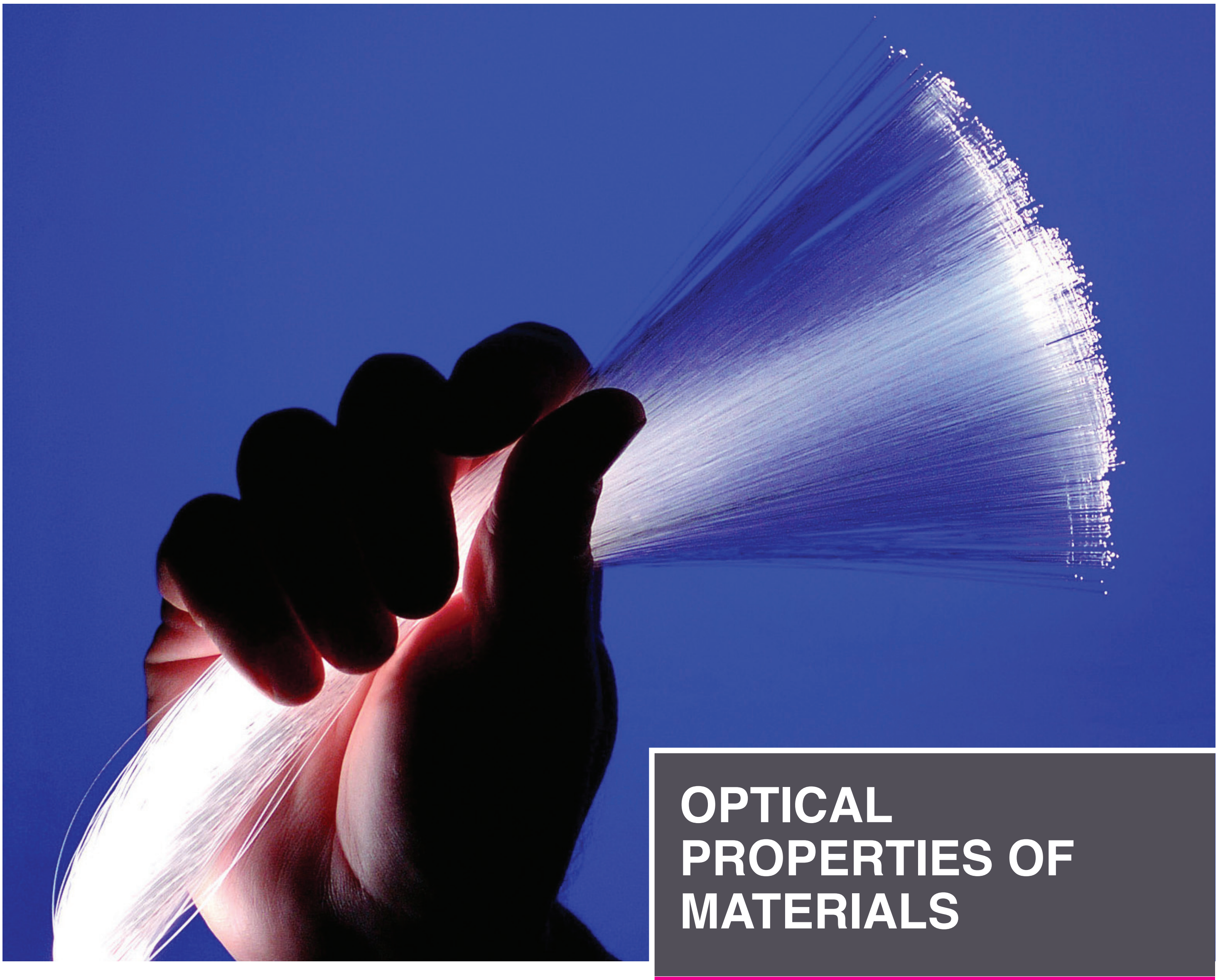

OPTICAL PROPERTIES OF MATERIALS

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

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OPTICAL PROPERTIES OF MATERIALS

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1. INTRODUCTION TO THE MODULE

INTRODUCTION TO THE MODULE

In the framework of the EU funded Material Science (MS) Project, "University-school partnerships for the design and implementation of research-based ICT-enhanced modules on Material Properties", the University of Naples (UoN) Physics Education Research group proposes a Module featuring research-based activities aimed at enhancing 14-16 years old students' interest and conceptual understanding about "Optical properties of materials". The specific Optical Properties we refer to are basically refraction index and transparency and the applications addressed relate to how optical fibers work.

The reason for such a choice is related to a threefold justification, which we illustrate in the following.

On one hand, nowadays, many technological innovations and applications are based on materials with suitable optical properties. It is sufficient to think about some every-day used techno-objects as laptop and mobiles monitors or DVD players. As a consequence the study of the optical properties of materials and in particular of one of its most important applications as the optical fibers, is one of those content areas which can help to motivate students through exploring exciting applications. To motivate students here means basically to: - engage them in student-centered activities aimed at increasing the perception of having an active role in the development of their own knowledge; - support their social skills when interacting with peers and increase their awareness of being part of a community of learning; - involve them in thought provoking tasks as well as open problems and scenarios which could stimulated their reflective thinking and help the construction of formal thinking; - enhance their curiosity and fun in learning new exciting contents.

As second feature of the UoN Module, it is possible to focus on the interplay between Science and Technology Knowledge. The issue here is to help students to understand that science endeavor to study nature is not unrelated to technology endeavor to propose solutions posed by practical human needs. As a matter of fact, to introduce the need of optical fibers as an important issue in a society which needs to share an increasing amount of information allows to closely relate the technology design of, e.g., materials with specific refractive index and a suitable geometrical arrangement and the scientific investigation about, e.g., propagation modes of electric field in a waveguide, embedding them in the current complex social scenario. Moreover, the specific optical properties characterizing the materials that constitute the optical fibers can be seen as an example of how these kind of materials' properties are at the basis of several everyday-used technical objects' functioning.

Finally, as third feature, a focus on some optical properties of materials and optical fibers, allows addressing also with young students basic as well as more advanced physics contents related to light transmission. Example of basic contents are the geometrical optics laws (total reflection is at the basis of the fibers' and light-guides' functioning) whereas example of more advanced topics is light absorption (the impurities in optical fibers' materials have to be minimized in order to ensure good transmission efficacy).

The UoN module is articulated in Units, the same rationale is shared by all activities. The general aims are informed by the Curriculum Development Guidelines drafted during this first part of the Project and that will be finalized in itinerary. More specifically, in Unit 1 the basic behavior of the fibers (i.e. how to guide the light) is addressed and interpreted by means of total internal reflection and materials' optics properties (e.g., index of refraction). In Unit 2, more complex behaviors (e.g., role of a cladding and light attenuation) are investigated and modeled through other specific materials' properties (e.g. fibers' main characteristics, impurities, bulk). Unit 3 addresses the modeling of the characteristics that a fiber must have in order to be used for specific applications in every-day contexts; the focus is on telecommunications (e.g. on how to build an optical fiber with low signal distortion and high signal to noise ratio). The modular structure allows preparing further Units to address contents related to applications of optical fibers in fields other than telecommunications.

