Finally, JR-Maglev is driven by a Linear Synchronous Motor (LSM) System. This system is necessary in means of supplying power to the coils at the guide way.

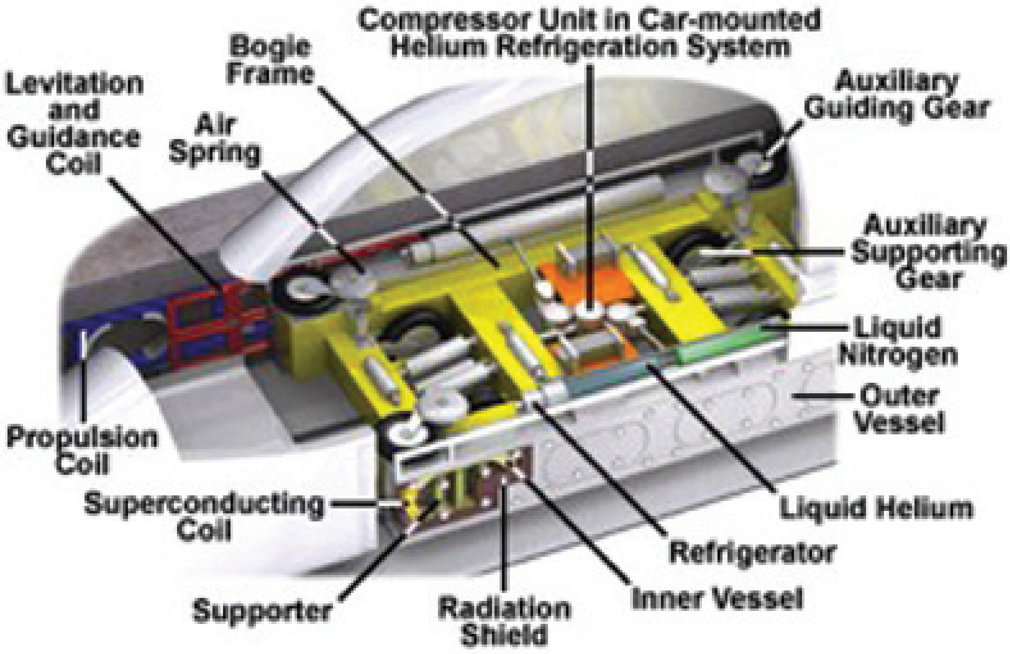


FIGURE 7: INTERNAL WORKINGS OF THE MAGLEV TRAIN

3.3. MAGNETIC SHIELDING

Without magnetic shielding, much of today's sophisticated electronic gear would be larger, less efficient and in some magnetic environments, impossible to function. Magnetic shielding is the process of limiting the flow of magnetic fields between two locations, by placing a material with permeability much greater than the one between the field and the sensitive components affected. Typical materials used are ferrous metals that will "attract" magnetic fields. Such materials as galvanized steel, silicon steel, and in general, every low carbon steel are the best materials to be placed in very strong magnetic fields.

The two basic properties that one considers when choosing what type of metal to use for a magnetic shield are permeability and saturation. Permeability is the ability of the metal to "attract" magnetic fields to it, while saturation is the ability of the metal to "absorb" magnetic fields within its walls.

There are various materials that cause a substantial reduction of the magnetic field, these materials have high magnetic permeability and examples include metal alloys such as Permalloy, Mu-metal and Giron. These materials don't block the magnetic field, they draw the field into themselves, providing a path for the magnetic field lines around the shielded volume. The best shape for magnetic shields is thus a closed container. The effectiveness of this type of shielding decreases with the material's permeability, which generally drops off at both very low magnetic field strengths, and also at high field strengths where the material becomes saturated. Permalloy is the term for a nickel iron magnetic alloy. Generically, it refers to an alloy with about 20% iron and 80% nickel content. Mu-metal is a nickel-iron alloy (75% nickel, 15% iron, plus copper and molybdenum) that has very high magnetic permeability. Giron is an iron alloy that does not contain nickel, but it is highly effective and moldable.

4. PRIOR KNOWLEDGE OF STUDENTS

The module does not assume substantial pre-requisite knowledge regarding Magnetism. It neither posits competence with advanced mathematics since it is constrained at the conceptual level and it precludes quantitative analyses.

5. AIMS OF THE MODULE

The module seeks to (a) help students understand basic ideas relevant to magnetism and electromagnetism, (b) lead them in the path of lifelong learning and authentic science practice and finally and (c) help them understand and appreciate the link between science and technology. These objectives are addressed through engaging students in inquiry and technological design.

5.1. SCIENTIFIC CONCEPTS

The main learning objectives of the module include:

- acquisition of experiences about the interaction between magnets and other objects
- understanding magnetic field as a model that accounts for interactions at a distance
- appreciating magnetic domains as a conceptual model for the magnetization and demagnetization of materials
- understanding essential aspects of the function of electromagnets

5.2. METHODOLOGICAL / PROCEDURAL SKILLS / COMPETENCIES

In addition to the conceptual understanding that students are expected to acquire, an attempt is also made to help them develop skills and competencies relevant to the process of technological design, such as the ideas of (a) testing models with respect to their ability to satisfy the specifications and constraints that had been formulated and (b) refinement of the models so as to optimize their structure.

5.3. REASONING STRATEGIES

The module involves activities specially designed to help students develop certain reasoning strategies. It specifically focuses on the ability to design valid experiments through appropriate control of the relevant variables.

5.4. EPISTEMOLOGICAL AWARENESS

As mentioned earlier, the module consists of two main parts. The first guides students through an inquiry-based activity sequence so as to develop certain ideas and concepts with respect to magnetism and electromagnetism. The second engages students in the design of a train model. Throughout both sections students are systematically engaged in explicit epistemological discourse about the distinction and the interconnections between science and technology. This is intended to help students:

- appreciate the distinction between the different goals of science and technology (producing reliable knowledge about natural phenomena Vs developing solutions to respond to human problems and needs).
- understand the different methodological frameworks that are usually adopted by science and technology (investigation and design, respectively).
- understand aspects of the contribution of science to the development of technology (science provides the knowledge basis for the development/improvement of technological equipment, science formulates questions that necessitate instrumentation i.e., the invention of specialized instruments/processes for measuring, monitoring or controlling).
- understand aspects of the contribution of technology to the development of science (technology facilitates the conduction of experiments by providing instruments and experimental techniques; new technologies tend to initiate scientific research by raising questions concerning the phenomena and mechanisms underlying the operation of these technologies).

6. PEDAGOGICAL APPROACH AND CONTEXT

Typically, science instruction deals with the various fields of science (e.g. biology, physics, etc.) separately. The interdisciplinary subject of Materials Science provides an appropriate context to explore the interconnections among diverse fields, including chemistry, physics and biochemistry. 'Materials Science' is an underestimated subject in school curriculum, even though materials are in the focus of research interest. In our everyday life, everything is linked to materials, from simple things such as clothes, books, etc., to advanced equipment that we depend on, such as cars, planes, computers, mobile phones, medical equipment, etc. All these examples signify the importance of Materials and the need for understanding the use of existing materials and the development of new ones to meet the demands of the future. In school curriculum 'Materials' as a subject offers also the possibility of exploring the relationship between science & technology and understanding the interdependency and differences. The EPM module examines magnetism, as one of the most common and recognizable properties of various materials, and electromagnetism, as a subject that has received much attention recently due to the many applications in technological artifacts.

For the whole duration of the module, students work in groups. Through the collaboration processes, students are expected to develop learning and social skills. Student-teacher interaction is organized around discussion at predetermined checkout points. During these discussions, rather than providing direct answers to students' questions or comments, the instructor attempts to facilitate consensus, consistency and accountability in students' thinking and helps them articulate their thoughts and negotiate the various epistemological, conceptual, reasoning or practical difficulties they encounter.

The design of the EPM module is based on combining principles from two theoretical perspectives guided inquiry and learning by design. Inquiry learning is a student-centred framework in which students engage in practices and reasoning similar to those used by scientists, such as posing questions, designing and conducting experiments, collecting data and formulating evidence-based explanations (Walker, 2007). In schools, it is very difficult to reproduce authentic scientific inquiry. The aim is to develop creative inquiry activities that are simple enough to be implemented in the classroom environment and cover the core aspects of authentic scientific inquiry (Chinn & Malhotra, 2002). Inquiry offers a natural way of searching for knowledge and thus it could contribute to the promotion of lifelong learning. Studies have shown that diverse students exposed to inquiry teaching and learning methods have improved considerably (Gotwals, 2006).

There are many different teaching strategies used in the EPM module in order to capture the essence of inquiry and respond to the diverse needs of the students. In science education, knowledge restructuring and self-regulation hold predominant positions in teaching and learning (Duschl, 1991). Examples of strategies exploited in the EPM teaching/learning sequence include, among others, cognitive conflict, elicit - confront - resolve (Mc Dermott, 1993), Predict-Observe-Explain (POE) (White, 1992) and conceptual modelling. Elicit, confront, resolve has been shown to be a very effective strategy for helping students restructure prior knowledge. Activities that embody this teaching strategy are usually designed in a way that students are initially confronted with common misconceptions and difficulties and, in the next instance, they are provided with guidance to resolve (Heron, 2009). The first part of these activities usually asks students to state their position with respect to certain aspect of a phenomenon or a physical system. Often, students are presented with given statements that involve either correct or incorrect predictions with respect to the phenomenon at hand and each statement is clearly articulated so as to facilitate students' confrontation with incorrect reasoning. The presentation of the positions is often embedded in the context of dialogues between (hypothetical) students. After committing themselves to the one side of the argument (which often happens to be false) the students are guided to make observations concerning the phenomenon, which tend to run counter to their position and, hence, induce the need for amendments. The final stage of the activity guides students to reflect on relevant ideas and resolve the inconsistencies. An additional step involves the application of the newly constructed knowledge in unfamiliar context helping students to consolidate and elaborate these ideas.

The POE strategy developed by White and Gunstone (1992) presents students with a specific situation (e.g., a physical system) and asks them to make a prediction about what will happen when the system undergoes a certain change and explain their reasoning. In the next instance, the actual change is being made and students make observations and attempt to reconcile possible conflicts between their prediction and data from observations. The explanation phase serves both as a reflection mechanism (e.g., reflect on the evidence) and as an opportunity to initiate planning for the next steps of the investigation (e.g., design follow-up experiments).

A central place in knowledge development and conceptual understanding and hence in the EPM module is reserved for modelling. Models are common tools used in different situations, for producing deeper understanding of complicated phenomena and understanding the nature of science (Schwarz, 2006). The EPM module gives emphasis on the development, testing and revising of conceptual models. The key models investigated or developed in the teaching/learning sequence are: a) the model for magnetic materials and b) the magnetic field as a model for interpreting interactions at a distance. The activity sequence guides students through the process of developing these models as a means to account for observations and engages them in their application to analyze unknown physical systems.

In recent years, many researchers (Lewis, 2006; Haury, 2002; Kolonder, 2002) have proposed the design process as a way for students to elaborate and develop better understanding of abstract, complex scientific concepts. This method is based on the fact that most important changes in science are attributed to the constantly increasing technological demands in society. Thus, if in real life science and technology go hand-by-hand, in science education this motive should also be followed. As described above, in the EPM module, the construction of the train, the technological design task, was selected as a way of improving understanding for scientific principles by applying the targeted concepts and ideas in an authentic problem solving task and as a way for promoting and developing scientific and technological literacy. The construction of a model based on an authentic problem gives students the opportunity to experience uses of science and test their knowledge discovering gaps and other difficulties. Additionally, the design process is an opportunity for students to unfold their creative and analytical abilities and to develop their social skills, since any authentic problem solving task requires an understanding of the people and their needs.

Even though inquiry has received great attention, the complementary strand, technological design has been often ignored. Science teaching combined with design offers numerous advantages. Examples include (Haury, 2002):

- Approaching science in the context of technology and society
- Bridging the gap between learning and daily life
- Developing students' skills such as critical thinking, problem-solving, decision making, as well as creativity and imagination
- Development of epistemological awareness
- Science is not taught as an independent subject but rather as a subject that at its entirety has numerous ideas embedded from different fields.
- Technological design in schools brings learning closer to the usual context of learning which is on a "need-to-know" basis.

The EPM activity sequence follows a scaffolded scheme. Students work in groups and collaborate to complete the tasks. In the first chapters the tasks are simple and as students progress in the teaching/learning sequence and develop the requisite tools they resolve increasingly complex tasks. Students learn to work by themselves and to trust their decisions (Reigosa, 2007). The module was designed to gradually transfer responsibility to the students. The checkouts points at the end of a series of activities could also be used to offer assistance or guidance to the group and to provide feedback. In the EPM module the tasks satisfy the important elements of successful scaffolding, such as (McKenzie, 2000): a) clear direction and purpose – students know exactly what they are expected to do and this helps to keep them on truck b) reduced risk of disappointment – the activity sequence has been tested and refined to help students resolve their difficulties.

To conclude, the aim of the EPM activity sequence is to create the conditions for students to understand magnetism and electromagnetism key concepts but more importantly to lead them in the path of lifelong learning and also to realize the relationship between the close fields of science and technology.

7. RELEVANT ICT TOOLS

The advent of computers has brought about tools that can potentially contribute to the enhancement of the science learning environment (Fishman, 2004; Krajcik 2002; Linn 2004; Wang & Holthaus 1997; European Commission, 2000; NRC, 1996). The EPM module sought to take advantage of the capabilities provided by ICT tools in two main ways. The first involved the use of a simulation tool, originally designed by Colorado University under the PhET project, to facilitate students' understanding of the abstract idea of the magnetic field. This simulation acquainted students with the opportunity to visualize the imaginary field lines using a compass and also provided them with instruments which they could use to measure the intensity of the field. In the case of the electromagnetism section this simulation allowed students to visualise the magnetic field created by a coil and also to "observe" the movement of the electrons inside the coil that causes the magnetic field. Two additional ways in which students could interact with the simulation involved the ability to switch between DC and AC current and "observe" the corresponding change in the direction of the magnetic field. At this point it should be stressed that students' interaction with the simulated environment was surrounded by activities so as to help them make productive use of the software. In addition to this, special care was taken to avoid possible misinterpretations on the part of the students owing to the simplified nature of the model that was used (e.g., imaginary field lines).

The second type of ICT tool that was employed involved data loggers. Specifically, students used a magnetic field sensor (PASCO CI-6520A Magnetic Field Sensor) to measure the intensity of the magnetic field in different parts of a horse-shoe magnet and shaded the different areas accordingly. The Magnetic Field Sensor is used in conjunction with a PASCO computer interface using *Science Workshop* software version 2.3 or newer edition, or Data Studio. As the name implies the Magnetic Field Sensor detects Magnetic fields. It has three, switch selectable, ranges: 100X (±10 gauss), 10X (±100 gauss) and 1X (±1000 gauss). The three ranges allow magnetic fields such as the earth's magnetic field, fields created by electrical coils or fields around permanent magnets to be measured. The sensor was also used during the construction of the train to facilitate the selection of appropriate materials to be used for magnetic shielding. Specifically, they used the sensor to measure the reduction of the magnetic field caused by the shielding material they selected.

8. COMMON STUDENT DIFFICULTIES

During the last 20 years, science education researchers have documented students' difficulties concerning magnetism and electromagnetism. Common misconceptions that have been reported include that magnets only attract, magnets attract all metals and repel non metals, magnetic fields are two dimensional, etc. In the following paragraphs we present the more complex misconceptions and conceptual difficulties as these are reported in the science education research literature. Given that the EPM module is constrained at a qualitative conceptual level of analysis the following review has been specifically focused on students' difficulties with respect to the relevant concepts and conceptual models rather than the corresponding mathematical equations and symbols (Sung, 2003; Albe, 2001).

There is extensive literature regarding students' misunderstandings with respect to fundamental ideas of Magnetism & Electromagnetism. One of the most important misconceptions that have been reported relates to students' failure to effectively differentiate between the electric and the magnetic fields. This difficulty is evident, for example, in students' tendency to conceive the North(N) and South(S) pole as being positively and negatively charged (or acting as being positively and negatively charged), respectively (Maloney, 2001). Similar results have been also obtained from the administration of assessment tasks to university students who were pursuing a degree in science. For example, Guisasola (2003) administered assessment tasks to University Physics and Engineering students and also to high school students and the results that emerged suggested that participants often identified magnets with charged bodies and conceived of the positive charges as being concentrated on the North pole and the negative charges on the South pole.

Another study exposes the problems students face with the meaning and interpretation of the terms *magnetic flux* density and magnetisation. The assessment instrument used in this case was a multiple choice test filled by undergraduate students pursuing a degree in Physics (Tanel, 2008). Even though the majority of students answered that the magnetic properties of a magnet depend on the number of atoms having net magnetic moments in the same direction, in a following question, 20% of these students stated that the size of the magnet affects its magnetic force (bigger magnet ⇒stronger magnetic force). Furthermore, half of the students failed to recognise that the shape of the poles affects the density of the field lines and the magnetic flux density. The study also included items regarding ferromagnetic, paramagnetic and diamagnetic materials (Tanel, 2008; Rudowicz, 2003). A significant number of students seemed confused with respect to the properties of materials representing each of these categories and held the belief that all metals interact with magnets in the same way. An additional misleading idea that was reported relates to students' belief that that magnetisation posits physical contact. This shows lack of understanding of magnetic field as a model for interpreting interactions at a distance. Finally, another notable misconception relates to the idea that the magnetic field lines are interrupted by matter (Tanel, 2008; Saglam, 2006).

Another study that has explored the understanding of first year university students on key ideas regarding electromagnetism led to interesting findings on students' difficulties. The researchers (Saglam, 2006; Albe, 2001) found that although students could easily state the formula for magnetic flux most of them were not able to explicate its meaning or effectively use it to address simple, unknown, problems.

Saarelaimen (2006) in his study revealed students' difficulties with respect to the magnetic field of a current carrying wire. The items that were used in this respect pertained to the right hand rule, the vector character of the field and superposition of fields. Even though most of the students that participated in the study were able to formulate the right-hand rule their majority did not seem to posses a functional understanding of its essence. Specifically, when they were asked to draw the field most of them restricted themselves to only drawing a few circles close to the wire while one of the students drew a spiral magnetic field. In addition to this, some students failed to identify the direction of the field and others conceived of the curly fingers as the magnetic force. Most importantly, all students failed to define the direction of a combined field consisting of two wires.

Generally, existing research reveals four main difficulties with respect to electromagnetism (Saglam, 2006; Raduta, 2005):

- an over-literal flow interpretation of magnetic field lines;
- confusion between the rate at which a variable (such as, magnetic flux) changes with the change per se;
- difficulties regarding the direction of the Lorenz force and the application of the right-hand rule.

The study revealed some interesting results demonstrating students' misconceptions regarding electromagnetism. In an assessment task that asked students to summarise the key concepts of electromagnetism and to rank them according to their relative importance, a significantly high percentage ranked Ohm's law in the first place whereas only an extremely low percentage gave the first place to Maxwell's equations. The conclusion of the study was in the same line as other studies stating that students' understanding was "fragmented and applied inconsistently" (Saglem, 2006).

Tanel & Erol (2008) attributed students' difficulty regarding the magnetic field strength (H), magnetic flux density (B) and magnetization (M) to the inconsistent presentation of these topics in many text books. The problem emerges from a disagreement about which the derived field is. The most acceptable presentations and interpretations are by: a) W. Thomson who gives both concepts (B& H) an equal status as field intensities acting on different elements of the medium, b) Faraday and Maxwell supporting that H is the primary magnetic field that causes B field in magnetized materials and c) Lorentz accepting B as the average of microfields and primary magnetic field and H as the derived field.

Students, also face difficulties in explaining induction phenomena. In a closed loop circuit consisting of a bar magnet and bulb, students were asked to describe under which circumstances the bulb will glow. Even though, the results included a few correct answers the explanations showed that they were guesses or a combination of wrong ideas that incidentally led to a correct answer (Saarelainen, 2006).

Electromagnetism is a complicated subject that combines many different concepts such as force, velocity, electric current, magnetic field. Thus, in addition to the various difficulties that students often encounter with respect to each of these individual concepts, an additional source of complexity derives from the need to coordinate them and integrate them into a coherent whole. The failure of conventional science teaching to help students emerge with such a coherent framework could account for students' inability to analyze the mechanism underlying the operation of relevant, unknown, phenomena and physical systems.

9. MONITORING STUDENT LEARNING

The learning progress of the students is assessed with pre- and post tests for each unit of the inquiry-based part (Unit 1-4) of the activity sequence. Pre- and post-tests consist of open-ended tasks intended to assess the extent to which the corresponding learning objectives have been attained. These provide an indication of the effectiveness of the activity sequence and also provide feedback that guides the refinement process of the module. The tasks usually present students with novel situations in which they have to apply concepts and ideas to analyze physical systems they had not discussed during the implementation of the activity sequence. The ability to effectively transfer concepts and ideas provides a reliable indication of functional conceptual understanding.

In the second part of the module, students (working in groups) design and development their own train models; these artefacts are another form of assessment. The design project posits the application of concepts and ideas that were elaborated in the first section of the module (inquiry-based activities concerning magnetism and electromagnetism). In addition to the construction of the train model each group also has to prepare a poster to describe the key stages of the design process. The train and the corresponding poster are presented by the various groups at the concluding part of the module. Furthermore, the student activity booklet includes short questions for scaffolding the design process for the development of the train model. Students' responses to these questions serve as an additional data source concerning students' ability to transfer the concepts and ideas they have been previously presented with. The final unit of the module is devoted to the interrelationship between science & technology. Moreover, throughout the module, activities have been added to help students comprehend the main differences of these fields. Students' learning gains with respect to this idea are assessed through pre- and post-tests administered at the beginning (before Unit 2) and at the final unit of the module (right after 6.1.2). The tests assess students understanding for the different goals and central processes of these fields. Also, a representative sample of students is selected for structured interviews aiming at gathering additional insights. The combination of the assessment tools (pre- & post-tests, interviews, posters and train models) provide enough evidence concerning student learning development and for evaluating the teaching/learning sequence.

In addition to students' gains with respect to the targeted learning objectives we also collect data on students' interest and motivation towards science and inquiry. Towards this end we use two different questionnaires. The first (Questionnaire 1) is administered before and after the implementation of the module and it consists of likert-scale items revolving around students' academic motivation for learning science. Based on the quantitative analysis of data students are clustered in categories (e.g., intrinsically and extrinsically motivated and a-motivated) and a representative sample of students in each category participates in semi-structured interviews after the completion of the module. The second questionnaire (Questionnaires 2) is administered once, prior to the implementation, and students have to respond having in mind a typical science activity from the school curriculum, and again after carrying out specific, predetermined, activities from the EPM module. This questionnaire comprises of likert-scale items that refer to students' interest in the specific (or similar type) activity. The data that emerges from students' responses to these items allows assessing for possible variations in students' interest as a result of their engagement with these activities. All the motivation evaluation tools are included in Part D.

10. OTHER USEFUL INFORMATION

10.1. INFORMATION ABOUT MAGNETS

The magnets must be checked before the students start using them. Over time, a magnet may develop multiple sets of poles. Also, certain pole configurations may confuse students. The poles of a magnet can be checked with a small compass. Be sure for chapter 1 and 2 to select bar magnets that their poles are located at the ends.

Students should be careful to keep the magnets away from computers, computer screens, credit cards, computer disks, etc.

Checkout points are to ensure that the students have developed conceptual understanding. A checkout should include questions and experiments intended to elicit incorrect student beliefs.

10.2. ADDITIONAL TEACHING RESOURCES

W. M. Saslow (2002) Electricity, Magnetism, and Light, Academic Press

Edward P. Furlani, (2001) Permanent Magnet and Electromechanical Devices: Materials, Analysis and Applications, Academic Press Series in Electromagnetism

Durney, Carl H. and Johnson, Curtis C. (1969) Introduction to modern electromagnetics, McGraw-Hill

Rao, Nannapaneni N. (1994) Elements of engineering electromagnetics (4th ed.). Prentice Hall

Griffiths, David J. (1999). Introduction to Electrodynamics (3rd ed.). Prentice Hall

Jackson, John D. (1999). Classical Electrodynamics (3rd ed.). Wiley

Tipler, Paul (2004). Physics for Scientists and Engineers: Electricity, Magnetism, Light, and Elementary Modern Physics (5th ed.), W. H. Freeman

Arageorgis, A., & Baltas, A. (1989) Demarcating technology from science: Problems and problem solving in technology, Journal for General Philosophy of Science, 20(2), 212-229

Custer, R. L. (1995) Examining the dimensions of technology. International Journal of Technology and Design Education, 5(3), 219-244

Gardner, P. L. (1993) Textbook representations of science-technology relationships, Research in Science Education, 23, 85-94.

Gardner, P. L. (1994). The relationship between technology and science: Some historical and philosophical reflections Part I, International Journal of Technology and Design Education, 4(2), 123-153.

11. REFERENCES

Albe V., Venturini, P., and Lascours, J. (2001) Electromagnetic Concepts in Mathematical Representation of Physics, Journal of Science Education & Technology, 10 (2), p. 197-203.

Agassi, J. (1980) Between science and technology, Philosophy of Science, 47(1), p. 82–99.

Arageorgis, A., Baltas, A. (1989) Demarcating technology from science: Problems and problem solving in technology, Journal for General Philosophy of Science, 20(2), p. 212–229.

Chabay R. and Sherwood B. (2006). Restructuring the introductory electricity and magnetism course. American Journal of Physics, 74 (4), 329 – 336.

Chinn, C.A., Malhotra, B.A., (2002) Epistemologically Authentic Inquiry in Schools: A theoretical Framework for Evaluating Inquiry tasks, Wiley Periodicals

Constantinou C. P. (1999) The Cocoa Microworld as an environment for modeling physical phenomena. International Journal of Continuing Education and Life-Long Learning, 9, 201-213.

Constantinou, C.P., Hadjilouca, R. Papadouris, N. (2009) Student's Epistemological Awareness concerning the distinction between Science & Technology, International journal of Science Education, 32 (2), 143-172.

Crawford B. & Cullin M. (2004). Supporting prospective teachers' conceptions of modeling in science. International Journal of Science Education, 26 (11), 1379-1401.

Demirci, N., (2005) University Students' conceptual difficulties about electricity and magnetism concepts

European Commission (2000). Science policies in the European Union: Promoting excellence through mainstreaming gender equality, ETAN Expert Working Group on Women and Science, Brussels

Fishman, B., Marx, R., Blumenfeld, P., Krajcik, J. S., & Soloway, E. (2004). Creating a framework for research on systematic technology innovations. Journal of the Learning Sciences, 13 (1), 43 – 76.

Gotwals, A.W., Songer, N.B. (2006) Measuring students' scientific concept and inquiry reasoning, International Conference of the Learning Sciences, p. 196-202.

Guisola, J., Almudi, J.M., Zubimendi, J.L., (2004) Difficulties in Learning the Introductory Magnetic Field Theory in the First Years of University, Wiley Periodicals.

Halloun, I. & Hestenes, D. (1987) Modeling instruction in mechanics. American Journal of Physics, 55, 455 – 462.

Harlen, W. (1999). Purposes and procedures for assessing science process skills. Assessment in Education: Principles, Policy and Practice, 6 (1), 129 – 144.

Harlen, W. (2000). Teaching, learning and assessing science 5-12 (3rd ed.) London: Paul Chapman.

Haury, D.L., (2002) Learning Science through Design, Educational Resources information Center, accessed Nov 8, 2008, http://df1d1f2be44ed1b00cfcf7d0e4f3861f9706d381.gripelements.com/pdf/science_design.pdf

Heron, P.L., Shaffer, P.S., & McDermott, L.C. (2009) Identifying and addressing student conceptual difficulties: an example from introductory physics, accessed Nov 08, 2008, http://www7.nationalacademies.org/bose/Heron_CommissionedPaper.pdf

Hestenes D. (1992). Modeling games in the Newtonian World. American Journal of Physics, 60, 732 - 748.

Hestenes, D. (1997) Modeling methodology for physics teachers. In The changing role of physics departments in modern universities: Proceedings of International Conference on Undergraduate Physics Education (eds E.F. Redish & J.S. Ridgen), pp. 935 – 957. The American Institute of Physics, NY.

Kearney, M., Treagust, D.F. (2000) An investigation of the classroom use of prediction-observation-explanation computer tasks designed to elicit and promote students' conceptions of force and motion, Paper presented at the National Association for Research in Science Teaching meeting.

Kolodner, L.J., (2002) Facilitating the learning of Design Practices: Lessons learned from an Inquiry into Science Education, J. of Industrial Teacher Education, 39 (3), p.9-40.

Krajcik, J. S. (2002). The value and challenges of using learning technologies to support students in learning science. Research in Science Education, 25, 727 – 758.

Lewis, T. (2006) Design and Inquiry: Bases for an accommodation between Science and Technology Education in the Curriculum?, Journal of Research in Science Teaching, 43(3), p. 255-281

Linn, M. (2004). Using ICT to teach and learn science. In R. H. E. Scanlon (Ed.), Mediating science learning through information and communications technology (pp. 9 – 26). New York: Taylor & Francis.

Maloney D. P., Hieggelke C. J. & Van Heuvelen A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. American Journal of Physics Supplement, 69 (7), S12 – S23.

Magnetically Levitated trains (MagLev), accessed Nov 04, 2008, http://www.123eng.com/seminar/Magnetically%20Levitated%20Trains%20%28Maglev%29.pdf

Mc Dermott, L., (1993) How we teach and how students learn. A mismatch ?, Am. J. Physics, Vol. 61 (4)

Mc Dermott, L., Redish, E.F. (1999) Resource Letter on Physics Education Research -1: Physics Education Research, American Journal of Physics, 67, 755-767.

National Research Council (1996).

McKenzie, J. (2000). Scaffolding for Success, Beyond Technology, Questioning, Research and the Information Literate School Community. Accessed Feb 17, 2009, http://fno.org/dec99/scaffold.html

NRC (National Research Council) (1996) National science education standards, Washington DC, National Academy Press.

Raduta, C., (2005), General Students' Misconceptions related to Electricity and Magnetism, accessed Nov 08, 2008, http://arxiv.org/ftp/physics/papers/0503/0503132.pdf

Reigosa, C., Jimenez-Aleixandre, M., (2007) Scaffolded problem-solving in the Physics and Chemistry Laboratory: Difficulties hindering students' assumption of responsibility, International Journal of Science Education, 29 (3), p. 307-329.

Rudowicz, C., (2003), On the fundamental conceptual problems in magnetism, accessed Jan 30, 2009, http://arxiv.org/ftp/cond-mat/papers/0304/0304099.pdf

Saarelainen, M., Laaksonen, A., and Hirvonen, P.E., (2007) Students' initial knowledge of electric and magnetic fields – more profound explanations and reasoning models for undesired conceptions, European Journal of Physics, 28, p. 51-60.

Saat, M. R. (2004). The acquisition of integrated science process skills in a web-based learning environment. Research in Science and Technological Education, 22 (1), 23 – 40.

Saglam M. & Millar R. (2006). Upper High School Students' Understanding of Electromagnetism. International Journal of Science Education, 28 (5), 543 – 566.

Schwarz C. V. & White B. Y. (2005). Meta-modeling Knowledge: Developing Students' Understanding of Scientific Modeling. Cognition and Instruction, 23 (2), 165 – 205.

Schwarz, C. V., Gwekwerere, Y., N., (2006) Using a guided inquiry and modeling instructional framework to support Preservice K-8 science teaching, published online in Wiley InterScience (www.interscience.wiley.com).

Sung H.W.F., Rudowicz C. (2003). Physics behind the magnetic hysteresis loop—a survey of misconceptions in magnetism literature. Journal of Magnetism and Magnetic Materials, 260, 250–260.

Tanel, Z., Erol, M., (2008), Students' difficulties in understanding the concepts of Magnetic field strength, Magnetic flux density and magnetisation, Lat. Am. J. Physics Education, Vol. 2 (3).

Thong W. M. & Gunstone R. (2007). Some Student Conceptions of Electromagnetic Induction. Research in Science Education.

Walker, M., (2007) Teaching Inquiry based science: a guide for middle and high school teachers.

Wang Yu-mei & Holthaus P. (1997). Student Teachers' Computer Use during Practicum. Proceedings of Selected Research and Development Presentations at the 1997 National Convention of the Association for Educational Communications and Technology.