THE RATIONALE OF THE UON MODULE

According to the Project's "Guidelines for Designing, Developing and Validating Research-based Teaching and Learning Materials", the Italy Local Working Group (about 4 University researchers and 8 school teachers) has developed a Module where the proposed activities "adhere to the principles of inquiry based science, active student engagement and collaborative learning". The 8 school teachers who participated in the Local Working Group had different roles: 2 were teachers-researchers, and actively participated to the design to the students' activities; 1 had the role of major advisor (i.e. in charge of giving a feedback to both the research design and the proposed students' activities, other 5 teachers were advisors (i.e. in charge of giving a feedback to the proposed students' activities)

To this aim the overall rationale of the Module's activities starts from observation of the behavior of one commonly used techno – object (in our case an optical fiber) and develops along a path aimed at studying under what conditions the chosen behavior can be modeled and thus designed.

The Schema in Figure A1 illustrates how this can be accomplished.

According to the above general schema, the Module is implemented in a set of activities that are clustered in separate Units. As a consequence, one may flexibly adapt the implementation to a particular teaching context of the Module itself, choosing whether or not to propose all the proposed Units.

All Units address the issue of designing an object that has specific, intriguing optical behaviors. The schema in Figure A2 gives an overall picture.

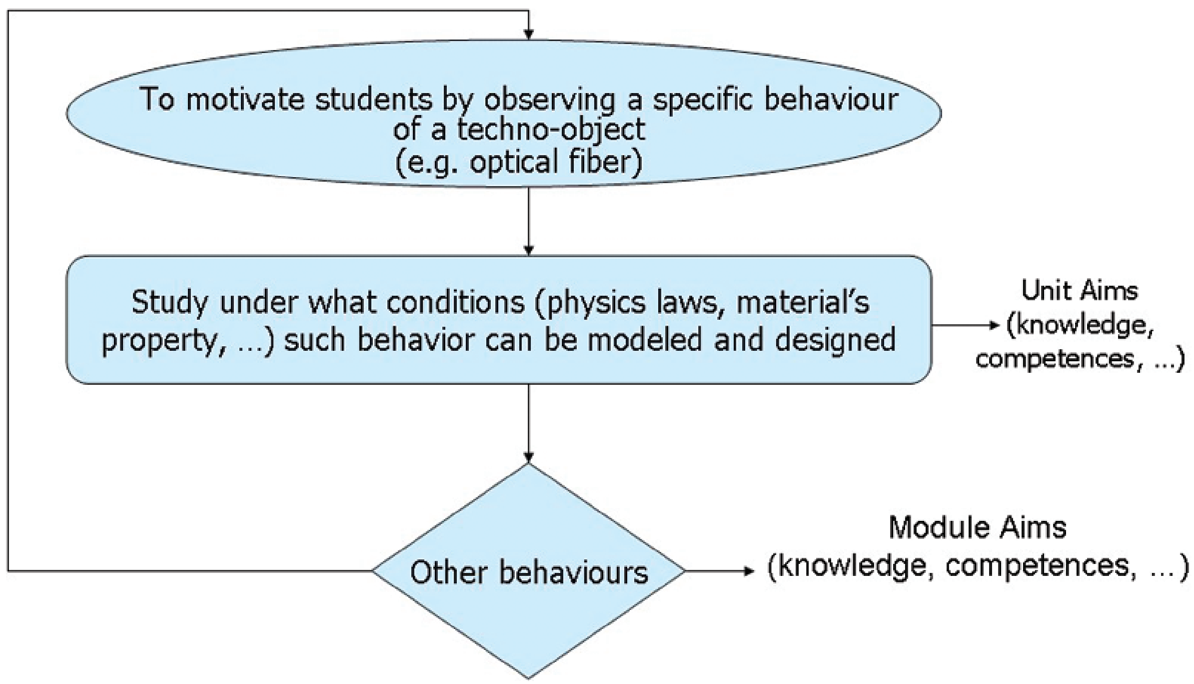

FIGURE A1: RATIONALE OF THE UoN MODULE

	Observations	Content	Clues for Design
UNIT 1	Some materials/objects can guide the light	Laws of reflection/refraction, total internal reflection	Any two transparent materials arranged as a sandwich with inner refraction index greater than outer are a guide light
UNIT 2	Some of above materials/objects also trap and do not attenuate light	Lightpropagation in the fiber Lightdiffusion at surface and bulk	A light guide with specific core and cladding and few/controlled impurities is an optical fiber
UNIT 3	Some optical fibers can transmit signals with high efficiency	Monomodal and multimodal fibers; Step and graded index fibers	To be used in telecommunication, an optical fiber must have suitable length and dimension and the signal must propagate almost parallel to its axis

FIGURE A2: SYNOPSIS OF THE THREE UNITS OF THE UON MODULE

RELEVANCE OF THE MODULE IN TERMS OF DEVELOPING AN AWARENESS OF THE ROLE OF SCIENCE IN SOCIAL CONTEXTS.

In the industrialized society, the interplay between Science and Technology Knowledge is becoming more and more important. Usually at school level the emphasis on such interplay is lacking or scarce (Gil-Perez & Pessoa de Carvalho, 1998). Therefore to focus on the relations between Science and Technology can help to increase the students' interest. The issue here is to help students to understand that the science endeavor aimed at studying nature is not unrelated to the technology endeavor aimed at proposing solutions to practical human needs. As an example, the optical fibers can be introduced as an effective solution to the need of sharing an increasing amount of information that characterized so deeply the current industrialized society to have labeled it as "Information Society". In this way it is possible to closely relate the technology design of, e.g., materials with specific refractive index and a suitable geometrical arrangement and the scientific investigation about, e.g., propagation modes of electric field in a waveguide, embedding them in the current complex social scenario. Moreover, the specific optical properties characterizing the materials that constitute the optical fibers can be seen as an example of how these kind of materials' properties are at the basis of several everyday-used techno-objects' functioning.

Optical Properties of Materials is a branch of optics which is rapidly developing in response to increasing technological demands. Current main research focuses on these areas: light sources (e.g., laser/light emitting diodes, solid state lasers, fibers' amplifiers and lasers); materials for nonlinear optics and light detection (e.g., semiconductors, organic compounds, photorefractive materials, artificial nonlinear materials and nanomaterials); passive optical materials (e.g., glassy materials and synthetic materials characterized by mesoscopic structures smaller than optical wavelength). Some most up-to-date applications of this widely applied field of research include: energy saving devices, telecommunication signaling and multiplexing, medical care, lithography, environmental monitoring, television and computer screens, glasses coating, etc.…

Although most of these applications exploit both well known basic physics topics (as geometrical optics laws) and more advanced contents (as lasers and non-linear devices), on another hand, many other applications are based on recent research about synthetic materials with suitable optical properties (as photorefractive materials).

Hence, progress in optical materials deeply influences advances in optical science and technology.

Science education has addressed Optics as one of those physics areas which can help to: - motivate students through exploring exciting applications; - address basic physics contents related to light production, transmission, manipulation, detection and use; - recognize that some optical properties of matter (as refractivity, reflectivity and transparency) are at the basis of how several everyday-used devices function; - show some links between technological/social demands and science progress and how basic science research often produces relevant technological fallouts.

Actually, as far as young students are concerned, the study of optics has an important lever to base upon (shared with motion and heating/cooling phenomena), i.e., the perceptual knowledge each human being has because of vision through our eyes as light detectors. This knowledge coming out from individual and everyday experience is a powerful starting point when the educational goal is to aim at integrating students' perceptual knowledge with formal and disciplinary representations and knowledge. Moreover, when the common sense knowledge about optical phenomena is elicited, quite often naïve ideas and reasoning strategies, conflicting with physics knowledge, appear and can be addressed.