Warnakulasooriya, R., Bao, L., (2001) Preliminary studies on students' understanding of electricity and magnetism for the development of a modelbased diagnostic instrument.

Wells M., Hestenes D. and Swackhamer G. (1995). A modeling method for high school physics instruction. American Journal of Physics, 63, 606 - 619.

Wikipedia, accessed Dec 10, 2008, http://en.wikipedia.org/wiki/Magnetism

White, R., Gunstone, R., (1992), Probing Understanding, Falmer Press.

B: DESCRIPTION AND ANALYSIS OF TEACHING AND LEARNING ACTIVITIES

B: DESCRIPTION AND ANALYSIS OF TEACHING AND LEARNING ACTIVITIES

UNIT 1: INVESTIGATION WITH MAGNETS

1.1. MAGNETIC INTERACTIONS

In this chapter, students explore the interaction between magnets and other materials. They classify objects into categories according to their magnetic interactions. On the basis of their observations, they develop an operational definition for the term magnet or permanent magnet. The term ferromagnetism is also introduced.

There are subtleties to magnetism that can cause confusion for some students. In this introductory section, an attempt has been made to simplify the ideas. Complexities are examined later as students develop the requisite tools for resolving the issues.

Students often use words which they have not yet defined (e.g., "magnetic pole") or bring up inappropriate terms (e.g., "electric" or "electromagnetic"). Encourage students to regard this module as a context through which they will gain familiarity with magnetic phenomena. They should express their ideas and observations with simple words without using any technical terms.

Equipment:

1.1.1. Two bar magnets without marked poles and a set of various objects including: several magnets of different size and shape, some ferromagnetic objects (e.g. iron, nickel, paper clips), and objects made of non-magnetic materials (e.g., non-magnetic metals, ceramics, glass, wood). The behavior of aluminum nails is often surprising to students.

Discussion of the experiments and exercises:

1.1.1. Students may say that there are only two categories of objects: those that interact with the bar magnets (e.g., other magnets and iron nails) and those that do not. They will not recognize that their observations for the nail and the permanent magnet are different: the nail is always attracted to the magnet. (Few students, on their own will conduct the types of experiments necessary to show there is no repulsion with the nail.) Help them to recognize that their observations suggest at least three categories of objects. Students will refine the classification scheme later in the module, after their model for magnets is sufficiently developed to account for their observations.

Many students will say that they observe that, for two magnets, "like" ends repel and "unlike" ends attract. Help them to recognize that this statement relies on outside knowledge and does not follow from the experiments they have performed. Encourage them to state their observations in simple, everyday terms without inferences as to why the magnets behave as they do.

1.1.2. The operational definition should be a series of steps one would take to identify magnets from other objects. The operational definition given by students should not simply be a statement such as, "A magnet will pick up or attract paper clips." If a student gives such a response, reach over, pick up a paper clip and ask whether you are a magnet. An acceptable operational definition should describe the process in stages, state the observable event(s) and conclusion(s) for each stage followed by the reasoning until the final conclusion has been reached. In the case of an operational definition for a magnet, students should describe the process of testing the different objects to find a set of three objects that interact differently from one another.

1.1.3. Often students will believe that magnets attract ferromagnetic materials, but that the reverse is not true. Students who believe the interaction is one-sided should close their eyes during this experiment.

Typical questions for use during check-out points:

- Which categories of materials did you identify?
- Which criteria do you use for distinguishing each of the materials?
- Why do we use the term "interaction"?

1.2. THE PARTS OF A MAGNET

The students continue their exploration of magnets by investigating how the various portions of a magnet interact magnetically. Based on their observations, the students develop an operational definition for a magnetic pole and examine the prevalence and nature of the poles in a single magnet.

Equipment:

1.2.1. Three bar magnets without labeled poles, several sets of small adhesive colored dots (a set of three or more colors). Prepare a box with 5 "test spots" marked on it. Take an empty small box and stick inside (at each box side) two magnets, one with its north pole and the second with its south pole facing towards the outside of the box, a ferromagnetic object and a non-magnetic material, a total of 5 test spots at each box. Preferably include two ferromagnetic materials instead of two non-magnetic materials.

1.2.2. Magnets with ends marked from the previous experiment

1.2.3. Magnets of various shapes (e.g., horseshoe, thin round disks and hoops)

Discussion of the experiments and exercises:

1.2.1. In this exercise, students develop a procedure by which to determine the "like" and "unlike" ends of several magnets. Most students "know" that there are only two types of magnetic "ends" and thus will find part C very difficult. Few will have previously recognized that the process of scientific inquiry often does not yield definite answers - even to such apparently simple questions as "How many types of magnetic poles are there?"

Students develop the rule for the interaction of "like" and "unlike" magnet ends. They also determine to which of the three categories from Experiment 1.1 each of the test spots on their box belongs.

1.2.2. In this experiment, students examine in detail the interaction of various portions of a bar magnet with ferromagnetic materials and with other magnets. This experiment sets the stage for introducing the idea of magnetic poles.

1.2.3. In this exercise, students infer a general rule for the number and types of poles in a single magnet. Some students may find magnets that appear to have 3 poles (e.g., two north poles at the ends and 1 south pole in the center). In this case, ask the students to consider what would happen if they were to glue two magnets together with the like poles in contact. Would they say that the magnet has only 3 poles or that it has 4 poles, two of which are spaced very closely together?

Typical questions for use during check-out points:

- How many different kinds of poles did you identify?
- How does each kind of poles interact with each other?
- How could somebody locate the poles of a magnet?

1.3. THE EARTH AS A MAGNET

Students make observations of the orientation of magnets suspended from strings. Their results are used as the basis to introduce a model in which the Earth acts like a large magnet. The terms north and south are introduced for the poles of a magnet based on the convention that the end that points towards the geographic North Pole (when the magnets are allowed to rotate freely) is called the north seeking pole and is named north pole of the magnet. The opposite end is the south seeking end thus the south pole of the magnet. Compasses are also introduced.

Equipment:

1.3.1. String, piece of paper, tape, several unlabeled long cylindrical or bar magnets

1.3.2. Several small compasses

Optional: Globe with north and south magnetic poles marked

Discussion of the experiments and exercises:

1.3.1. In this experiment, students explore the behavior of magnets suspended by strings so that they are free to rotate. They make an analogy between this situation and that of a small magnet suspended above a large magnet to develop a model for the magnetic properties of the Earth. This is not always straightforward because not all students are able to realize the association between Earth and the large magnet stabilized on the table. Try with questions like: “How is the suspended magnet affected by the stabilized one?” and “What do you think is orienting the suspended in the room magnets?”

1.3.2. Students are introduced to the standard convention for labeling the poles of a magnet and decide on the basis of their experience whether the north geographic pole of the earth is a north or a south magnetic pole. Many students are surprised by their conclusions. The phrase that “the north pole is a south magnetic pole” will be a continuing problem for many students. Be sure that all the students have gone through the reasoning leading to that conclusion and are not relying on a partner for the answer.

The compass is introduced and students explore its use. They make observations that lead them to recognize that a compass needle is a weak magnet.

Typical questions for use during check-out points:

- Why is the north pole of a compass directed towards the geographic North?

1.4. COMPARING THE STRENGTH OF MAGNETS

Students develop a method for comparing the strength of magnets. The chapter also deals with a general students’ misconception that the size of the magnet affects its magnetic “strength”.

Equipment:

1.4.2. Several unlabeled magnets of various sizes, shapes and strengths, several compasses and paper clips

Discussion of the experiments and exercises:

1.4.1. Students develop a method for measuring the strength of a magnet. Various methods are possible. Some students will select to check how many paper clips can a magnet hold, other students will measure the distance from where the magnet attracts a paper clip at rest on a table and others prepare chains of paper clips and check which magnet is going to hold the longest chain.

Some students might become frustrated when their measurements are slightly different each time they perform the experiment.

1.4.2. Students compare the strength of several magnets to overcome the belief that the size affects the strength of a magnet. You have to provide the students with a couple of small magnets that are stronger than the larger ones.

Typical questions for use during check-out points:

- What procedures did you think of for measuring the strength of a magnet?
- Does the size of a magnet affect its magnetic strength?

UNIT 2: MAGNETIC INTERACTION AT A DISTANCE

2.1. MAGNETIC FIELDS

Students explore the region around a magnet with a compass and iron filings. These activities provide the foundations for the introduction of the magnetic field concept as a model for explaining interactions at a distance. They repeat the procedure for two magnets placed near one another and recognize how the effects of the two magnets add.

Equipment:

2.1.1. A bar magnet, a plastic bag, large sheets of paper, and iron filings

2.1.2. A small compass, a bar magnet and large sheets of paper (butcher block paper works well)

2.1.3. Two bar magnets and a small compass or iron filings

2.1.4. Several magnets that are not bar magnets and iron filings

2.1.5. Pasco interface, Pasco magnetic field sensor

Discussion of the experiments and exercises:

2.1.1. Students make an iron filing pattern for a single magnet. They should recognize that the regions in which the interaction between the magnet and the filings is strongest is near the ends of the magnet.

2.1.2. Students draw magnetic lines using a compass and should develop some of the standard rules for drawing magnetic field lines. In 2.1.2A, some students may have difficulty in understanding that all field lines of a single magnet return to the magnet. In this case ask them to consider Experiment 2.1.1 again. Some students might choose a line that seems to leave the magnet's pole following a straight path. Ask them what they would have gotten if they had used a smaller piece of paper or a larger piece of paper. You might also ask them to repeat the experiment using a magnet with a different shape (e.g., a horseshoe magnet).

Students who have difficulty in answering 2.1.2C should be reminded of the method that they used to draw the field lines.

Also, students should be able to understand that there is nothing special on the lines and that the effect is taking place all over the space around the magnet.

At the end of the whole activity students are asked to discuss and agree on what they think that the goal of science is and reflect on why the magnetic field is an important concept for science. Through a follow-up discussion of each group with the teacher, students are guided through examples of their own goals so far (e.g., we try to explain how magnets interact with various materials), as well as research goals in other scientific contexts (e.g., we are interested in understanding how tsunami waves are created, we want to explain how the influenza virus grows when it affects an organism), in order to generalize the main goal of science as an attempt of producing explanations for natural phenomena.

While running the simulation, students observe how the direction and the magnitude of the field alter around a magnet. Comparing these measurements with their observations at the experiment 1.2.2, they should be able to relate the strength of different parts of a magnet with the form and intensity of its magnetic field.

2.1.3. Students begin to develop the idea of superposition in this experiment. First the students observe how a compass needle behaves near two magnets of equal strengths and equal distances from the compass. This is accomplished by looking at the effect of each magnet individually on the compass needle and then together. Then one of the magnets is moved further from the compass and the new total direction is noted.

2.1.4. Students explore the magnetic fields of various shape magnets.

2.1.5. Students make measurements of the magnetic field around a magnet using the PASCO magnetic field sensor. The aim is to get familiar with the sensor and the Datastudio software. Throughout the activity, students are expected to familiarize themselves with the procedure for (i) making measurements, (ii) zeroing the device so as to eliminate the earth's magnetic field, and (iii) changing the accuracy scale.

Typical questions for use during check-out points:

- What information concerning the magnetic field can we extract by observing the magnetic field lines of a magnet? (direction, intensity)
- When two magnets are brought close to each other, is it possible for their magnetic field lines to intercross? (superposition)

UNIT 3: A MODEL FOR MAGNETIC MATERIALS

3.1. BREAKING AND STACKING MAGNETS

Students observe that several magnets put together have the same characteristics as a single magnet. The observations made in this unit suggest possible ways of making stronger and weaker large magnets out of small magnets. The results of this unit lay the groundwork for the development of a model for magnetism.

Equipment:

3.1.1. Set of small rectangular magnets that can be assembled into a magnetic "stack," paper clips and compasses

3.1.2. Magnets from preceding experiment and compasses

3.1.3. Magnets from the preceding experiments and two bar magnets, Pasco interface, Pasco magnetic field sensor

Discussion of the experiments and exercises:

3.1.1. Students examine a stack of small identical magnets and compare the magnetic behavior of the stack with that of a bar magnet. Through the use of a compass, students should detect that the stack has also two poles and that the magnetic field around it is similar to the one around a bar magnet.

3.1.2. Students "break" a magnet (a magnetic stack) and examine qualitatively the properties of the parts. The aim is to understand that each part, which in fact is a small magnet, has poles at its ends, but they are not evident when each part is jointly connected to form the stack.

3.1.3. Often students will regard their results in this experiment with suspicion. Many will look for a "trick." Some will hold very strongly to their intuitive idea that placing magnets end-to-end will result in a much stronger magnet and that its strength will be analogous to the number of magnets consisting the stack.

Typical questions for use during check-out points:

- Can we consider a stack of magnets as a bar magnet?
- Why is it important to keep constant the distance from which measurements are taken in experiment 3.1.3?

- The results were the same with what you expected to find? If no, what was different?
- How much was the percentage increase of intensity when you added the second magnet? Do you think that the increase of the intensity will be the same when placing end-to-end a bar magnet to another? Explain your reasoning. (Ask students to make a hypothesis and then to test it. Then ask them to explain the result.)

3.2. A MODEL FOR MAGNETIC MATERIALS

In this chapter, students tie together their observations and conclusions from the entire module in order to build a model for magnetic materials. Additional activities and questions are included to help them account for the various phenomena. The term ferromagnetic is refined further.

Equipment:

3.2.1. Several small magnets that can be formed into a stack

3.2.2. Several small rectangular magnets that can be formed into a stack and several small compasses

3.2.3. A bar magnet and several small compasses

3.2.5. A bar magnet, a similarly sized ferromagnetic bar that is not magnetized, iron filings

3.2.8. Two small plastic pieces, tape, a strong disk-shape magnet, paper clips and some small sheets of several materials including iron, plastic, copper, aluminum, stainless-steel etc.

Discussion of the experiments and exercises:

3.2.1. Students should begin to consider that all magnets are made up of smaller magnets. And that the alignment of the smaller pieces is what determines the strength of the magnets. While trying different alignments with pairs of magnets, they should conclude that placing magnets with their unlike poles pointing to the same direction, results to stronger magnetic stacks.

3.2.2. Using the magnetic stack from 3.1 students check the behavior of the compass "inside" the stack. Although their experiment yields an answer, students should recognize that they have not yet come up with a definitive answer to the question of the field inside a magnet. This question is revisited in the following unit dealing with Electromagnets.

3.2.3. This experiment should reinforce the idea that ferromagnetic objects are also made up of smaller magnets. And that they are free to rotate when exposed to different fields.

3.2.4. In this experiment the idea of the previous experiment should be used to help students extend the model of magnetic domains presented in 3.2.1 in order to explain the behavior of ferromagnetic materials. A misunderstanding that might appear relates to the notion that tiny magnets exist inside a ferromagnetic material, which are able to rotate. This notion indicates that students fail to understand that a ferromagnetic material consists of magnetic domains. Their experience of magnets placed in stack with various orientations should be reminded.

At the end of the activity students are asked to reflect and discuss on how invented ideas like the model for magnetic materials relate to the goal of science. Students are expected to think again that the main goal of science relates to the attempt to produce knowledge about how nature functions. Consequently, ideas such as the "model for magnetic materials" they have developed, are useful in science because they serve towards explaining as well as predicting how various materials get magnetized and interact.

3.2.5. Students should discuss the model for magnetic materials in the context of several observations they have made throughout the module.

3.2.6. Ferromagnetic materials affect the form of the magnetic field, they alter the direction of the magnetic field lines in order to pass through the ferromagnetic material.

3.2.7. Extends the model to even more sophisticated observations.

3.2.8. Use of the model to explain magnetization and demagnetization phenomena.

Typical questions for use during check-out points:

- What are the similarities and differences between ferromagnetic materials and magnets?
- Could you explain now your measurements in experiment 3.1.3?

UNIT 4: INVESTIGATIONS WITH ELECTROMAGNETS

4.1. MAGNETIC FIELD OF A CURRENT-CARRYING WIRE

Students should be aware that an electric current creates magnetic field and that the magnetic lines form circles around a current-carrying wire.

Equipment:

4.1.1. Ring stand, clamp, piece of cardboard, fresh battery, connecting wire, a switch, and several compasses

4.1.2. Equipment from the preceding experiment

Discussion of the experiments and exercises:

4.1.1. Students explore the magnetic field of a current-carrying wire by looking at the pattern obtained by several compasses near the wire. In this and the rest of the experiments involving the magnetic field of current-carrying wires students may have difficulty determining the field for several reasons. One could ask students what the effect of the earth's field has on the pattern they are seeing

4.1.2. Students are asked to design an experiment to investigate the magnetic field of a current-carrying wire in three dimensions. Ideally students will design their experiment rotating the wire so that is horizontal rather than rotating the compass. The compass must then be placed either on top of or underneath the wire. The students should find that the field does not wind like a helix about the wire but is circles around the wire in perpendicular planes since there is no component of the magnetic field parallel to the wire.

Typical questions for use during check-out points:

- What do you think causes the magnetic field around the wire?
- Did you identify any magnetic poles around the wire?
- How does the direction of the compasses relate with the direction of the current flow? (the right hand rule can be introduced here after the discussion)

4.2. MAKING MAGNETS WITH A CURRENT-CARRYING WIRE

Students discover that when a wire is shaped into a coil the magnetic field looks just like the magnetic field of a bar magnet. The students confirm this by making a nail into a very strong magnet when it is placed inside a current-carrying coil. In the final part of this chapter, students discover how is it possible to move a permanent magnet using electromagnets.

Equipment:

4.2.1. Ring stand, clamp, piece of cardboard, a fresh battery, connecting wire, a switch, and several compasses

4.2.2. A fresh battery, a switch, connecting wire, an iron nail, and paper clips

4.2.3 Connecting wire, a fresh battery, a switch, a small disk-shape magnet, a piece of wood or polystyrene

Discussion of the experiments and exercises:

4.2.1. Students explore the field of a coiled wire using a set up similar to that of Experiment 4.1.1 Students are asked to look at the field of a long coil of wire when there is current passing through it. Students should recognize that the field of the coil is very similar to that of a bar magnet. The students are led to consider the coil as a bar magnet and are asked to identify the north and south end of it.

4.2.2. Students build an electromagnet out of an iron nail. They should observe that the nail is a very strong magnet when there is current flowing and that the poles of the magnet are where they were for the current loops from Experiment 4.2.1. In addition, the students may find that the nail remains somewhat magnetized even after the current is turned off. Students should be asked to account for this observation by considering how magnets were made in chapter 3.2 and relate that to the field they observed for the current loops around the nail.

The more sophisticated students may use their model for magnetic materials developed in chapter 3.2 to explain their observations. These students may recognize that when there is current flow, the little magnets that make up the iron rod will align with the magnetic field to make it a very strong magnet. In order to get such a strong magnet, the students may recognize that this orientation of the smaller magnets is not stable. So when the current is turned off, some of the smaller magnets that make up the iron rod will flip to a more stable configuration. This leaves the iron nail much weaker than before, but still behaving like a magnet overall. Experiment 3.2.2.D aims to help students realize that the polarity of the electromagnet depends on the direction that the current spins around its core rather than on the side of the battery that is connected to.

4.2.3. Using the model that a wire coil has a field similar to that of a bar magnet with a north and a south pole, students observe the behavior of a magnet near the coils. On the basis of their observations, students are introduced to the idea of moving a permanent magnet using alternating magnetic fields.

Typical questions for use during check-out points:

- Why does the nail become a magnet?
- How is this explained with the model for magnetic materials?
- How does the polarity of the electromagnet relate to the direction of the current flow? (the right hand rule can be introduced here after the discussion)

4.3. INVESTIGATION WITH ELECTROMAGNETS

Students investigate different variables and identify which ones influence the strength of an electromagnet. The final activity of the unit introduces investigation as the core process in science.

Equipment:

4.3.2 Batteries, wire, nail, pencil, paper clips

Discussion of the experiments and exercises:

4.3.1. Students are asked to choose among two predictions made by others. There is no need to provide a correct response to this question for the moment.

4.3.2. Students are asked to predict which variables affect the strength of an electromagnet and to describe an experiment to test one of these.

4.3.3. Students should be able to formulate the investigative question and to understand that when they test one variable, they have to keep all the others constant. You might give some examples in order to make this idea more comprehensible.

4.3.4. Students are expected to describe the way that they will follow for testing the chosen variable (4.3.3). They should state explicitly which variable are going to vary, the variables that will keep constant and the variable that will measure.

4.3.5. Students should carry out the experiment as they described it previously. They should be supervised in order to keep the other variables constant in practice. A common mistake is to take measurements using the same nail, ignoring its magnetization from the previous use. They should be promoted to use identical nails for different measurements.

4.3.6. The experimental design proposed by a group of students is given to the rest of the groups and students are asked to check whether all the variables except the one under investigation were kept constant.

4.3.7. Students decide which new variable are going to measure and how.

4.3.8. They carry out the experiment and conclude which variables affect the strength of an electromagnet. To do so, they need to ask for information about the parameters that other teams have checked. The reliability of this information should be discussed.

4.3.9. The last question targets at connecting the process of investigation as a control of variables procedure, which is central for achieving the main goal of science. Students should discuss the idea that investigation produces reliable knowledge about causal relations between variables included in a natural phenomenon.

Typical questions for use during check-out points:

- Pose questions to verify that the investigation process is well understood by each student.
- Discuss with students whether the conclusions revealed from the investigation (4.3.6) are reliable or not. In doing this, prompt students to focus on the controlled variables that were taken into account for the design and implementation of their own valid experiments.
- The conclusions you've reached through your investigations, what do they refer to?
- How does this type of conclusions help in attaining the main goal of science?
- How do you know that your conclusions are reliable? What process did you follow?

UNIT 5: TECHNOLOGY PROJECT: DESIGN AND CONSTRUCTION OF A MAGNETIC LEVITATION TRAIN

Science and Technology represent two closely linked domains of human activity, which are strongly interdependent. Despite this strong connection, they are clearly discernible fields, in that they serve entirely different social purposes. Science aims at producing reliable knowledge about how systems function; technology seeks to generate solutions to problems encountered by society or to develop processes or products that address human needs. Investigation is a core process in science; design is a core process in technology. The properties of materials and their influence on the material selection process for various applications offer a rich context for epistemologically rich discussions on the interconnections between science and technology and their role in modern society.

In the previous units of the activity sequence, students became familiar with the goal and the central process of Science. On the other hand, in this unit students follow the design process er to solve a given social problem. Students have to produce a working train model. The provided diagram at the beginning of the unit depicts the technological design process. Discuss the importance of following these steps.

5.1. DESIGN AND CONSTRUCTION OF A MAGNETIC LEVITATION TRAIN

5.1.1. **Problem:** The context of the technology project is given along with a general description of what students are expected to do. Also, the specifications that the train should fulfil are presented. Make sure that students understand these specifications.

The question that follows intends to recall the goal of science so that students become explicitly aware of the fact that their goal concerning the development of magnetic levitation train is not aligned with the goal of science.

5.1.2. **Collection of information:** Ask students to search for information in the internet or bibliography (e.g., books, journals, etc). Prompt students to focus their research on finding useful information about the mechanisms (functions).

5.1.3. **Initial ideas:** Students should present here their initial ideas of how they intend to solve the problem. Ask them to check whether the initial ideas they have proposed fulfil the specifications set previously.

5.1.4. **Development of the best idea – Construction designs:** At this stage, students should select the best idea for implementation. Students evaluate their designs with guidance from the teacher. They are expected to describe and explain how the mechanisms related to the train specifications function and draw orthographical projections of the train model. The designs must include dimensions and the type of materials that will be used for each part of the train.

5.1.5. **Scientific goal or other type of goal?** Examples of research at different areas are given and students are asked to decide for every goal whether it is aligned with the goal of science or not. Make sure that they use a common criterion. This is intended to lead to the generation of the common characteristic of the goal, i.e., researchers of the cases categorised in group B are trying to find solution to human problems. If students have difficulty in identifying this similarity, the teacher should mention some additional examples that are categorised in group B (e.g., We try to make better building materials that are antiseismic, Many electrical appliances emit great amounts of radiation while operating and this might cause health problems, we try to develop an instrument that measures the amount of radiation emitted by these appliances). At the end of the discussion, the teacher explicitly explains that the main difference between science and technology is their goals.

5.1.6. **Construction:** The questions of this paragraph aim to help students reflect on the construction process and, also, to collect information from the preceding activities for solving any problems that might appear. Prompt students to seek information about the propulsion mechanism in the activities of Unit 4, and about magnetic shielding in activity 3.2.6.

An anticipated example of what students could design and construct concerning the mechanisms that a model of a magnetic train should fulfil is described below:

The basic idea for electromagnetic propulsion is to have an array of electromagnets that are placed in a way that the distance between each of them is exactly the same (2cm) their wires are connected in row with a frequency generator. The core of the electromagnets might be an iron nail fixed on a piece of wood or polystyrene (see Picture 1). The length of the wire that is wrapped around the core of each electromagnet, as well as the way that is wrapped around the core should be identical for all cases. Please note that in order to make a strong electromagnet, you should choose a wire that is as thick as possible.

FIGURE 8: A DEMONSTRATION OF THE ARRANGEMENT OF THE ELECTROMAGNETS

The electromagnets are connected in such a way that the polarity of the pole on the top of each electromagnet is opposite than the pole on the top of the next one, at each moment of time (see Figure 1).

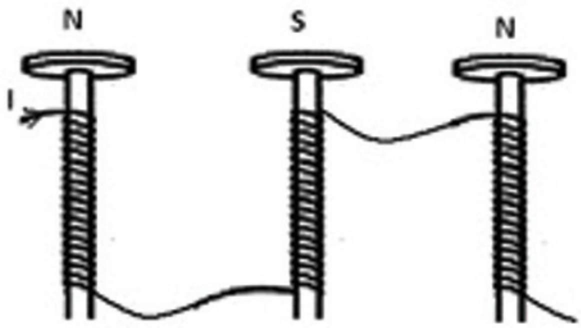


FIGURE 9: CONNECTIONS BETWEEN ELECTROMAGNETS

When the current is changing direction, all the poles are changing simultaneously from North to South and the opposite. This array of electromagnets is placed under the rail track (see Figure 10).

FIGURE 10: ARRAY OF ELECTROMAGNETS IS PLACED UNDER THE RAIL TRACK

Under the wagon, three small disk shaped magnets are placed at exactly the same distance (2cm) as the electromagnets (see Figure 11). Again, the magnet in the middle must have on the bottom side different pole than the two others. We found out, through several trials with different types of magnets, that ceramic magnets work better for the purposes of this construction.

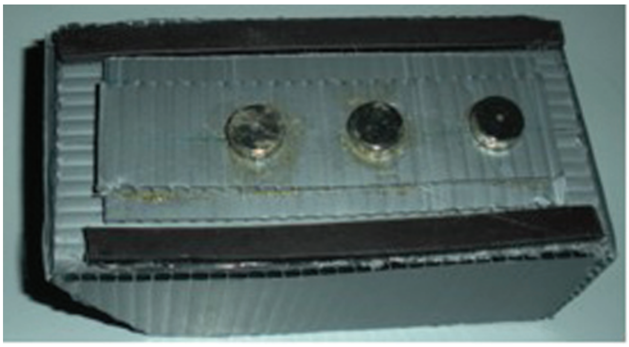


FIGURE 11: DISK SHAPED MAGNETS PLACED UNDER THE WAGON

The wagon is placed on the rail (see Figure 12) and is able to move, if the current alternates slowly (3-4 Hertz). For this, you need a frequency generator that will give you a current of 1.5-2A in low frequency. The idea is that each electromagnet repels a magnet of the wagon and attracts the next one. When the next magnet arrives at the position of the original one, its polarity changes, so it is repelled and the next is attracted and so on.
Factors that students are expected to experiment with are the intensity of the current, the amount of wire around the nails, the distance of the nails from the wagon and the frequency of the alternating current.

FIGURE 12: WAGON IN THE RAIL

5.1.7. **Exercise: Investigation or Design process?** Students' categorization is discussed. If they refer to the similarity concerning the goal (goal of science) and not to the process (investigation) the teacher should ask the students to focus on the procedure that is described for achieving the research goal in each description and think whether there are any similarities in the procedures of group A. Students are expected to explain similarities according to the main components of variable controlling that they had imprinted in question 4.3.6

Next, they are asked whether the remaining procedures that were categorized in B have anything in common. This is intended to lead to the generation of the common characteristics of the design process such as the formulation of specifications, the trial of the designed solution, the evaluation and refinement of the solution. At this point, the design as process that has these components is connected to a main procedure that is followed in technology for pursuing technological goals and the teacher explicitly mentions that a second difference between science and technology is the different processes followed in order to achieve the main goal of each field, i.e., investigation in science and design in technology.

5.1.8. **Testing – Evaluation:** Students are asked to test and evaluate their construction describing the method they followed. They are also expected to reflect on the whole design process to identify difficulties and suggest alternative approaches.

5.1.9. **Instructions for Creating Posters:** Students should present on a poster the whole design process they have followed for the construction of their electromagnetic train model. All the stages of this process should be described in detail.

UNIT 6: LINKAGES BETWEEN SCIENCE & TECHNOLOGY

6.1. LINKAGES BETWEEN SCIENCE & TECHNOLOGY

6.1.1. Examples of Science- & Technology-oriented activities. In this part students reflect on the activities they have been engaged with within the whole module in order to identify activities that are aligned with science and activities that are aligned with technology, by applying the criteria they have developed to discriminate between the two fields, i.e., differences in the main goals and central processes. During discussing their responses, students should be asked to explain why they consider some activities as science-oriented or technology-oriented and therefore engage in an epistemological discourse concerning these two criteria.

6.1.2. Next, students are asked to think about types of connections between science and technology based on their experiences from the previous units. Students' responses to the existing questions are discussed.

6.1.3. Story examples that demonstrate the interconnection between Science & Technology. Students are given two stories that describe research projects that incorporate scientific and technological practice. Through the questions that follow students are guided to extract contributions of science to technology and vice-versa.

Typical questions for use during check-out points:

- Does progress in technology help science progress? In what ways?
- Does progress in science help technology progress? In what ways?

C: DESCRIPTION OF EXTENSION ACTIVITIES

C: DESCRIPTION OF EXTENSION ACTIVITIES

1. DESCRIPTION OF THE ACTIVITIES

4.4. MAGNETIC FIELDS BY INDUCTION

Although magnetic field by induction is a topic that is typically subsumed in science textbooks under the section of Electromagnetism, in our curriculum we decided to develop it as an extension activity for two reasons:

- it is considered as a complex topic and the EPM module is addressed to students aged between 14-17 years old
- the already extensive length of the EPM module

Equipment:

4.4.1. Copper wire, string, bar magnet
4.4.2. Electromagnet, lamp, magnet bar, amperometer
4.4.3. Two electromagnets, battery, switch, amperometer
4.4.4. Two electromagnets, two pencils, wire, battery, switch, amperometer

Discussion of the experiments and exercises:

4.4.1. Students should observe that the copper bronchus is repulsed from the magnet when it moves towards it and is attracted to the magnet when the magnet moves away.

4.4.2. Students should observe that current flows in different direction through the coil when the magnet approaches or moves away from the electromagnet and they should try to explain the behavior of the bronchus in 4.1.1.

4.4.3. The aim of this experiment is to help students understand that when the current flow through an electromagnet changes (e.g., change of the intensity or the direction of the flow), its magnetic field also changes. This change also results in the production of current flow in another electromagnet that is placed near the first electromagnet. Students should be able to understand that the current flow exists in the second electromagnet only while there is a change in the magnetic field of the first electromagnet.

4.4.4. Students are asked to examine if the electromagnets' core material affects their interaction. They are expected to repeat 4.1.3 using different materials as the core of the coils.

2. TEACHING & LEARNING ACTIVITIES

4.4. MAGNETIC FIELDS BY INDUCTION

We know from the previous chapters that current, more specifically moving electrical charges create a magnetic field. What happens to a copper wire that is placed in a variable magnetic field.

4.4.1. INDUCTION CURRENT

Suspend, with a piece of string, a copper ring so that it swings freely. Approach a magnet like it is shown on the figure below.

A. Describe what happens when you approach the magnet.

....

....

....

B. Describe what happens when you start increasing the distance between the copper ring and the magnet.

....

....

....

What do you think causes this behaviour?

....

....

....

C. Repeat A and B, this time approach the ring with the other pole of the magnet. Did you notice anything different?

....