In many traditional school programs (including the Italian secondary school one) Optics has a minor weight and impact than Mechanics, Thermology and Electromagnetism. As Ogborn pointed out (2006): 'In many physics courses geometrical optics (restricted to thin lenses and mirrors, paraxial rays) fell by the wayside when new reformed curricula were developed. Now, a different kind of optics needs to be re-introduced; one which corresponds to the massive developments in the field'. In other words, a paradox is evident: many students are familiar with (and often are able to use) everyday life applications of optical research (e.g. video mobile, CD/DVD players, cameras, spectacles/binocular/telescope) but such practical knowledge usually does not correspond to a knowledge of the basic physics underlying these devices.

2. RELATIONS OF THIS MODULE WITH OTHER MODULES

The optics module shares with the other modules of the project common features as:

- choice of properties of materials as main topic (in this case, the index of refraction); such common theme allows to address, describe and interpret basic phenomena related to energy transfer in the bulk of materials and surface effects. Examples of such common view are, for instance, present in the optics module, the acoustics module (by Spain group) where absorption and reflection of light and sound are addressed;
- pedagogical approaches as, e.g., student centered teaching, inquiry-oriented and modeling activities;
- ICT based instruction, with the use of, e.g., simulations or applets as in the case of the optics and conductivity (by Thessaloniki group) and density (by Florina group) module.
- focus on how to enhance students' interest and motivation towards science, by means of, for instance, the use of teaching scenarios, use of up-to-date technological applications

3. BACKGROUND INFORMATION: THEORY

VISION

We see: - because light reaches our eyes, which are the apparatus devoted to reveal visible light; - if our eyes are directly hit by the light emitted from the sources of light or the light reflected from illuminated objects. The first is called direct light, the other diffused light; - because there is matter that diffuse light. The diffusion of light is the main process of vision. In the activity with laser in clean air and then "dirtied" with smoke or dust we understood that only if there are particles (large enough) hit by the laser light, we can see the path of light.

If particles of smoke or dust are illuminated by the light, act as diffusion centers of the light that have hit them and hence allow "see" the light beam. If there was no diffused light it would be impossible to see anything. Moreover, the transparency of the medium in which the object and the observer are immersed is a necessary condition to clearly see the object

GEOMETRICAL OPTICS

When the light hits perpendicularly the separation surface between the two substances, water and air, the light beam passes through undisturbed, following the same path with no change of direction. If, however, the beam hits the separation surface with certain angle, part of the light beam is reflected and part is instead refracted, i.e., it crosses the separation surface

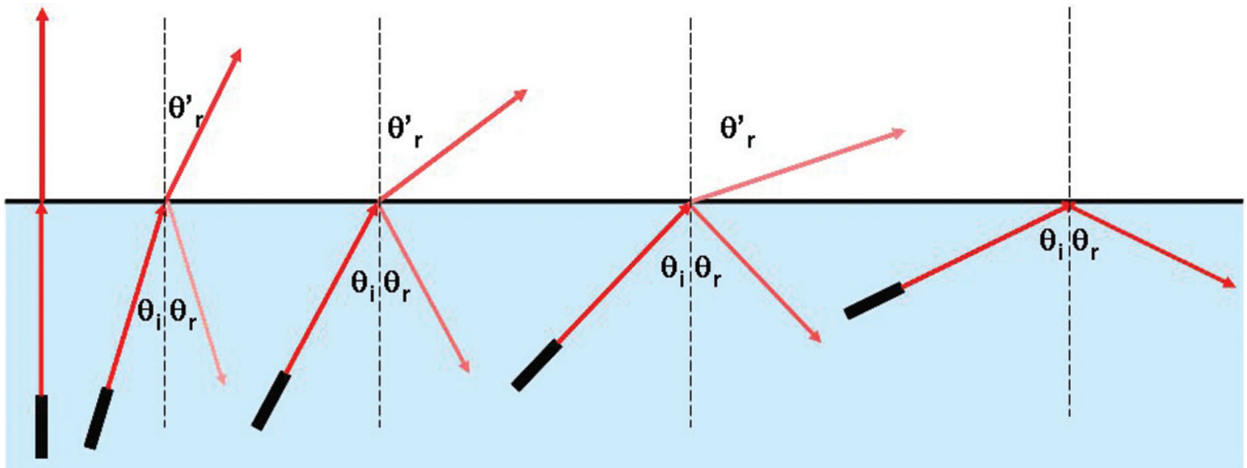

FIGURE A3: REFRACTIONS AND TOTAL REFLECTION AT AN INTERFACE

changing the direction of propagation (Figure A3).

In the following we clarify some of the concepts introduced above:

- The separation surface between two substances or materials delimits the spatial extension and defines their contours. The separation surface between two substances or materials can also be called interface between the two substances or materials. For example, the flat surface of a table is the *interface* between the table and the air. The flat surface of water in a bowl is the interface between the water the air. The interfaces are not necessarily smooth, in general they are rough.
- The beam which hits the interface between two substances or materials is called incident beam; the beam which does not goes beyond the interface after having hit it, i.e. it bounces back in the substance or material in which it was propagating before hitting the interface, is called reflected beam. The beam which goes beyond the interface after hitting it, i.e., it is transmitted from one substance of material to the other, along a *different* direction of propagation with respect to the incidence one is called *refracted beam*.
- In the schema of Figure A3 a beam propagates from water to air, then it hits the water-air surface at a certain angle with respect to the perpendicular to the surface. The angle between the straight line which represents the direction of propagation of the incident beam and the line perpendicular to the same interface is called *angle of incidence*. In the figure, the different angles of incidence depicted are all indicated with the symbol θ_i. The angle between the straight line representing the direction of propagation of the reflected beam and the line perpendicular to the interface is called angle of *reflection*. In the same figure, the different angles of reflection depicted are all indicated with the same symbol θ_r. The angle between the straight line representing the direction of propagation of the refracted beam and the line perpendicular to the interface is called angle of refraction. Finally, the different angles of refraction depicted in the schema are all indicated with the same symbol θ'_r

The following evidences can be verified by means of laboratory activities:

- in an homogenous substance or material, i.e., with the same physical and chemical characteristics, *light goes along a straight path*. Both air and water are homogenous substances.
- when light is reflected in the same substance, the incident and *reflected angles*, respectively θ_i and θ_r , are equal:
- given two homog $\theta_i = \theta_r$ ubstances, separated by an interface, when light is transmitted from one substance to another, the incident and refracted angles (respectively θi and θ'r) are such that (Snell's law):

$$n_{1,2} = \frac{n_2}{n_1}$$

where $n_{1,2}$ is a constant which depends on both substances and materials. In particular, $n_{1,2}$ is defined as:

$$n_{1,2} \equiv \frac{n_2}{n_1}$$

where n_1 and n_2 are called the refraction indices of the substances in which respectively the incident beam and the refracted beam propagate. The air has a refraction index very similar to that of vacuum, for which $n_{vacum}=1$. It is possible to experimentally determine that $n_{water} \cong 1.33$.