....

....

4.4.2. INDUCTION CURRENT THROUGH AN ELECTROMAGNET

A. Connect an electromagnet and a small light bulb with wire, in a closed circuit. Repeat the same procedure as in activity4.4.1, first approach the magnet and then start to increase the distance between the circuit and the magnet. Write down your observations.

....

....

....

B. Repeat the experiment, this time approach and pull away the magnet in a faster motion. Did you notice anything different?

....

....

....

C. In the circuit replace the light bulb with an amperometer and repeat the procedure, as previously described. Write down the amperometer readings. What do you observe?

....

....

....

What is the relationship between the observations in activities 4.4.1. and 4.4.2.?

....

....

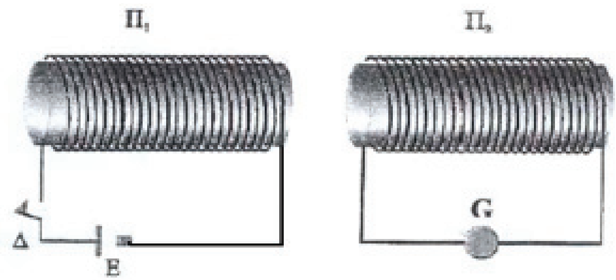
....

In 1834 the Russian physicist Heinrich Lenz formulated the following rule:
«There is an induced current in a closed conducting loop if and only if the magnetic flux through the loop is changing. The direction of the induced current is such that the induced magnetic field always opposes the change in the flux».

DISCUSS YOUR PROGRESS WITH YOUR TEACHER

4.4.3. INDUCTION & ELECTROMAGNETISM

A. Prepare two coils using ferromagnetic materials for core and place them next to each other, as shown in the figure below.



B. In one of them connect a battery in series and a switch; in the other one connect an amperometer.

C. Close the switch. What do you observe? What is causing this?

....

....

....

D. Open the switch. Why is the meter reading different in this case?

....

....

....

What do you observe when the switch is constantly closed or open? How do you explain this?

....

....

....

4.4.4. INVESTIGATION OF ELECTROMAGNETIC COUPLING

A. Write down a procedure in order to investigate if the core materials affect the intensity of the induction current in the second coil.

....

....

....

....

....

B. Perform the experiment and write down your results in a table.

What are your conclusions?

....

....

....

DISCUSS YOUR PROGRESS WITH YOUR TEACHER

D: EVALUATION TASKS & RUBRICS

PART D: EVALUATION TASKS & RUBRICS

A range of assessment tasks have been employed for measuring the improvement of students' conceptual understanding and as a consequence the effectiveness of the teaching/leaning sequence. The assessment tasks include pre- and post-tests for Units 1-4. Unit 5 is assessed by studying the artifacts produced by each group of students. The artifacts include a poster presenting the design process for the development of the train model and the model itself. The evaluation of the train model examines the operation (the three functions), design features and the procedure that was followed for its design and development. Furthermore, epistemological awareness is assessed with pre- and post-tests administered at the beginning (before Unit 2) and at the final unit of the module (after paragraph 6.1.2). The tests assess students understanding for the different goals and central processes of these fields. Also, a representative sample of students is selected for semi-structured interviews aiming at collecting additional data on the criteria students use for discriminating between these two fields and how these criteria change after the intervention. Finally, for measuring students' interest and motivation two questionnaires are used. Both questionnaires consist of likert-scale items, the first one examines students academic motivation for learning science and is administered at the beginning and at the end of the intervention and the second one measures students' interest towards specific activities and is administered once at the beginning of the implementation (students fill in the questionnaire having in mind a typical science activity from the school curriculum) and after predetermined activities of the module.

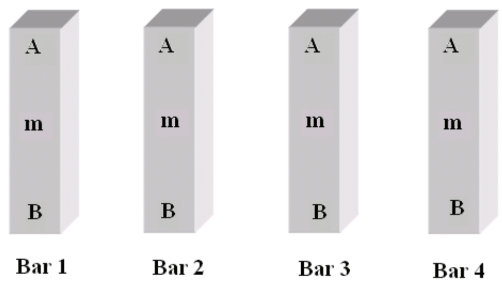
UNIT 1

1. The aim of this activity is to assess students' ability to distinguish magnets, non-magnetized ferromagnetic objects and non-ferromagnetic objects through their magnetic interactions.

A student has four metallic bars. Each one of the bars may belong to one of the following categories:

i) Permanent magnets
ii) Ferromagnetic objects (non-magnetized)
iii) Objects that cannot be magnetized

The bars are numbered from 1 to 4 as presented in the following figure. The ends of the bars are also denoted with the letters A or B, while the centre of each bar is identified with the letter m. (Note: At the case of a magnet, the poles will be located at the ends of the bar.)



- 1A and 4A are attracted to each other
- 2A does not interact with 4m
- 3A and 4B are repulsed

A. Is the bar 1 a permanent magnet? If you are not sure, in which other category(ies) could this bar belong to? (Look at the categories above)

B. Is the bar 2 a permanent magnet? If you are not sure, in which other category(ies) could this bar belong to? (Look at the categories above)

C. Is the bar 3 a permanent magnet? If you are not sure, in which other category(ies) could this bar belong to? (Look at the categories above)

D. If we approach 1A to 1B, how would these ends react? If it is hard to answer with certainty, state the possible interactions. Explain your reasoning.

Students' responses are categorized below:

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	• A magnet is attracted with ferromagnetic materials which have no interaction between them. • A magnet interacts with another magnet both through attraction and repulsion "Bars 3 and 4 are magnets because there is repulsion between them.	*"Bars 3 and 4 are magnets because there is repulsion between them. Bar 1 might be a magnet or ferromagnetic because is attracted with bar 4. Bar 2 is non-ferromagnetic because it doesn't interact with bar 4 which is a magnet."*
2	• A magnet is attracted with ferromagnetic materials which have no interaction between them.	*"Bars 1 and 4 are either both magnets or one is a magnet and the other ferromagnetic, since they are attracted with each other."*
3	• A magnet is attracted with ferromagnetic materials. • A magnet interacts with another magnet both through attraction and repulsion	*"Bars 3 and 4 are magnets because there is repulsion between them. Bar 1 is ferromagnetic because is attracted with bar 4. Bar 2 is non-ferromagnetic because it doesn't interact with bar 4 which is a magnet."*
4	• A magnet interacts with another magnet both through attraction and repulsion	*"Bars 3 and 4 are magnets because they repel each other."*
5	• Interaction with metallic objects	*"Bar 1 is a magnet because attracts bar 4 which is metallic. Bar 4 is not a magnet because it does not attract bar 2 which is also metallic."*
6	Irrelevant answers or answers with internal inconsistencies	

2. This question examines whether students are able to transfer the idea of the interaction between magnets and the Earth to a different situation that involves another planet.

Imagine that you belong to a crew of a spaceship that is landed on an unknown planet. You realize that the north pole of your compass is pointing to the direction that Sun rises and the South Pole is pointing at the direction that Sun sets. Could you state the position of the magnetic poles of this planet? Explain your reasoning.

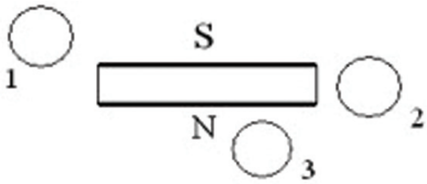
Students' responses are categorized below:

	CATEGORY OF RESPONSE	**TYPICAL STUDENT RESPONSE**
1	• The compass needle is a magnet and its poles can be attracted by the unlike magnetic poles of the planet. • The North pole of the compass points towards the South magnetic pole of the planet and vice versa.	*"The compass is oriented according the magnetic poles of the planet because it functions like a magnet. That is the like poles repulse and the unlike attract each other. So, the north pole of the compass is attracted by the south magnetic pole of the planet."*
2	• The North pole of the compass points towards the South magnetic pole of the planet and vice versa (no explanation)	*"I think that the north pole of this planet is where the sun rises and the south at the opposite side."*
3	• The compass is oriented according to the geographical poles	*"The north pole of the compass is attracted by the geographic north of the planet and the south pole of the compass by the geographic south."*
4	• The North pole of the compass points towards the North magnetic pole of the planet	*"Since the north pole of the compass is directed to east and the south pole to west, this means that the north pole of this planet is at east and south at west."*
5	Irrelevant or no answer	

UNIT 2

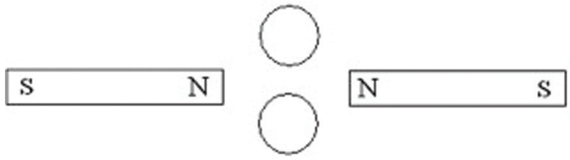
The following questions examine if students have understood the form of the magnetic field around different sets of magnets and how is this related to their interactions with compasses.

1. *At the following figure a magnet is shown along with some compasses around it. Show, with arrows, the orientation of each compass needle and mark its poles.*



Explain why you drew the direction of the compasses' needles as you did.

2. *In the following figure two magnets are shown along with two compasses. Show, with arrows, the orientation of each compass needle and note its poles.*



Explain why you drew the direction of the compasses' needles as you did.

Students' responses are categorized below:

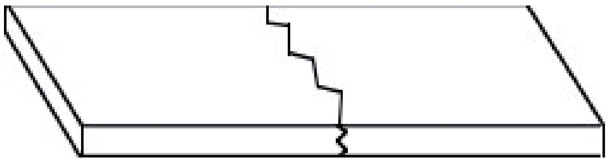
	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Magnetic field Interaction: The alignment of the compasses' needles and the explanation provided illustrate understanding of the form and effect of the magnetic field. The response implies an understanding of "interaction at a distance".	*"The magnetic field lines begin from the north pole and end up in the south pole. The magnetic field lines at the centre of the poles are straight lines, therefore, the compasses situated near the poles of the magnet, point towards the magnet's poles with their opposite pole. The compass in the middle of the magnet is aligned along the magnetic field lines following the direction of the magnetic field."*
2	Interaction between magnets: Magnetic interactions (attraction & repulsion between the poles) determine the direction of the compasses' needles.	*"The compasses near the south pole are positioned with their opposite (north) pole towards the magnet's pole. The compass situated in the middle is separated by an equal distance from the two poles, thus it is aligned in the opposite direction of the magnets' poles because its north pole is attracted by the south pole of the magnet and the other way around."*
3	Interaction between magnets: The alignment of the compasses' needles show lack of understanding of the interaction between the compasses' poles and the magnets' poles.	*"The needle of compass 1 is horizontally aligned because the north pole interacts with the south pole of the magnet. The north pole of compass 2 is up and left because it interacts with the south pole of the magnet and the south pole of compass 3 is up because it interacts with the north pole of the magnet."*
4	Irrelevant answers or answers with internal inconsistencies.	*"The red needle of the compass always points towards the North pole. Thus, all the compasses will point towards the north pole of the magnet with their north pole."*

3. *I used a magnet to remove a nail from a hole that it was too narrow to catch it using any other object. Which capability of the magnet makes it useful for this situation? Which concept of the physics science was invented to explain this capability of the magnet?*

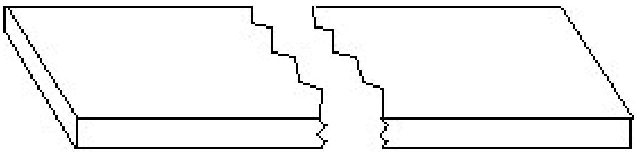
UNIT 3

The aim of the next questions is to examine students' understanding of the magnetic domains model for magnetic materials and their ability to use it to make informed predictions for their behavior.

1. *A magnet, like the one presented in the figure next, is broken to two pieces along the interrupted line, as it is shown.*

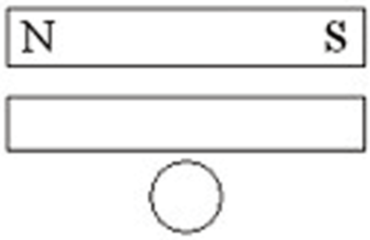


What do you thing you would observe if you try to bring back together the two pieces?



Can you determine the poles of each piece? If yes, show them on the diagram and explain your reasoning. If no, explain why not.

2. *A ferromagnetic bar is placed next to a magnet. Show the direction of the compass needle and explain your reasoning.*



Students' responses are categorized below:

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	When a ferromagnetic material is placed into a magnetic field ... • ...its magnetic domains are aligned according to the direction of the magnetic field. • ...the magnetic field is then formed around the ferromagnetic material according to its magnetization.	*"The ferromagnetic bar consists of many small magnets (magnetic domains), which are irregularly placed. When the ferromagnetic bar is placed into the magnetic field of a permanent magnet, its small magnets align and the ferromagnetic material acquires magnetic properties (magnetic poles appear at its ends). Thus, the ferromagnetic bar acts from then on as a magnet and the compass needle aligns with the magnetic field lines of the ferromagnetic bar.*
2	When a ferromagnetic material is placed into a magnetic field... • ...it is magnetised and poles appear at its ends. • ...the magnetic field is then formed around the ferromagnetic material according to its magnetization.	*"The ferromagnetic bar is magnetized when approached near a magnet and poles appear at its ends. The poles are determined by the magnet's pole that attracts the ferromagnetic bar. The compasses are oriented according to the poles of the ferromagnetic bar."*

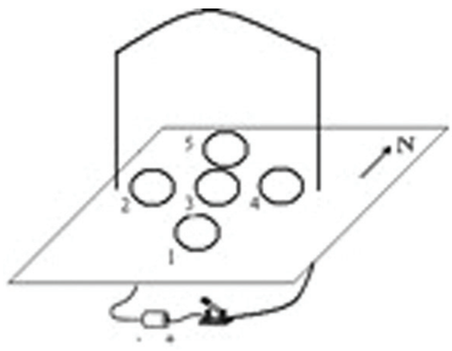
	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
3	When a ferromagnetic material is placed into a magnetic field... • ...it is affected from the source of the magnetic field and as a consequence it acquires magnetic properties (no poles are mentioned). • the magnetic field is then formed around the ferromagnetic material accordingly, but no poles appear at the ends of the ferromagnetic bar.	*"The magnet attracts the ferromagnetic bar. So, the ferromagnetic bar will be magnetized and will attract the compass' needle. The compass' needle will follow the magnetic field lines."*
4	When a ferromagnetic material is placed into a magnetic field... • ...it is not affected from the magnetic field and consequently, • the magnetic field retains its form around it as in the case of a paramagnetic material.	*"The south pole of the compass is positioned towards the north pole of the magnet, because it is affected by the magnet's magnetic field. Even though between the compass and the magnet there is a ferromagnetic bar, the orientation of the compass will not be affected because the ferromagnetic bar is not a magnet."*
5	Irrelevant response or response with internal inconsistencies.	

3. If we let a ferromagnetic object in a room for a long period of time, poles might appear at its ends. How is the magnetization of the object explained? Why is the magnetization lost if we hit it with a hammer?

UNIT 4

The following exercise examines students' understanding regarding the form of the magnetic field around current carrying wires

1. *Some compasses (numbered from 1 to 5) are placed close to an appropriately configured wire, like in the figure below. Show the direction of each compass needle when current flows through the wire. Explain your reasoning for drawing the direction of the compasses' needles as you did.*



Students' responses are categorized below:

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	• The magnetic field is produced by the flow of electric current through a wire. • Its direction is perpendicular to the current flow (correct form of magnetic field). • Its direction is explained by the idea of the current flow.	*"When the switch is closed, the current wire creates magnetic field around it. The magnetic field has the form of circle around the wire and does not intersect with that. The direction of the flow depends on the direction of the current."*
2	• The magnetic field is produced by the flow of electric current through a wire. • Its direction is perpendicular to the current flow (correct form of magnetic field). • Its direction is not explained by the idea of the current flow.	*"Around a current carrying wire, a magnetic field is created in the form of circles."*
3	The polarity of the magnetic field (North-South pole) coincides with the polarity of the battery (+, -) to which the wire is connected.	*"When the circuit is closed, magnetic field develops around and at the edges of the wire. North pole appears on the wire-end connected to the positive pole of the battery and vice versa."*
4	The flow of the magnetic field follows the flow of the electric current.	*"Since the current starts from the positive pole of the battery, the magnetic lines also begin from the positive pole and travel to the negative pole of the battery."*
5	There is no magnetic field created by the current flow.	*"The compasses won't be affected because there is no magnetic field, but only electric current."*
6	None or irrelevant answer.	

The aim of the following question is to assess students' ability to carry out scientific investigations correctly.

2. *A cube is left to slide on a smooth, declining surface. An experiment is carried out to investigate which parameters affect the time needed to travel a distance of 2 meters on this surface. The results from four trials are presented on the following table. All trails were carried out several times with the same results. Other parameters that might affect the results are kept constant.*

PARAMETER	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4
Length of cube's edge	6 cm	6 cm	12 cm	12 cm
Decline of surface	30^o	60^o	30^o	45^o
Mass of the cube	50 gr	60 gr	72 gr	72 gr
Time	0.9 sec	0.7 sec	0.9 sec	0.75 sec

Is it possible to verify the following statement using these measurements?
"The mass of a cube affects the time needed to travel the distance of the 2 meters".
If yes, explain which measurements support the statement. If not, explain why.

Is there another parameter for which is possible to conclude if it affects the time needed? Explain your answer.

Expected response:

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	• Identification of the variable under investigation (independent variable) that is going to be altered. • Identification of the dependent variable that is going to be measured. • State the variables that must be kept constant.	*"The statement cannot be verified because while mass is altered in trials 1&2, there are other variables, that might affect it, that are not kept constant. However, it is possible to conclude that the decline of the surface affects the time needed because it is altered on trials 3 and 4 and the other variables are kept constant."*

UNIT 5

Unit 5 is the technological design project. Unit 5 is assessed by the creation of a poster describing and explaining the design process and the development of the train model. Information and examples for the creation of the poster are presented in the activity sequence. Furthermore, the design and development of the train model is guided by scaffolded activities. In the table below, there are examples of the stages and the content that we would be expecting for a representative poster. The following table provides guidance for assessing the train models.

POSTERS

DESIGN PROCESS STAGES	CONTENT

Description of the *Problem*	• Identify the problem and possible causes (e.g. Low-quality public transportation, frequent traffic jams)
	• Description of the problem from a social & an environmental perspective (e.g., traffic jams impact on people's schedules, pollution, etc)
	• Determine the specifications/functions (requirements-restrictions)
	  • Levitation
	  • Propulsion
	  • Magnetic Shielding

Research of the *Problem*	• Collection of information regarding the construction of the model train (e.g. how others developed similar models, materials they used, cost of the construction, etc.) • Technical Information regarding the specifications/functions • Description of the history of the magnetic levitation ("maglev") train
Development of *possible solutions\Initial Ideas*	• Application of the acquired knowledge in proposing realistic ideas for the construction of the model train • Evaluation and utilization of available technology & materials for the construction of the final product • Construction designs accompanying each proposed solution (e.g., orthographical projection, dimensions, materials to be used, etc)

DESIGN PROCESS STAGES	CONTENT
Selection of the *Best Possible Solution*	• Detailed description explaining the rationale behind selecting the specific solution • Detailed construction designs illustrating dimensions and materials that will be used for each part of the model train • In depth description of the ways that the specifications/functions would be implemented • *Levitation:* o Magnetic Repulsion - using permanent magnets o Magnets' arrangement on the wagon and the rails. • *Propulsion:* o Use of electromagnets - description of their operation (e.g. how is the magnetic field produced, the direction of the magnetic field and the relationship between current flow and direction) o Use of alternating current to create the continual reversal of the polarity o How it works (why is the train moving?) o Reference to the corresponding activity in the module • *Shielding:* Justification of the Material Selection (ferromagnetic materials and ferromagnetic alloys) with reference to the corresponding activity in the module
Model Construction	• Description of the construction process • Difficulties met and how these were resolved
Model Evaluation	• Evaluation of the model train in terms of specifications that have been met. • For functions/specifications that have not been met, identification of possible causes and suggestion of ways to overcome the problem
Redesign	• Detailed description of the design process giving emphasis to the differences between the first and the second attempt and the importance of each modification (e.g. is it an improvement or a crucial modification that makes the model functional)

TRAIN MODELS

	ELEVATION	PROPULSION	PASSENGER PROTECTION
Successful construction of the model train	Placement of magnetic strips under the wagons and on the rails with the like poles facing each other → Successful elevation	• Identical electromagnets (core material, number of wire loops, density of loops) • Right connections between electromagnets and consequently correct polarity • High density of wire loops • Stable distance between electromagnets and good alignment → Successful propulsion	Ferromagnetic material in form of sheet is covering the bottom of the wagons → Significant decrease of the intensity of the magnetic field
Moderate construction of the model train	Placement of magnetic strips under the wagons and on the rails with the like poles facing each other → Successful elevation	• Similar electromagnets (core material, number of wire loops, density of loops) • Right connections between electromagnets and consequently correct polarity • Almost stable distance among electromagnets, average alignment • Relatively low density of wire loops → Low ability of movement	Diamagnetic material in form of sheets is covering the bottom of the wagons → No significant decrease of the intensity of the magnetic field
Inadequate construction of the model train	Placement of magnetic strips under the wagons and on the rails with the like poles facing each other but not in appropriate distance between them → Elevation without good balance	• Non-similar electromagnets (core material, number of wire loops, density of loops) • Right connections between electromagnets and consequently correct polarity • Relatively low density of wire loops • Unequal distance among electromagnets and bad alignment → Propulsion is not achieved	No action is taken for magnetic shielding

EPISTEMOLOGICAL AWARENESS

DISTINGUISHING BETWEEN SCIENCE AND TECHNOLOGY (UNITS 2-6)

Below there are some statements that describe what different researchers are trying to do in their research. For each research goal tick √ the appropriate box according to whether you consider that what they do is aligned with the goal of **science**, the goal of **technology** or **neither**.

	THE RESEARCHERS' GOAL IS ALIGNED WITH THE GOAL OF SCIENCE	THE RESEARCHERS' GOAL IS ALIGNED WITH THE GOAL OF TECHNOLOGY	THE RESEARCHERS' GOAL IS NOT ALIGNED NEITHER WITH THE GOAL OF SCIENCE NOR WITH THE GOAL OF TECHNOLOGY
We observe the sky through telescopes in order to study the motion of planets.			
We are trying to find the best way that will measure with accuracy the wind's speed.			
We are studying a newly located species in a park, in order to see how it differs from the other known species living in the same park.			
We try to make filters to absorb polluting fumes that are emitted from factory chimneys.			
Now that we understand many things about the properties of certain viruses that affect people, we try to create a vaccine against various dangerous viruses.			
We try to make an artefact that will protect us from lightning.			
The raw materials that are normally used for producing electricity are oil and coal. The amounts of these materials are continuously diminished, so we try to find new ways of producing electricity.			
We do experiments with car machines in order to find a way to reduce polluting fumes that are emitted from factory chimneys.			

	THE RESEARCHERS' GOAL IS ALIGNED WITH THE GOAL OF SCIENCE	THE RESEARCHERS' GOAL IS ALIGNED WITH THE GOAL OF TECHNOLOGY	THE RESEARCHERS' GOAL IS NOT ALIGNED NEITHER WITH THE GOAL OF SCIENCE NOR WITH THE GOAL OF TECHNOLOGY
We try to study factors that might cause various types of cancer.			
We take monthly water flow measurements of natural streams.			
We try to modify some food, so as to add substances known for their ability to cure some diseases.			
We try to predict how the climate will change in 500 years. We use computers in order to make some complicate mathematical calculations easily and fast.			
We try to develop an instrument that will predict when earthquakes will happen and how strong they will be.			
We are trying to decide the best location to build a desalination plant.			
Recently, there has been a car accident and now a research is conducted in order to find the causes that led to it.			
We examine whether microwave ovens are dangerous for our health and also what sort of problems they might cause			
We are trying to develop a substance that acts against known viruses linked to cancer.			
In many cases, drinkable water contains substances that are bad for our health. We try to find a way to remove them.			

Question: Concerning all your answers above, how did you determined whether a given research project seemed either scientifically or technologically oriented?

	EXPECTED RESPONSE	TYPICAL STUDENT RESPONSE
1	Discriminating based on the goal of each field	*"A project belongs to science when it deals with natural phenomena and studies them in depth to establish theories and conclusions. A project belongs to technology when it tries to find solutions to address human problems and improve our life conditions."*
2	Discriminating based on the object of study in each field	*"When it relates to a living organism, the research belongs to the field of science. But when it relates to electronics or stuff made by people, then it belongs to the field of technology."*
3	Discriminating based on the methods that appear in each field	*"A project belongs to science when we do an experiment.. A research project belongs to technology when we construct something."*
4	Science and technology have a joint orientation towards improving human life but they differ with respect to the role played by each field; science finds solution to problems, while technology is responsible for their practical implementation.	*"Both fields (science and technology) have the same goal: to improve human life. Scientific achievements help people have a better life. Technology is the medium through which science is applied."*
5	Inadequate or ambiguous discrimination (use of a criterion in a way that the two fields match or too general and insufficient descriptions)	*"Science: when we try to improve something and discover something new with the help of experiments. Technology: when we try to discover something new, that simplifies and improves our lives."* *"'Technology is something that develops, while science is something that we discover."*
6	Irrelevant answers (the answer does not respond to the question or the answer involves circular reasoning or tautologies or the answer refers only to one of the two fields)	*"In science we do scientific stuff and in technology we do technological stuff."*
7	No response	

Below there are some statements that describe what different researchers are trying to do in their research. For each research goal tick √ the appropriate box according to what in your opinion fits better.

	THEY TRY TO GET A BETTER UNDERSTANDING ABOUT THE OPERATION OF NATURAL PHENOMENA	THEY TRY TO DEVELOP SOLUTIONS TO PROBLEMS ENCOUNTERED BY SOCIETY AND TO MEET HUMAN NEEDS	NEITHER OF THE TWO PREVIOUS GOALS INTERESTS THEM
We observe the sky through telescopes in order to study the motion of planets.			
We are trying to find the best way that will measure with accuracy the wind's speed.			
We are studying a newly located species in a park, in order to see how it differs from the other known species living in the same park.			
We try to make filters to absorb polluting fumes that are emitted from factory chimneys.			
Now that we understand many things about the properties of certain viruses that affect people, we try to create a vaccine against various dangerous viruses.			
We try to make an artefact that will protect us from lightning.			
The raw materials that are normally used for producing electricity are oil and coal. The amounts of these materials are continuously diminished, so we try to find new ways of producing electricity.			
We do experiments with car machines in order to find a way to reduce polluting fumes that are emitted from factory chimneys.			
We try to study factors that might cause various types of cancer.			
We take monthly water flow measurements of natural streams.			
We try to modify some food, so as to add substances known for their ability to cure some diseases.			

	THEY TRY TO GET A BETTER UNDERSTANDING ABOUT THE OPERATION OF NATURAL PHENOMENA	THEY TRY TO DEVELOP SOLUTIONS TO PROBLEMS ENCOUNTERED BY SOCIETY AND TO MEET HUMAN NEEDS	NEITHER OF THE TWO PREVIOUS GOALS INTERESTS THEM
We try to predict how the climate will change in 500 years. We use computers in order to make some complicate mathematical calculations easily and fast.			
We try to develop an instrument that will predict when earthquakes will happen and how strong they will be.			
We are trying to decide the best location to build a desalination plant.			
Recently, there has been a car accident and now a research is conducted in order to find the causes that led to it.			
We examine the possible health hazards that stem from the use of microwave ovens.			
We are trying to develop a substance that acts against known viruses linked to cancer.			
In many cases, drinkable water contains substances that are bad for our health. We try to find a way to remove them.			

Below there are two excerpts from two newspaper articles that describe processes that two research groups follow in their research. Both researches relate to mobile phones and our health.

Read the following descriptions and answer the questions.

First research group: *"We have chosen a specific type of sensor among various sensors that detect radiation emitted from mobile phones. Our choice was based on particular criteria that we had initially defined. Next, we will upgrade the sensor's operation so as to measure in an accurate manner the intensity of the radiation."*

1. Is the process described above aligned with processes followed in science, in technology, or neither? Explain your reasoning.

....

....

....

Second research group: *"We will use two mice that resemble in the following ways: age, time of daily travel, time of daily sleep, same motion speed. Next, we will put them inside two identical rooms under the same conditions (same room temperature, same food, etc.). The only difference between the two mice is that in one of the two rooms we will change the radiation amount by placing a charged mobile phone in the ceiling of the room. We will observe the behavior of both mice. Specifically, we will measure how long they move each day, how much time they sleep and how fast they run".*

2. Is the process described above aligned with processes followed in science, in technology, or neither? Explain your reasoning.

....

....

....

Below there are two excerpts from two articles of a medical magazine that describe processes that two research groups follow in their research. Both researches concern health hazards that might relate to cancer.

Read the following descriptions and answer the questions

First research group: *"We already know that smoking relates to the appearance of specific types of cancer like lung cancer, mouth cancer, etc, but we don't have a definite opinion whether smoking relates to the appearance of leukemia. Therefore, we will collect different information from patients that have developed leukemia. We will then divide them in two categories: smokers and non-smokers. Next, we will compare the amount of leukemia patients between smokers and non-smokers and further analyze the results to examine to what extent differences are found."*

1. **Is the process described above aligned with processes followed in science, in technology, or neither? Explain your reasoning.**

....

....

....

Second research group: *"We have developed a medicine for curing cancer. Next we plan to pilot-test it in some patients in order to track down possible side effects. Then we will improve it based on the pilot-test results."*

2. **Is the process described above aligned with processes followed in science, in technology, or neither? Explain your reasoning.**

....

....

....

Understanding relationships between science and technology (unit 6)

Read the following text

Recent proficiency that led to a better understanding of the operation of lenses, has oriented researchers of MedLab group in ***trying to develop special microscopes that consist of appropriate lenses and consequently serve towards performing specialized eye examinations.*** *These microscopes will be useful in eye operations for people that have vision problems. In particular, they will help doctors in observing in more detail their patients' eyes. In order to achieve this, MedLab researchers need to know which types of lenses are most suitable and how they should be placed in install them in order to obtain the best possible magnification.*

1. Tick √ the appropriate box according to what in your opinion fits better.

The goal of Medlab research group concerning the development of microscopes for better eye examinations:

- o is mainly aligned with the goal of science ☐
- o is mainly aligned with the goal of technology ☐
- o is not aligned neither with the goal of science nor with the goal of technology ☐

Explain your reasoning for the choice you have made.

....

....

....

2. Try to find in the text as many ways as you can where progress in science can help progress in technology and reverse.

   Explain your reasoning.

....

....

....

Read the following text

Recent photomaps of Amazon forests taken through satellite indicate the existence of a new type of insects. These new data have stimulated researchers of Natur group in ***trying to observe this new type of insects found in Amazon forests and describe the characteristics and their life.*** *These insects were located in very quiet places away from rivers, perhaps because they are disturbed by noise and other visitors. Therefore, a problem that the researchers face is that they need a way that allows them to make detailed observations remotely. In a different case the insects might be frightened and hide.*

1. Tick √ the appropriate box according to what in your opinion fits better.

The goal of Natur research group concerning the observation of a newly found insect in Amazon forests:

- o is mainly aligned with the goal of science ☐
- o is mainly aligned with the goal of technology ☐
- o is not aligned neither with the goal of science nor with the goal of technology ☐

Explain your reasoning for the choice you have made.

....

....

....

2. Try to find in the text as many ways as you can where progress in technology can help progress in science and reverse.

Explain your reasoning.

....

....

....

Semi-structured interview protocol concerning students' understanding about the distinction and interconnection between science and technology

The interview is intended not to exceed 20-25 minutes. Part E is usually not included in pre-interviews, except for cases where a student during Parts A or B refers to the distinction between the main goals of science and technology.

PART A

Instructions given to the student by the interviewer:
Below there are some statements that describe what different researchers are trying to do in their research. For each research goal that I will read to you, I need you to think whether what they do is aligned with the goal of science, the goal of technology or neither, put a tick accordingly and explain your reasoning.