- when light goes from a substance with a certain index of refraction to a substance with higher index of refraction, the refracted beam approaches the perpendicular to the interface, whereas if light is transmitted in a substance with lower index of refraction, the refracted beam goes away from the perpendicular to the interface.
- when light goes from a substance with a certain index of refraction to a substance with higher index of refraction, as in the carried out experiment, since the refracted beam goes away from the perpendicular to the interface, it will reach a value of 90° after which there will be no more refracted beam and the all the light will be reflected back in the substance or material in which the incident beam propagated. The lowest incident angle for which there is no more the refracted beam (or, conversely, the largest incident angle for which refraction can still occur) is said critical angle. The existence of the critical angle is related to the fact that, from the Snell law, it is possible to find values of θ_i for which the refraction angle θ'_r is such that:

$$\frac{n_1}{n_2}\sin(\theta_i) \geq 1$$

the lowest of these values is when $\theta'_r = 90°$; in this particular case, the incident angle θ_i is indicated as θ_l, and hence we have:

$$\sin(\theta_l) = \frac{n_2}{n_1}$$

In the case of air and water one has $\theta l \cong 48{,}75°$. Therefore, to have total reflection, a beam has to propagate from a substance with a given index of refraction to another with lower refractive index.

NTENSITY AT THE SURFACE

The intensity of reflected and refracted light at the interface between two media varies according to the angle of incidence. In particular, when the angle of incidence is null, the intensity of transmitted light is essentially equal to that of incident light, no reflection occurring. Gradually increasing the angle of incidence of the beam, the intensity of refracted light decreases, while that of reflected light increases. For angles of incidence larger than the critical angle, the intensity of light incident is equal to that of reflected light, no refraction occurring. The variations in intensity of reflected and refracted light can be explained in terms of conservation of energy. The energy transmitted by the incident light beam redistributes among the reflected and refracted beam. Let the intensity of incident light be **I**, whereas $\mathbf{I_r}$ and $\mathbf{I_t}$ be respectively the intensity of reflected and refracted light, and hypothesizing that the intensity is linked to the energy transferred from light in the time unit to an object, for the conservation energy, we have: $\mathbf{I = I_t + I_r}$. In the cases where the angle of incidence is null or is larger than the critical angle two situations can occur $\mathbf{I = I_t}$ or $\mathbf{I = I_r}$. In all other cases, if the intensity of reflected light increases, that of refracted light must decrease, so that their sum remains constant and equal to the intensity of incident light.

The phenomenon of total reflection allows conducting light from one place to another, not following a straight path. For this phenomenon to happen, two substances (or materials) with two different indices of refraction are needed.

In conclusion, if we have a substance or a medium with a given index of refraction surrounded by another substance or medium of *lower* index of refraction and light is sent in the substance or medium with larger refractive index, it is possible to guide the light along a predetermined route. We actually have built a **light guide**.

OPTICAL FIBERS[1]

Once understood the mechanism underlying the functioning of a guide of light, it is rather easy to understand that of an optical fiber, which we explored initially.

The optical fiber is generally constituted by a thin wire silica-based glass, which exists in nature in the form of sand from the erosion or alluvial deposits; it has an inner part called "*core*", whose diameter range from 10 to a few tens of micron, covered with a concentric coating, of glass transparent to light and infrared radiation, called "*cladding*", whose diameter is about 125 µm. There are also optical fibers of plastic-like materials. The "*cladding*" has a refractive index slightly lower than that of the core. The core and the cladding are covered by means of a "primary coating" of plastic for protecting the optical fibers from mechanical scratches: its diameter is 250 µm. In Figure A4 the structure of a typical optical fiber is shown:

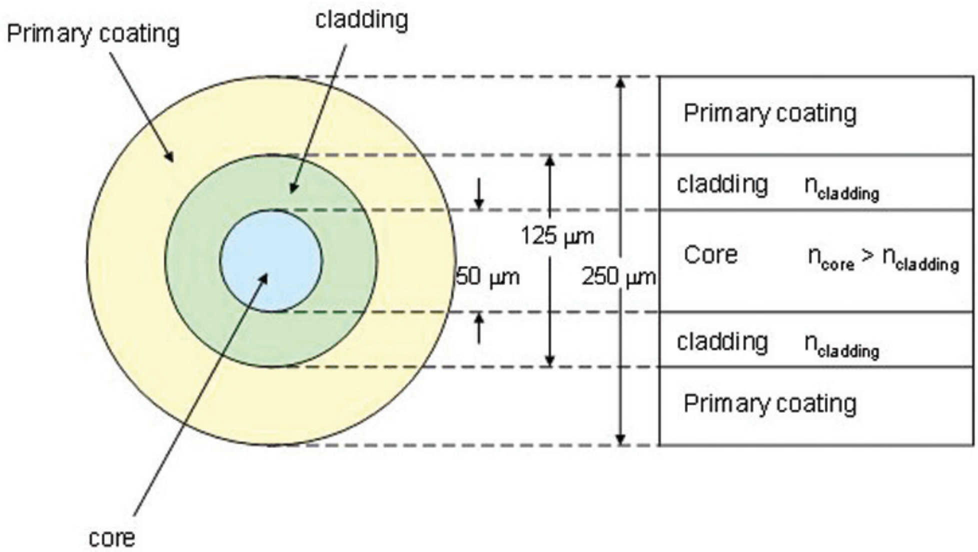

FIGURE A4: INNER SCHEMA OF AN OPTICAL FIBER

The propagation of light in an optical fiber happens in the core. Since the index of refraction of the core is larger than that of the cladding, it possible to obtain multiple total reflections within the fiber by sending a light beam so that the angle of incidence θ'_i on the interface between core and cladding is greater of the critical angle θ_l of these two materials. In this way the light beam undergoes a total reflection and propagates in the core by means of multiple reflections. If the angle of reflection was less than the critical angle, there would be refraction in the cladding: part of light beam would spread out in the outer part of the fiber and only the remaining part would propagate in the core by means of reflection. The latter part, then, would undergo further reflection and refraction and so on: after a short path, the light beam would vanish completely. Given the aim of a small loss of light intensity, the typical working condition for the optical fibers is total reflection. In Figure A5 a typical light beam pattern is shown.

The light enters in the fiber from a substance with index of refraction n_1, and travels in the core, whose index of refraction is n_2. Let θa be the angle of incidence between the light beam in the substance with refractive index n_1 (usually air) and the axis of the core; the law of refraction in our case takes the form:

$$n_1 \sin(\theta_a) = n_2 \sin(\theta_r)$$

If n_3 is the refraction index of the cladding, at the core-cladding interface, the law of refraction can be written as:

$$n_2 \sin(\theta'_i) = n_3 \sin(\theta'_r)$$

where θ'_r is the refraction angle in the cladding (not indicated in the figure).