During the students' responses, the interviewer asks for clarifications as follows:

- How did you think in order to make this choice? Why did you choose science and not technology? Why did you choose technology and not science? Why did you rejected the one and why the other? When you say "..." what do you mean?
- If the student considers that a statement belongs to more than one choice, then the researcher asks the student to explain what he/she think about each choice and select the one he/she thinks that fits better
- In cases where the researcher identifies inconsistencies (e.g. cases in which interviewees provided incompatible responses to the various items or responded differently compared to the written test), then he/she explicitly confronts students with these discrepancies and asks them to elaborate on them

RESEARCH GOALS	THE RESEARCHERS' GOAL IS ALIGNED WITH THE GOAL OF SCIENCE	THE RESEARCHERS' GOAL IS ALIGNED WITH THE GOAL OF TECHNOLOGY	THE RESEARCHERS' GOAL IS NOT ALIGNED NEITHER WITH THE GOAL OF SCIENCE NOR WITH THE GOAL OF TECHNOLOGY
Now that we understand many things about the properties of certain viruses that affect people, we try to create a vaccine against various dangerous viruses.			
We do experiments with car machines in order to find a way to reduce polluting fumes that are emitted from factory chimneys.			
We try to modify some food, so as to add substances known for their ability to cure some diseases.			
We try to predict how the climate will change in 500 years. We use computers in order to make some complicate mathematical calculations easily and fast.			
We are trying to decide the best location to build a desalination plant.			
We examine whether microwave ovens are dangerous for our health and also what sort of problems they might cause.			
We are trying to develop a substance that acts against known viruses linked to cancer.			
In many cases, drinkable water contains substances that are bad for our health. We try to find a way to remove them.			

PART B

Question: In general, when do you determine whether given research project seems either scientifically or technologically oriented or neither?

PART C

Instructions given to the student by the interviewer: Now, I will read again some statements that describe what different researchers are trying to do in their research. This time I need you to think and choose whether they try to get a better understanding about the operation of natural phenomena, or whether they try to develop solutions to problems encountered by society and to meet human needs or neither of the two previous goals interests them.

RESEARCH GOALS	THEY TRY TO GET A BETTER UNDERSTANDING ABOUT THE OPERATION OF NATURAL PHENOMENA	THEY TRY TO DEVELOP SOLUTIONS TO PROBLEMS ENCOUNTERED BY SOCIETY AND TO MEET HUMAN NEEDS	NEITHER OF THE TWO PREVIOUS GOALS INTERESTS THEM
We try to modify some food, so as to add substances known for their ability to cure some diseases.			
In many cases, drinkable water contains substances that are bad for our health. We try to find a way to remove them.			
We are trying to develop a substance that acts against known viruses linked to cancer.			
We examine whether microwave ovens are dangerous for our health and also what sort of problems they might cause.			
We are trying to decide the best location to build a desalination plant.			

PART D

Instructions given to the student by the interviewer: Next, we will see two cases of research that are both related to mobile phones and our health. I will read it to you. Next I want you to mention whether you can find any differences concerning the process the two groups follow.

First research group: *"We have chosen a specific type of sensor among various sensors that detect radiation emitted from mobile phones. Our choice was based on particular criteria that we had initially defined. Next, we will upgrade the sensor's operation so as to measure in an accurate manner the intensity of the radiation."*

Second research group: *"We will use two mice that resemble in the following ways: age, time of daily travel, time of daily sleep, same motion speed. Next, we will put them inside two identical rooms under the same conditions (same room temperature, same food, etc.). The only difference between the two mice is that in one of the two rooms we will change the radiation amount by placing a charged mobile phone in the ceiling of the room. We will observe the behavior of both mice. Specifically, we will measure how long they move each day, how much time they sleep and how fast they run".*

Questions:

(i) Do these two descriptions differ with respect to the processes the two researchers follow? That is, are there any differences between the two processes? I am not referring to thematic differences (e.g., in one research they use mice, in the other they don't), but differences in the methodology they implement in each case.

(ii) Could you say whether each of the two processes is aligned more with science or technology? Explain.

PART E

Read the following text.

Recent proficiency that led to a better understanding of the operation of lenses, has oriented researchers of MedLab group in ***trying to develop special microscopes that consist of appropriate lenses and consequently serve towards performing specialized eye examinations.*** *These microscopes will be useful in eye operations for people that have vision problems. In particular, they will help doctors in observing in more detail their patients' eyes. In order to achieve this, MedLab researchers need to know which types of lenses are most suitable and how they should be placed in install them in order to obtain the best possible magnification.*

Recent photomaps of Amazon forests taken through satellite indicate the existence of a new type of insects. These new data have stimulated researchers of Natur group in ***trying to observe this new type of insects found in Amazon forests and describe the characteristics and their life.*** *These insects were located in very quiet places away from rivers, perhaps because they are disturbed by noise and other visitors. Therefore, a problem that the researchers face is that they need a way that allows them to make detailed observations remotely. In a different case the insects might be frightened and hide.*

Question:
Do you think that there are any connections between science and technology?
In other words, are there any cases where one field contributes in the development of the other?
If yes, then how? If not, then why not?

Clarifications asked:
The goal of Medlab research group concerning the development of microscopes for better eye examinations is mainly aligned with the goal of science, the goal of technology, or neither?

Can you find in the first text any ways where progress in science can help progress in technology and reverse?

The goal of Natur research group concerning the observation of a newly found insect in Amazon forests is mainly aligned with the goal of science, the goal of technology, or neither?

Can you find in the second text any ways where progress in technology can help progress in science and reverse?

MOTIVATION

QUESTIONNAIRE 1

ACADEMIC MOTIVATION FOR LEARNING SCIENCE

DATE: ______________________________ STUDENT No.:__________ COUNTRY: _____________________

NAME:____

	WHEN I ENGAGE IN SCIENCE INQUIRY ACTIVITY ...	DOES NOT COR-RES-POND AT ALL			CORRES-PONDS MODER-ATELY			COR-RES PO-NDS EXAC-TLY
1.	Because I have the impression that it is expected of me.	1	2	3	4	5	6	7
2.	To show myself that I am a good student.	1	2	3	4	5	6	7
3.	Because I choose to be the kind of person who knows many things as an adult.	1	2	3	4	5	6	7
4.	Because it’s important to me to learn science.	1	2	3	4	5	6	7
5.	Because I enjoy the feeling of acquiring knowledge about science.	1	2	3	4	5	6	7
6.	For the enjoyment I experience when I grasp a difficult subject in science.	1	2	3	4	5	6	7
7.	Because it will help me make a better choice regarding my career orientation.	1	2	3	4	5	6	7
8.	For the "high" feeling that I experience when I am taken by discussions with interesting science teachers.	1	2	3	4	5	6	7
9.	Because studying science allows me to continue to learn about many things that interest me.	1	2	3	4	5	6	7
10.	Because I think it is good for my personal development.	1	2	3	4	5	6	7
11.	For the pleasure that I experience in knowing more about science.	1	2	3	4	5	6	7
12.	Because I would feel ashamed if I couldn’t discuss with my friends about things concerning science.	1	2	3	4	5	6	7
13.	I don’t know why I study science, and frankly, I don’t give a damn.	1	2	3	4	5	6	7
14.	In order to get a more prestigious job later on.	1	2	3	4	5	6	7
15.	For the "high" feeling that I experience while reading about various interesting science subjects.	1	2	3	4	5	6	7
16.	Because science learning allows me to experience a personal satisfaction in my quest for excellence in my studies.	1	2	3	4	5	6	7
17.	Because I really like science learning.	1	2	3	4	5	6	7
18.	Because I would feel guilty if I didn’t study science.	1	2	3	4	5	6	7
19.	Because I’ll get in trouble if I don’t do so.	1	2	3	4	5	6	7

	WHEN I ENGAGE IN SCIENCE INQUIRY ACTIVITY …	DOES NOT COR-RES-POND AT ALL			CORRES-PONDS MODER-ATELY			COR-RES PO-NDS EXAC-TLY
20.	For the pleasure I experience when surpassing myself in science studies.	1	2	3	4	5	6	7
21.	Honestly, I don't know, I truly have the impression of wasting my time in studying science.	1	2	3	4	5	6	7
22.	I once had good reasons for learning science; however, now I wonder whether I should continue.	1	2	3	4	5	6	7
23.	Because I choose to be the kind of person who knows matters concerning science.	1	2	3	4	5	6	7
24.	For the satisfaction I feel when I am in the process of accomplishing difficult exercises in science.	1	2	3	4	5	6	7
25.	Because I want the teacher to think I'm a good student.	1	2	3	4	5	6	7
26.	For the satisfied feeling I get in finding out new things.	1	2	3	4	5	6	7
27.	Because for me, science learning is fun.	1	2	3	4	5	6	7
28.	I don't know why I am studying science.	1	2	3	4	5	6	7
29.	In order to have a better salary later on.	1	2	3	4	5	6	7

QUESTIONNAIRE 2

ACADEMIC MOTIVATION FOR LEARNING SCIENCE

DATE: ____________________________ STUDENT No.:_________ COUNTRY: ___________________

NAME:____

For each of the following statements dealing with scientific inquiry activities, please indicate how true it is for you, using the following scale: not at all true (1) ... very true (7)

	WHEN I ENGAGE IN SCIENCE INQUIRY ACTIVITY ...	NOT AT ALL TRUE			SOME-WHAT TRUE			VE-RY TR-UE
1.	I enjoy the activity very much.	1	2	3	4	5	6	7
2.	I think I am pretty good at the activity.	1	2	3	4	5	6	7
3.	I put a lot of effort into the activity.	1	2	3	4	5	6	7
4.	I did not feel nervous at all while doing the activity.	1	2	3	4	5	6	7
5.	I believe I had some choice about doing the activity.	1	2	3	4	5	6	7
6.	I believe the activity has some value for me.	1	2	3	4	5	6	7
7.	I feel really distant from my peers while doing the activity.	1	2	3	4	5	6	7
8.	The activity is fun to do.	1	2	3	4	5	6	7
9.	I think I do the activity pretty well, compared to other students.	1	2	3	4	5	6	7
10.	I didn’t try very hard to do well at the activity.	1	2	3	4	5	6	7
11.	I felt very tense while doing the activity.	1	2	3	4	5	6	7
12.	I felt like it was not my own choice to do the activity.	1	2	3	4	5	6	7
13.	I think that doing the activity is useful for my science studies.	1	2	3	4	5	6	7
14.	I really doubt that my peers and I would ever be successful team through the activity.	1	2	3	4	5	6	7
15.	The activity is boring.	1	2	3	4	5	6	7
16.	After working at the activity for a while I feel pretty competent.	1	2	3	4	5	6	7
17.	I tried very hard on the activity.	1	2	3	4	5	6	7
18.	It was important to me to do well at the activity.	1	2	3	4	5	6	7
19.	I was very relaxed in doing the activity.	1	2	3	4	5	6	7
20.	I didn’t really have a choice about doing the activity.	1	2	3	4	5	6	7
21.	I think the activity is important to do because it can help me in learning	1	2	3	4	5	6	7
22.	I feel I could really trust my peers participating in the activity.	1	2	3	4	5	6	7
23.	The activity did not hold my attention at all.	1	2	3	4	5	6	7
24.	I am satisfied with my performance at the activity.	1	2	3	4	5	6	7
25.	I didn’t put much energy into the activity.	1	2	3	4	5	6	7

	WHEN I ENGAGE IN SCIENCE INQUIRY ACTIVITY …	NOT AT ALL TRUE			SOME-WHAT TRUE			VE-RY TR-UE
26.	I was anxious while working on the activity.	1	2	3	4	5	6	7
27.	I felt like I had to do the activity.	1	2	3	4	5	6	7
28.	I would be willing to do similar activities more because they have value for me.	1	2	3	4	5	6	7
29.	I'd like to interact with my peers participating in the activity more often.	1	2	3	4	5	6	7
30.	I would describe the activity as very interesting.	1	2	3	4	5	6	7
31.	I am pretty skilled at the activity.	1	2	3	4	5	6	7
32.	I felt pressured while doing the activity.	1	2	3	4	5	6	7
33.	I do the activity because I have no other choice.	1	2	3	4	5	6	7
34.	I think doing the activity could help me to learn science.	1	2	3	4	5	6	7
35.	I feel close to my peers during the activity.	1	2	3	4	5	6	7
36.	I think the activity is quite enjoyable.	1	2	3	4	5	6	7
37.	I couldn't do the activity very well.	1	2	3	4	5	6	7
38.	I do the activity because I want to do it.	1	2	3	4	5	6	7
39.	I believe that doing the activity could be beneficial for me.	1	2	3	4	5	6	7
40.	I don't feel like I could really trust my peers who are participating in the activity.	1	2	3	4	5	6	7
41.	When I am doing the activity, I think about how much I am enjoying it.	1	2	3	4	5	6	7
42.	I do the activity because I have to do.	1	2	3	4	5	6	7
43.	I think the activity is an important activity.	1	2	3	4	5	6	7

INTERVIEW QUESTIONS

QUESTIONS OR TOPICS DISCUSSED WITH THE STUDENTS DURING THE INTERVIEW.

0. Orientation.

   Can you tell me about what helps you to learn in science? What is it that makes a science activity interesting for you? What makes learning enjoyable for you?

   Please tell me about what you have been doing in [this module] and what you have been learning...

1. What did you find (most) interesting in the [MaterialsScience module] lessons?

   What else was interesting or motivating?

2. What was (most) motivating in the learning activities (motivation is a reason why you were doing the activities)? Was there something that made you want to continue learning about this topic?

   What else was interesting or motivating?

Ask about the following features of the module/learning activity.

3. Please tell me about any situations where you could make decisions about what to do or how to do some activity. [autonomous learning]

   Did you find this interesting or motivating?

   Were there situations where you could make choices without having to consult the teacher or any other source of information?

   Give the following hints if a student is not saying anything: mention a specific student-centred learning activity like inquiry task, collaborative learning activity or ICT use or co-planning of the learning activities, or an activity that promotes the feeling of effectiveness and importance of working

4. Can you please tell me about situations in these learning activities where interactions with other students were important and useful for your own learning? [*social relatedness*].

   Did you find this possibility interesting or motivating?

   Were there situations where you felt you could trust or not trust the other students in your group? Did you feel that there were opportunities for supporting the other students' learning? Did you find support from other students?

   Give the following hints if a student is not saying anything: mention a specific inquiry task, collaborative learning activity, co-planning or ICT use, or an activity that promotes the feeling that the students can trust each other and feel themselves close to each other

5. Can you please describe any situations where you felt good about achieving something? Were there activities where you felt you could do well? [*feeling of competency*].

   Did you find this interesting or motivating?

   In what situations did you feel you learnt something important?

   Give the following hints if a student is not saying anything: mention a specific inquiry tasks, collaborative learning activity, co-planning or ICT use or an activity that involves choice and use of constructive evaluation methods, like self assessment, portfolio evaluation, informal discussions, or an activity that promotes the feeling that the task has some value or use for the student

6. Were there any activities that you considered interesting?

   Were there activities that you really enjoyed doing? [*interest and enjoyment*].

   Did you find this interesting or motivating?

   Were there activities which were more likely to wake up your curiosity?

   Were there activities which held your attention more?

   Were there activities which you found funny or enjoyable to do?

   Were there activities with some value from the point of view of science learning (benefit) or future studies or career?

   Were there activities which made you feel that what you were doing was important?

   Were there interesting ideas or issues that you had to deal with?

7. Can you please tell me about any activities that made you want to learn more on this topic? Were there any situations in this module that you found interesting and you wanted to think more about them? [*motivating or interesting content or context of the module*].

8. Overall, what did you think about the module? Did it help you learn? Do you think it was useful for you?

E: BRIEF DESCRIPTION OF MODULE DESIGN, DEVELOPMENT AND VALIDATION PROCESS

E: BRIEF DESCRIPTION OF MODULE DESIGN, DEVELOPMENT AND VALIDATION PROCESS

There are common trends in the educational systems across the EU countries. Particularly the problems in science education have been realized many years now. However, instead of declining, the symptoms persist and grow. Among the most important signs are (a) significant decrease in the number of students that wish to continue their studies in science, (b) students loosing their interest to scientific school subjects by the age of 14 years and (c) student poor results in international comparative studies. All these draw a clear picture that there is a need to reform the educational system. The main reason behind these problems is the way science is taught in schools. Science teaching in schools does not resemble the way science is done in an authentic context. In Cyprus, science education is restricted to knowledge, with memorization being the target and solving exercises the proof of understanding. Moreover, laboratory activities are performed to activate student interest towards science rather than giving meaning to scientific investigations.

The MS project proposes as a solution the development of research based modules through national partnerships between University researchers and school teachers, in order to promote science as a process of inquiry. In this context the Cypriot Local Working Group (LWG) designed the module "Electromagnetic Properties of Materials", from now on referred as EPM. The subject of the module was selected as a common subject in physics, taught in schools from the elementary years. Students have their own experience of magnetic phenomena which combined with inappropriate teaching methods leads to naive ideas and difficulties in understanding and interpreting key concepts. Furthermore, electromagnetism has many applications in today's technological era (see A1, paragraph 2).

The design of the initial version of the activity sequence drew on information stemming from three main directions. The first involved the review of the science education literature with respect to learning principles and teaching strategies. The second entailed the documentation of the conventional teaching practice in electromagnetism by reviewing the textbooks that are commonly used. The third direction pertained to the review of the existing research literature with respect to teaching and learning on the topic of electromagnetism. Specifically, we undertook a thorough review of the available research on students' initial ideas and conceptual difficulties with respect to the targeted learning objectives. In addition to this, our review also focused on studies reporting on teaching innovations that have been developed in this area. The synthesis of the information that emerged from these directions provided valuable insights which were taken into account in designing the activity sequence.

The development of the activity sequence was particularly informed by the "Physics by Inquiry" curriculum (McDermott and the Physics Education Group, 1996). Specifically, the module that we have developed has largely relied on "Physics by Inquiry" in that we have adopted, and often adapted as needed, a substantial part of its activities. Of course these activities served to address only a part of the learning objectives we had formulated and the module incorporated additional activities that we specifically designed so as to deal with the remaining learning objectives.

The activity sequence was implemented several times so as to evaluate its effectiveness and identify possible ways to revise it so as to further increase its ability to promote the learning objectives it was designed for. First, the initial version of the activity sequence was pilot tested with a group of students in the context of a science summer school that was organised at the University of Cyprus in 2008. The summer school spanned a period of four weeks during which students attended daily (four days per week) two two-hours sessions. Participants were high school students in the age range 15 to 17, who volunteered to take part. The 16 students worked through the activity sequence in mixed groups (boys & girls). The implementation of the module was undertaken by a group of three instructors who were familiar with the rationale underlying the activity sequence, its content and the "Physics by Inquiry" pedagogy. In line with this pedagogy the instructors sought to support students' attempt to productively interact with the activity sequence while rejecting the role of the authority that is supposed to transfer knowledge to students. Instead, during the discussions with the groups of students, rather than providing direct answers to students' questions or comments, the instructors attempted to facilitate consensus, consistency and accountability in the student thinking and helped them articulate their thoughts and negotiate the various epistemological, conceptual, reasoning or practical difficulties they were encountering.

Taking into account the data that had emerged from the assessment of students' learning gains the activity sequence underwent substantial revisions. These revisions ranged from slight modifications of isolated activities to more radical changes such as the removal/replacement of activities (or series of activities) or the introduction of additional sets of activities. The revised version of the activity sequence was then implemented during the fall semester in the context of a compulsory course dealing with science content, which is offered by the department of education to prospective elementary teachers. Participants were 61 pre-service teachers. Throughout the semester students met with instructors twice a week for a two-hour session. Overall, the implementation of the activity sequence lasted 40 hours. Throughout this period we collected data on students' learning gains with a view to assess the effectiveness of the activity sequence. The activity sequence was then revised taking into account the data that had emerged and the revised version was tested for a third time with a group of 71 pre-service teachers in the context of this same course during the spring semester of 2009. The data from the evaluation of students guided the further refinement of the activity sequence.

The next implementation took place in four intact classes of a private middle school in Larnaca (the third largest city in Cyprus). The total number of participants was 112. The teacher who undertook the responsibility to implement the activity sequence lacked formal teaching experience in that she had just entered the profession of physics teaching. However, the lack of experience was compensated for by her interest in trying teaching innovations and her background in science teaching as a result of her enrolment in a postgraduate programme in science education. The implementation of the activity sequence lasted 20 teaching periods which spanned a period of five weeks. This implementation was solely focused on magnetism and excluded the activities on electromagnetism. Consequently, we revised the project on the design of the train model so as to solely focus on the specification relevant to the elevation of the train.

The fifth implementation of the activity sequence took place in the context of a summer science school that was organized at the University of Cyprus in 2009. Participants were 31 students (14 girls and 16 boys) aged between 15 and 18 years. Finally, the last enactment took place in two intact classes of a public high school in Larnaca. The total number of participants was 44 (21 and 23 students) and the implementation lasted 40 teaching periods. The teacher had a degree in physics and had a teaching experience of 13 years. The students were attending an introductory physics class that was targeted at basic concepts.

Data sources

The assessment tools that we had used were the same for all the implementations mentioned above. A major source of data involved the various open ended tasks that were administered prior to and after the implementation of either the entire activity sequence or certain parts of it. These tasks were primarily intended to provide insights about the extent to which students' interaction with the activity sequence helped them improve their understanding with respect to the targeted concepts. In addition to this, they were also used to assess for students' learning gains in relation to the epistemological learning objectives that were formulated (e.g., distinction between science and technology). Two further data sources that were used for these learning objectives include the combination of the two parallel forced-choice tests and the semi-structured follow-up interviews with a subsample of students.

An additional main source of data that was used pertains to the train models constructed by the students in the context of the design project and the accompanying posters. These data yielded significant insights regarding students' conceptual understanding and their ability to transfer concepts to a novel context.

Data analysis process

Students' responses to the open ended data were exposed to content analysis so as to organize them into a limited set of categories that describe the qualitatively different ways of reasoning about the tasks. The categories were not imposed a priori. Instead, the categorization scheme emerged gradually during data analysis and it underwent several revisions at various stages throughout this process before converging to its final version. The final version of the categorization scheme for each task includes a set of categories that are ordered according to their accuracy. Specifically, the first category in the rubric tables (see section D) reflects the highest level of accuracy and comprehensiveness that we had encountered in the data.

Artefact analysis was used for the posters and the train models. This analysis was focused on the extent to which the models constructed by the groups of the students satisfied the three main specifications that had been formulated (i.e., levitation, propulsion and shielding). Specifically, we inspected the actual models developed by the students and we consulted the accompanying posters so as to document whether, and how, each of the three functions was addressed. This provided us with valuable insights about students' ability to transfer concepts that were dealt with throughout the activity sequence to the specific problem at hand. For instance, the artifact analysis allowed us to evaluate students' ability to apply the concept of polarity so as to achieve the propulsion of the train (the propulsion can be achieved by arranging the electromagnets in such a way that the polarity alternates and the distance between consecutive electromagnets is kept constant) and the effect of the number of coil turns on the strength of the electromagnet

Refinement of the activity sequence

The results from the comparison of the categorization of students' responses to the various tasks prior to and after the implementation of the activity sequence, in combination with the outcomes of the artefact analysis guided the refinement process of the activity sequence. An additional data source that served a complementary role and further informed the refinement process pertains to the reflective diaries that were completed by the teachers for each session. In these diaries the teachers documented interesting aspects of the teaching and learning process such as unanticipated students' difficulties and activities whose objective was systematically misunderstood by the students. Finally, a further data source that also contributed to the refinement process involved the feedback that was provided by experts who observed the implementation of parts of the activity sequence.

Based on the data that stemmed from these sources we undertook to revise the activity sequence so as to further enhance its ability to realize the targeted learning objectives. Below we discuss the main revisions that were made at various stages throughout the development of the module. These revisions can be divided into four categories, as follows:

a) conceptual understanding and knowledge transfer
b) knowledge transfer
c) epistemology
d) technological design and
e) systemic

The main changes under the "conceptual understanding" category pertain to the section dealing with the magnetic model. Two ideas that hold a central position in the activity with respect to the explanation of the behaviour of magnetic materials include the magnetic field and the magnetic domains model. We found that the model of magnetic domains confronted students with formidable difficulties which tended to constrain their ability to understand its essence, as evidenced by students' failure to transfer this idea to address relevant tasks. In an attempt to resolve this issue we have switched the position of certain sets of activities. The chapter on the properties and behaviour of magnetic stacks was moved before the chapter on the magnetic model. The construction of a magnetic stack out of small magnets in a way that the stack has the same properties as a single magnet is aligned to the idea of the magnetic domain model (e.g., a magnet is consisted of tiny magnetic domains aligned in the same direction). Finally, the activity through which students experiment with different alignments of magnetic stacks was incorporated in the chapter dealing with the magnetic model chapter since this activity essentially links the relevant core ideas. These changes were intended to help them meaningfully construct the relevant ideas and appreciate their coherence.

A common misconception among students is that the size of a magnet affects its strength. The EPM module contains an activity intended to confront students with a situation that runs counter to this belief. Specifically, in this activity students are asked to determine the strength of various magnets that differ in terms of shape and size, by measuring either the maximum distance at which each magnet attracts a paper clip or the number of paper clips it can hold. Based on the observations that emerged in this context, students could be easily persuaded that size does not influence the strength of a magnet. This same difficulty was also encountered by students in a following chapter on the properties of magnetic stacks. In this case, students usually express the idea that as the number of the magnets comprising the magnetic stack increases, the strength of the magnetic stack increases by an equal magnitude. Our experience with the implementation of the activity sequence suggested that the measurement of the strength of magnetic stacks using paper clips could not effectively challenge this belief. This was due to the function of several confounding parameters including the magnetization of the paper clips and the inconsistent measurement of the distance from where the paper clips and the magnetic stack attract. We sought to alleviate this shortcoming by taking advantage of an instrument that could be used to reliably measure the strength of magnets, namely the magnetic field intensity. This instrument can be attached to a computer interface and depict the intensity of the magnetic field as a number in Gauss units. This activity significantly helped us to address students' difficulty about the relation between the number of magnets in a magnetic stack and its strength and this was evidenced by the data that we collected through the assessment tasks, which showed improved conceptual understanding.

The next category of changes is "knowledge transfer" and they were initiated by certain weaknesses that we consistently identified in students' train models. The majority of the student groups failed to achieve two of the functions, namely magnetic shielding and propulsion, and the corresponding posters revealed various difficulties. Magnetic shielding was dealt with in the chapter on the magnetic model as an application of magnetic materials. Students' failure to incorporate into their design (train model) ferromagnetic materials for the redirection of the magnetic field provided evidence suggesting the need for modifications. The complex apparatus arrangement used in the initial experiment was modified accordingly so as to allow students to clearly discern the materials that cause magnetic retention. The effectiveness of this change was evident in the train models and the posters constructed by the student groups that participated in the next implementation.

Electromagnets and the laws underlying their operation present students with considerable conceptual difficulties which are evident by the fact that the implementation of the mechanism of propulsion was the most difficult one. After the second implementation of the teaching/learning sequence the electromagnetism unit was enriched with activities intended to help students appreciate the relationship between current movement in the wire and the polarity of the electromagnet. Additionally, an activity was added to show movement of a permanent magnet using electromagnets with opposite polarity. Data from subsequent implementations of the activity sequence suggested a significant improvement which was reflected by the increased number of students who exhibited understanding of the propulsion mechanism. However, in the construction of the train model, the large number of variables that the students had to coordinate led many groups to fail to accomplish the propulsion mechanism.

In addition to the learning objectives relevant to conceptual understanding of core concepts of magnetism and electromagnetism, a further objective of the activity sequence involves the development of epistemological awareness with respect to a certain aspect of NOS, namely the distinction and the interrelationships between science and technology. The initial version of the activity sequence sought to address this taking an implicit approach. Specifically, it was assumed that students' engagement with the two different parts of the module (a) inquiry-oriented activities to introduce and elaborate concepts relevant to magnetism and electromagnetism and (b) the design project would suffice to help them draw a distinction between science and technology in terms of the different social goals they seek to address (science aims at producing reliable knowledge about how systems function; technology seeks to generate solutions to problems encountered by society or to develop procedures or products that meet human needs). However, the results that emerged from the assessment of students in this respect failed to verify this assumption. This led us to reconsider the design of the module and adopt a more explicit teaching approach. Towards this end, we supplemented the existing activities with probes intended to engage students in explicit epistemological discourse with respect to the aim of science and technology and the core processes they involve. For instance, after the concept of the magnetic field was introduced, we engaged students in a structured discussion on the nature of this construct. Our intention was to get students to reflect on the invented nature of this construct and to appreciate that in science we invent models with predictive and explanatory capability so as to account for the operation of physical phenomena and systems. In addition to the activities that were dispersed throughout the activity sequence so as to initiate epistemological discourse on the targeted aspects of NOS, we also added an extra section at the end of the module that was specially designed to tackle these issues. This section presented students with narratives relevant to science and technology, which were specifically designed so as to serve as a context for the elaboration of the roles of science and technology, their distinction and their interrelationships. Except from the changes in the activity sequence per se we also supplemented the teachers' manual with suggestions on how to initiate and sustain the epistemological discourse with the groups of students.

The next category of changes emerged from the technological design, the construction of the train. Apart from the development of students' epistemological awareness with respect to the issues discussed above, through the construction of the train model, students familiarize with the design and construction process of a technological project and practice their ability to transfer and transform their previously acquired knowledge. The analysis of the artefacts showed multiple difficulties in the design and construction process of the train. The majority of the students failed to follow the key design stages in the development of the train. Furthermore, the content of the technological stages that appeared in the posters was insufficient at most of the cases or sometimes irrelevant with the expected one. Lastly and most importantly, students had difficulty in transferring knowledge and principles from the activity sequence they had been previously engaged with and effectively apply them on their technological construction. Based on the abovementioned problems, we decided to provide students with a series of questions to act as prompts in order to help them to follow the stages of the technological design process and further support them to carry out each stage of technological design in a meaningful way.

The final category involves systemic problems. The most significant problem that we encountered relates to the time constraints that typically emerge when seeking access to real classroom settings. Teachers were typically reluctant to implement such an extensive activity sequence in their class and they felt that this cannot be easily coordinated with the already overloaded list of topics they were expected to teach. In an attempt to address this issue we undertook to devise a shorter version of the activity sequence by removing parts of activities (or even entire activities) in cases when we felt that this would not significantly compromise the effectiveness of the module. One example relates to an activity that students had to give directions to a captain travelling from Cyprus to Tel-Aviv. The purpose of this task was to help students appreciate the role of magnetic declination and to further familiarize them with the angular difference between the geographic and magnetic poles of the Earth. Despite the value of this activity we felt that its removal could serve the need for reduction of the length of the module without significant impact on its effectiveness.

The iterative design process followed for the development of the EPM activity sequence offers numerous advantages. The iterative design approach links the expected outcomes with the results and focuses on "understanding learning and influencing educational practice" (Sandoval, 2004). The design, in this methodology, is theory-driven and grounded on relevant research and practice. Moreover, research based design embraces many different aspects of education giving emphasis "on developing, enacting and sustaining innovative learning environments" (Design-based Research Collective, 2002). The intention of design based research is to offer results that can be interpreted to shareable theories. The target is not only to report on how successful or not a cycle of interventions has been but rather to gather information that expand our knowledge on the learning issues involved in a complex educational environment. The significance of the results lies on the fact that the designs are implemented in authentic settings (Design-based Research Collective, 2002). Summarizing, design based research is a method that has the potential of bridging the gap between theoretical research and educational practice by creating designs that are based on grounded theory and practice, placing them in authentic settings and refining them according to the findings. The purpose is the documentation of the research process, contextual influences, and findings and in a latter stage the generalizability of the findings in order to inform and improve practice (Barab, S., 2003).

REFERENCES:

Barab, S., Squire, K. (2004) Special Issue: Design based Research: Clarifying the terms, The Journal of the Learning Sciences, 13 (1), Lawrence Erlbaum Associates Publishers

Design-based Research Collective (2002) Design-Based Research: An emerging paradigm for Educational Inquiry.

Mc Dermott, L., (1996) Physics by Inquiry Vol. 1&2, An introduction to Physics and Physical Sciences, Wiley & Sons

Sandoval, W., Bell, P., (2004) Design-based Research methods for studying learning in context, Educational phychologist, 39 (4), 199-201

MATERIALS
SCIENCE PROJECT

UNIVERSITY-SCHOOL PARTNERSHIPS
FOR THE DESIGN AND IMPLEMENTATION
OF RESEARCH-BASED ICT-ENHANCED
MODULES ON MATERIAL PROPERTIES

ISBN 978-9963-689-59-0
2009