1. *More details on optical fibers available on the web:*
http://www.unipi.it/athenet1-14/08/articoli/Addobbati.htm
http://www.synova.ch/pdf/ALAC04.pdf
http://www.synova.ch/english/synova.html
http://www.corning.com/opticalfiber/discovery_center/tutorials/fiber_101/aperture.asp
http://www.rpi.edu/dept/phys/ScIT/InformationTransfer/reflrefr/rr_summary.html

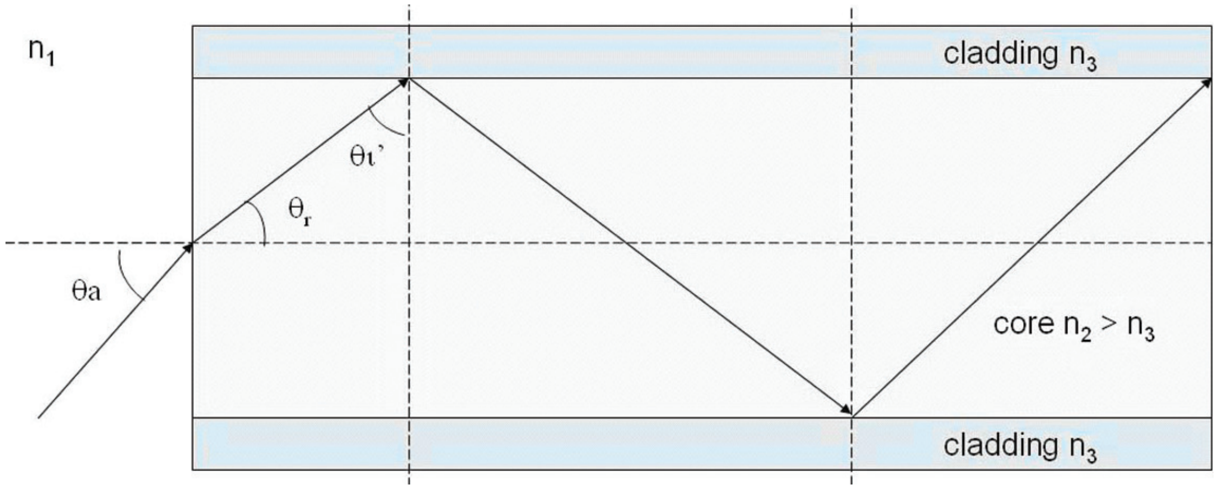

FIGURE A5: LIGHT PATTERN IN AN OPTICAL FIBER

Then one has,

$$n_2 \cos(\theta_r) = n_2\sqrt{1-\sin^2(\theta_r)} = n_2\sqrt{1-\left(\frac{n_1}{n_2}\right)^2 \sin^2(\theta_a)} = n_3 \sin(\theta'_r)$$

Simplifying we have:

$$n_1 \sin(\theta_a) = \sqrt{n_2^2 - n_3^2 \sin^2(\theta'_r)}$$

Given the refraction indices of the core and the cladding, we define the acceptance angle θ_M of the fiber the lowest value of θ_a which allows the total reflection at the interface between core and cladding, i.e. the lowest value for which $\sin(\theta'_r) = 1$, that is:

$$n_1 \sin(\theta_M) = \sqrt{n_2^2 - n_3^2}$$

The quantity

$$NA \equiv n_1 \sin(\theta_M)$$

is called numerical aperture of the fiber.

- by varying the refraction indices of the core and of the cladding, also θ_M changes and hence the numerical aperture of the fibers. From the relation:

  $$NA \equiv \sqrt{n_2^2 - n_3^2}$$

  if $n_2 = n_3$ we have $NA = 0$ and hence $\theta_M = 0$. In this case the propagation can happen only if the light beams travels in a direction parallel to the axis of the core. If $n_2 \cong n_3$ total reflection condition is obtained for a large critical angle , hence the beam propagates in the core with few reflections, but the acceptance angle θ_M and consequently the numerical aperture NA are still small. If $n_2 >> n_3$ it can be obtained a larger numerical aperture NA and acceptance angle θM, but the critical angle θl is small, so that the beam propagates following a rapidly varying zig-zag trajectory.

  Typical values of core and cladding refraction indices are $n_2 = 1.48$ and $n_3 = 1.46$, for which $\theta_l \cong 80.6°$ and $NA = 0.242$. Moreover, if $n_1 = 1$, $\theta_M \cong 14°$.

OPTICAL FIBERS' CHARACTERIZATION

- Multimode vs. Single mode optical fibers

In the following we will assume that different light beams constitute a certain type of **signal** to be transmitted along the fiber. Moreover, we will assume that the light beams can be characterized by their **wavelength[3] λ**. If the fiber's core has a diameter *d* many times greater (for example 100 times) than the light wavelength, the beams can enter at very different entrance angles. Such angles of entry are usually called modes of propagation (or modes) of the fiber: this kind of fiber is called **multimode**. An approximate relation to determine the number of modes M for a given wavelength λ is:

$$M \cong \frac{1}{2}\left(\frac{\pi d}{\lambda} NA\right)^2$$

2. *In fact $\sin(\theta_l) \cong 1 \rightarrow \theta_l \cong 90°$*
3. *At this point, the difference between the ray and wave model of light should be clarified to students*

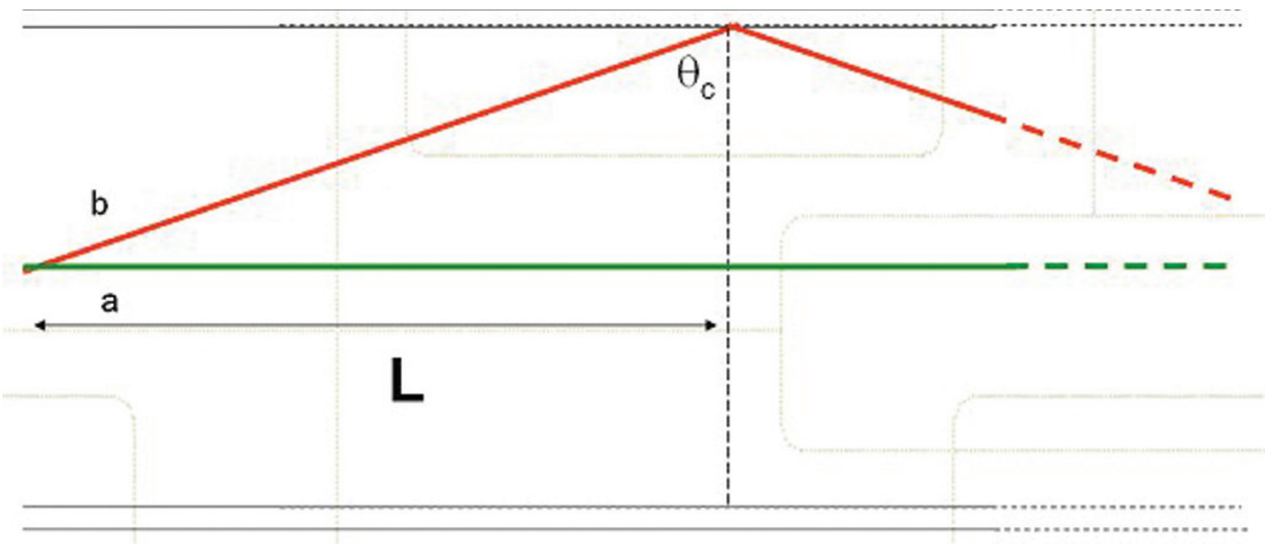

FIGURE A6: MODEL DISPERSION IN A FIBER

Typical values of core's diameters are around 50 µm, cladding diameter is about 125 µm. Multimodal fibers has several shortcomings: the major of these is that light beams can enter at angles greater than the acceptance angle, undergoing refraction at the core-cladding interface with consequent losses of information. One possible remedy is to force light beams enter the fiber within its acceptance angle in order to have only total reflection at core-cladding interface. Even in this favorable situation, some problems in the transmission of the signal may arise. Also in this case, light beams can be both parallel and not parallel to fiber's axis. The following situation may occur: beams parallel to the axis (characterized by an entrance angle = 0°) travel **faster** than the not parallel ones (characterized by an entrance angle > 0° but less than the acceptance angle) since they cover a shorter path. To demonstrate this, consider the beams **a** and **b** in Figure A6.

Beam **b** enters the fiber at the acceptance angle (not indicated in the figure) hence it is totally reflected at the core – cladding interface at the critical angle θ_C. When **b** reaches the interface it has travelled a distance equal to:

$$\frac{L}{\sin(\theta_c)}$$

whereas beam **a**, which travels along the fiber's axis has travelled a distance equal to *L*. For a given length *L*, beam **b** covers the longest path whereas beam **a** the shortest one. Since both **a** and **b** travels in the same material with the same velocity, beam a travels in the shortest time, **b** in the longest one. We then have, if n_2 and n_3 are respectively the refractive indices of the core and of the cladding.

$$t_{min} = \frac{L}{v} = L\frac{n_2}{c}$$

$$t_{max} = \frac{1}{v}\frac{L}{\sin\theta_c} = L\frac{n_2^2}{cn_3}$$

where we have used the fact that:

$$v = \frac{c}{n_2}$$

If Δt is the delay of the beam **b** with respect to beam **a** we have

$$\Delta t = t_{max} - t_{min} = \frac{L \cdot n_2}{c \cdot n_3}(n_2 - n_3)$$

It is easy to see that the same holds if we consider all the length of the fiber. If the beams constituting the signal take different times to travel within the core, the overall duration of the signal at the end of the fiber is not the same of the initial duration. This phenomenon is known as modal dispersion. To reduce modal dispersion it is necessary to have the core and cladding refraction indices n_2 and n_3 very similar. In some cases, if the core diameter is several times greater than the wavelength of the used light, this design solution could be not sufficient. Hence, to further reduce modal dispersion, it is necessary to reduce the core's diameter (for example down to 10 times of the light wavelength). In this case, the acceptance angle is very small[4]: as a consequence, the beams travel almost parallel to the fiber's axis. At limit, light beams enter at only one angle and only one mode is allowed. Such fiber is said **single-mode**. An approximated value for the core's diameter *d* of a single-mode fiber is:

$$d \cong 0.76 \frac{\lambda}{NA}$$

where λ is the wavelength of the light used. Single mode fibers are the most used in transmission systems. Typical values of core's diameters are around 5 μm, cladding diameter is about 125 μm.

- Step-index vs. graded-index optical fibers.

When the core and cladding refraction indices are everywhere constant, the fiber is said **step-index**. This name comes from the fact that the refraction index in going from the core to the classing decreases with a step-like discontinuity (Figure A7).

Step-index fibers are extremely affected by modal dispersion. To avoid this and other problems, special fibers have been designed in such a way that going from the core to the cladding, the difference between the refraction indices is smoothed (Figure A8). In this kind of fibers the light beams do not follow rectilinear but curved trajectories. Amongst the many advantages of these fibers, the reduction of the modal dispersion is one of the most appreciable ones.

OPTICAL FIBERS' APPLICATIONS

Usually an optical fibers is inserted into a structure called optical cable which is able to withstand external tension and torsion (Figure A9). The optical cable has characteristics that depend on the number of fibers in the cable (from four to several hundred).

The optical fibers are currently used in many fields and it is now impossible to determine what their main application it. Since the 70s, optical fibers were used as decorative object for the production of lamps; today they are an essential component in the telecommunications industry. The optical fiber in general is part of an instrument (fiberscope), important for uses in medicine, but also widely used in industry control process. Recently, the use of fiber optics is combined with that of lenses, probes, lamps and electrical components.
Schematically, optical fibers are used in four different areas:

- in the transmission of light at low power. An example is the decorative lamp which receives light from a light bulb in a small base and transmit it to the external end of the fibers (Figure A10)
- as instrument of observation, to focus the light in a confined space, and therefore to examine small objects in otherwise inaccessible locations (Figure A11). The main applications are the external and internal inspection of components like engines, mechanical devices, etc….
- in the data transmission: this is the sector of telecommunications in which the optical fibers are used over both long distances (as metropolitan areas of large cities) and short distances (local networks). The information are converted into light waves to transmit, and then re-converted in the original form. Modern telecommunication systems typically consist of a transmitter device used for encoding electrical signals into light signals, optical fiber for the transmission of the signals and a light sensor for the conversion of light signals into electrical signals.
- in endoscopy, a medical term that indicates a field of diagnostics. In this case, the inspective instruments are made of optical fibers both rigid and flexible. The main instruments used in endoscopy are the endoscopes, which are used for lighting and display a larger picture of objects inside cavities, and fibroscopes, which are used for enlightening places where it is not possible to have a straight path between the eye and the object. These tools can be equipped at the end with forceps, retractors, needles, tubes for injection and extraction of gas, injection and extraction of liquids. These instruments can also be connected to cameras for a suitable display of the acquired images.

4. *Note that the relationship for the numerical aperture $NA = (n_2^2 - n_3^2)^{½}$ was obtained in the geometric optics approximation, hence when the dimensions of the core's diameter were greater than those of the light wavelength. Here, this hypothesis does not hold.*

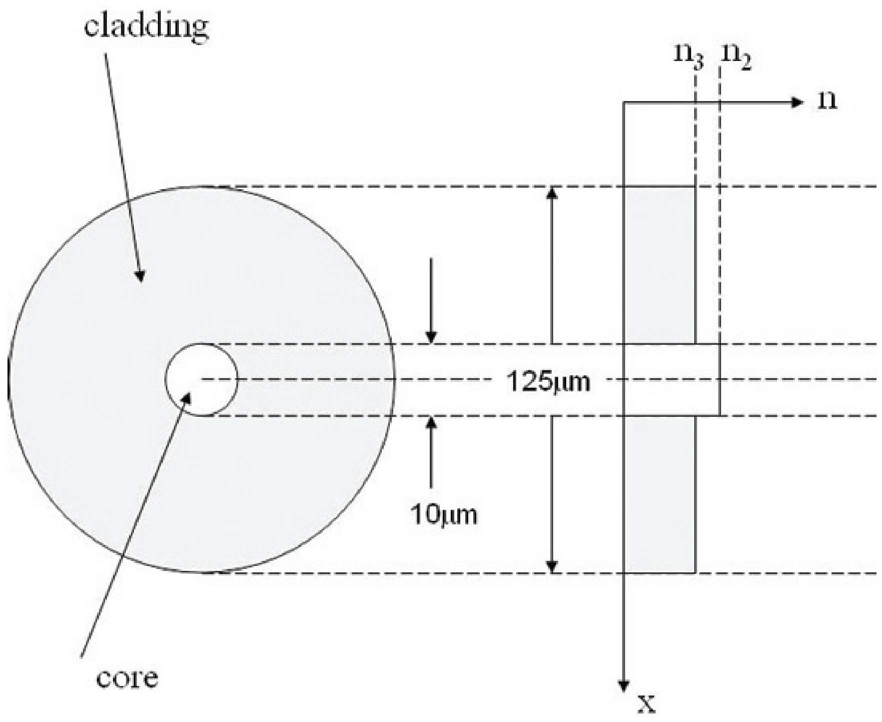

FIGURE A7: INNER SCHEMA OF A STEP-INDEX OPTICAL FIBER

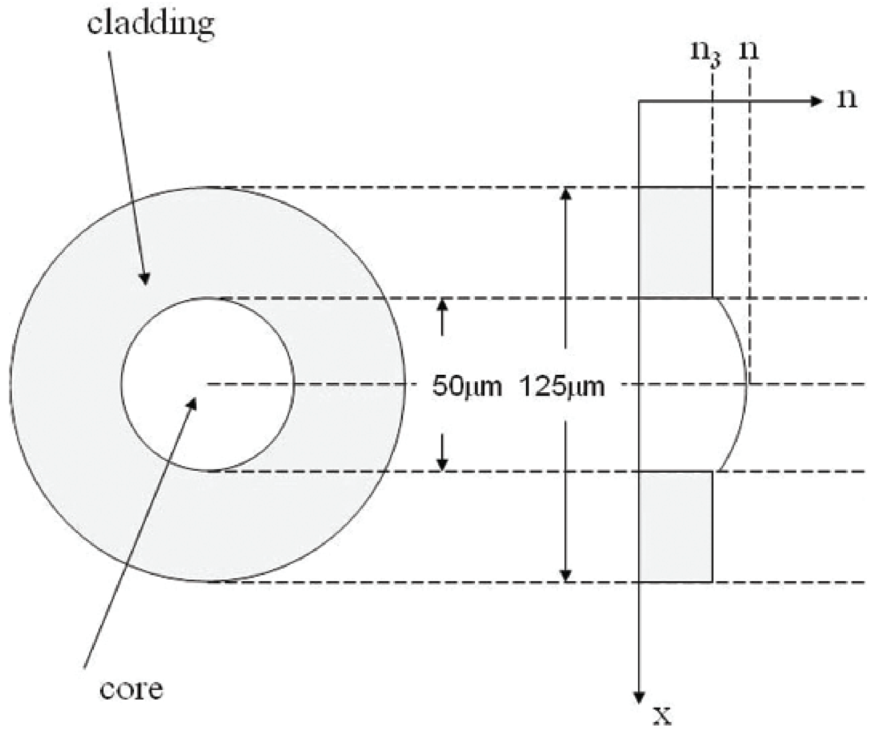

FIGURE A8: INNER SCHEMA OF A GRADED-INDEX OPTICAL FIBER

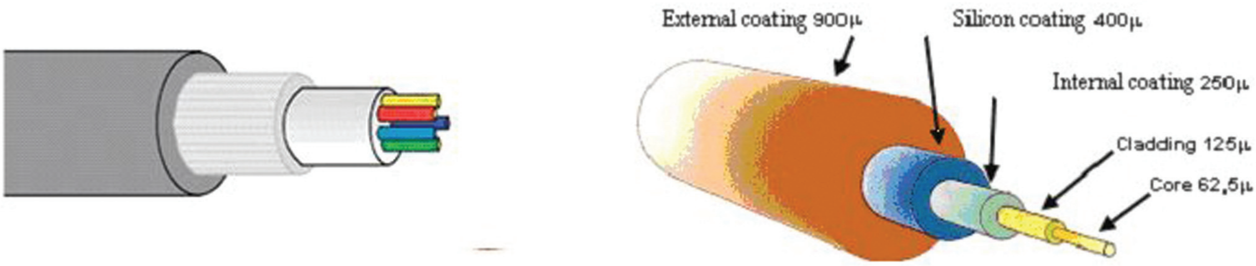

FIGURE A9: STRUCTURE OF AN OPTICAL FIBER

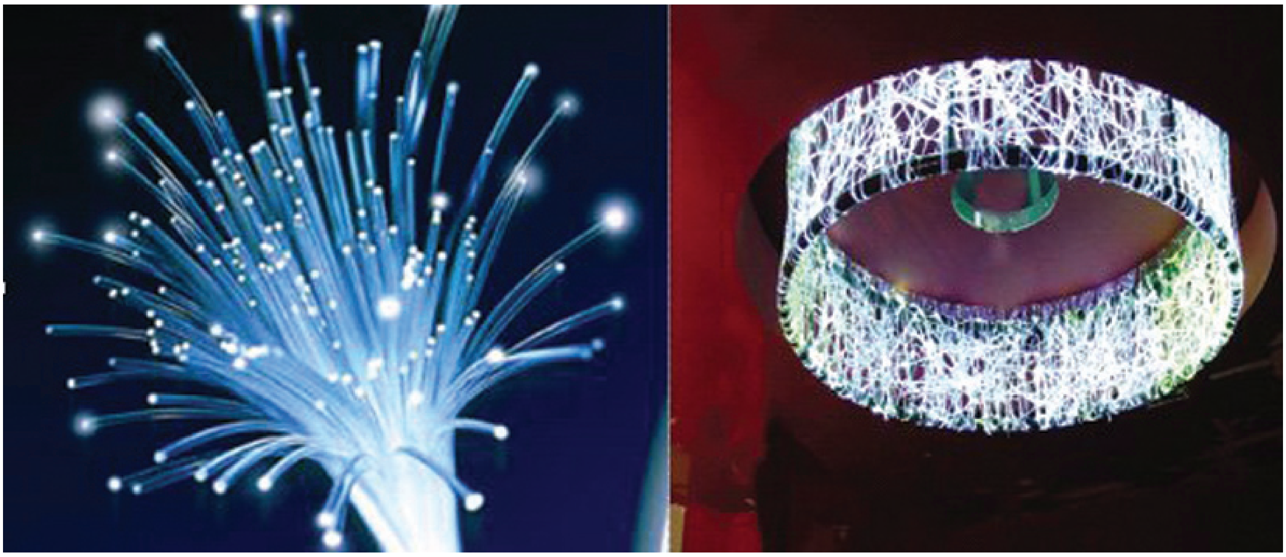

FIGURE A10: LIGHTING APPLICATIONS OF OPTICAL FIBERS

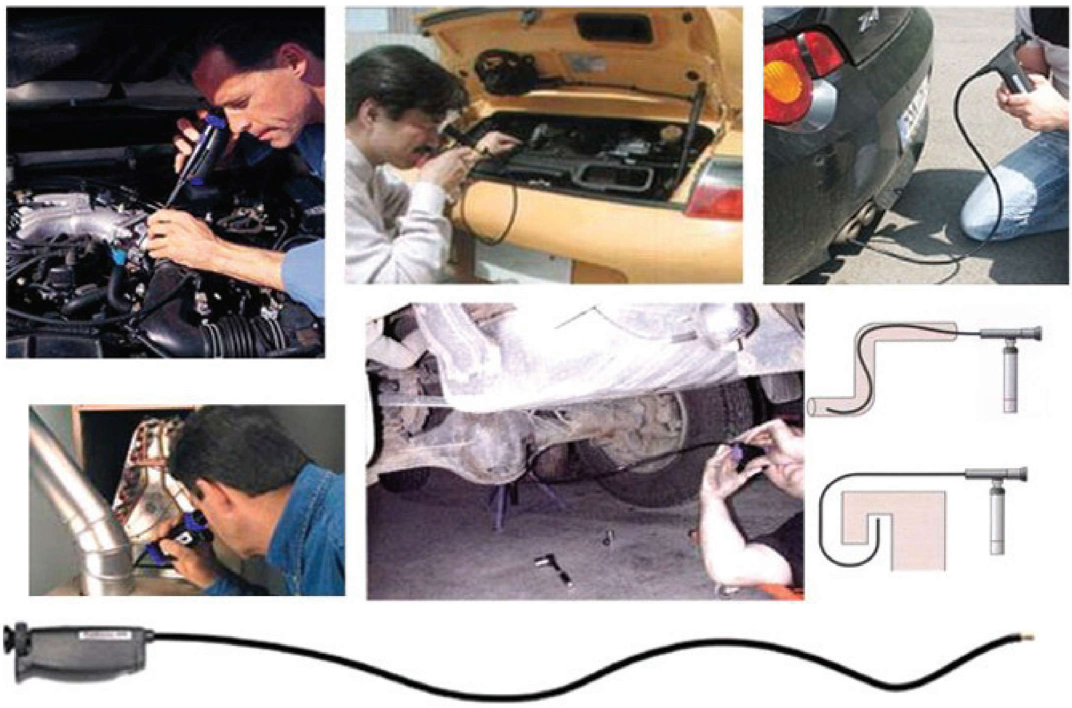

FIGURE A11: CAR APPLICATION OF OPTICAL FIBERS

4. PRIOR KNOWLEDGE OF STUDENTS

Euclidean geometry: line, angles, perpendicular line, parallel line, Talete's and Pitaghora's Theorems

Basic principles of physics measurements and instruments (means, standard deviation, repeat measurements, sensibility, accuracy,……)

5. AIMS OF THE MODULE

The choice of light guides and optical fiber as main contents has driven the choice of the main UoN Module aims.

In fact, from the disciplinary viewpoint, the study of optical fibers can allow/help students to understand how and under which conditions light can be guided along a specific path and how optical fibers do so. The role played by the refraction index of the fiber's material(s) can be clarified via concrete examples and its knowledge therefore deepens, beyond a mere formula rote learning. The analysis of different types of fibers facilitates the awareness about why so diverse fibers are used in diverse fields. Finally, to observe and study the fact that in the fiber the light not only is trapped and proceeds to the end top but also undergoes attenuation is a value per se and may lead to discuss how light behaves when propagating within materials and to look at such behavior in terms of Energy (transfer and conservation). From the technological viewpoint, the focus is on the awareness of science in social contexts: the optical fibers allow putting a strong emphasis on the relationships between scientific/technological issues and every-day applications. The main aim is to motivate the students toward scientific studies through an attention on "techno-object" which can be found every-day life (many students not only are used to see the "cabling" of cities via fibers, but they use fibers-based gadgets) and to know what are the main applications of optical fibers (medicine, telecommunications, house lighting, etc…). In the following two paragraphs we detail these broad aims.

SCIENTIFIC CONCEPTS

In this category we have identified two broad areas of aims, namely those related to traditional secondary school curricula ("traditional physics") and those related to more advanced topics, not usually present in secondary school curricula ("not traditional physics"). The UoN module's activities will exploit optical fibers' properties as a suitable mean to reach such aims.
In particular, after completing this module a student should be able:
("traditional physics")

- to describe propagation of light in terms of the 'ray' model
- to qualitatively and quantitatively describe how and under what conditions light bends from rectilinear path (Reflection and Refraction phenomena)
- to characterize materials by means of their refraction index
- to explore under which conditions total internal reflection occurs

("not traditional physics")

- to state under what conditions light can be guided along curved paths
- to interpret the role of diffusing particles in determining materials' transparency
- to explain the basic physics principles underlying attenuation in a fiber
- to distinguish between the role of the interfaces and that of the bulk properties;
- to become aware of how material's optical properties determines of the critical angle's value.

TECHNOLOGICAL ISSUES

Some activities of the UoN Module aim specifically at bridging scientific and technical knowledge. This is achieved, in particular, emphasizing the basic principle underlying specific characteristics of optical fibers. Hence, after completing this module a student should be able:

- to relate acceptance angle and numerical aperture of a step optical fiber to the optical properties of the fiber's materials
- to state and apply the qualitative relationships between numerical aperture and core and cladding refraction indices
- to interpret the phenomenon of modal dispersion
- to introduce basic physics properties at the basis of a graded index optical fiber

In Document D a complete list of the learning objectives is provided.

6. PEDAGOGICAL APPROACH AND METHODOLOGICAL ASPECTS

The Module's activities are based on a teaching approach that features the following pedagogical and methodological aspects.

PEDAGOGICAL ASPECTS

The main choice is to give evidence to students of what is the light path in certain conditions. Such a choice is related to the fact that geometrical optics has to do basically with light trajectories but seldom students have the possibility in their every-day experience to observe such path. To this concern, taking into account also previous studies in science education about other disciplinary areas (e.g., electric circuits), we chose to address this issue from both global and local viewpoints.

At a global level, we address the distinction between the behavior of light when it travels within a material and when it encounters the separation surface of two materials. Such behavior is related with the materials' optical properties (as the transparency and the index of refraction) first by means of the light's rectilinear propagation principle, then by means of the refraction and reflection laws. We start from the behavior of light within a material since it can be related to the mechanism of vision and to a wider students' every-day experience.

Then, at a local level, we deepen the behavior of light at the interface between two materials: here the focus is on refraction and reflection. These phenomena are introduced as aspects of the deviation of light from the rectilinear path and consequently they are not treated as independent but addressed in the same situation of a laser beam propagating into a water tank. In particular, refraction is introduced first and described by a law which features an optical property of the two involved materials, index of refraction, whereas reflection is discussed in a situation of total reflection. More specifically, reflection is interpreted as a way to bind the light to propagate within a material in a not rectilinear way. This leads to identify, at the local level of a given material, the conditions to guide the light when it does not propagate in a rectilinear way. The reflection and refraction laws previously introduced are then used to interpret the basic functioning of the optical fiber addressed in the initial scenario. Throughout the activities a strong focus is put on what happens at a local level to the changes in the light path when some conditions at the surface between two materials are changed (e.g. different inclinations and positions of the surface).

A global viewpoint on light propagation is again adopted when addressing the design of optical fibers for telecommunication purposes, deepening the propagation of light beam in cores made of not homogenous materials

METHODOLOGICAL ASPECTS

The first methodological choice is a descriptive modeling approach (Lijnse, 2008) inspired to the "from Real to Ideal" rationale, experienced in UoN since many years (Sassi, 2001). The paths implementing this rationale start from experiments which explore real, complex facts well known to students in terms of common sense knowledge, to facilitate this background and to elicit naïve ideas. They proceed to the identification of phenomenological regularities which are transformed in rules, through more "clean" experiments, in which secondary effects have been minimized. They proceed further to modeling these rules with simple mathematical functions. The final step is the abstraction toward the ideal case/model representing the appropriate physics law. This rationale is implemented in the Module through a method, proposed by our group (Monroy, Lombardi & Testa, 2008; Testa & Lombardi, 2007), by means of which it is possible to carry out accurate measurements and build-up effective descriptive models of phenomena where a trajectory is visible and an image is produced via a digital camera. The trajectory can be that of an accelerated electron beam, as it is the case in the Thomson-like apparatus, or of a water wave in a ripple tank or of a laser beam propagating in different media. The basic idea is to model the trajectory by means of geometrical entities (line, circumference, parabola, etc…) and then to measure its parameters by means of the well-known educational software Cabrì Géomètre. We have obtained accurate measurements (about ±0.1%) of wavelength of straight and circular water waves in a ripple tank and of the electron charge to mass ratio.

In the Module' framework described above, the following steps are implemented: - to observe a complex phenomenon of light propagation (in a water tank or in air) and to perform experiment; - to import a picture of the experiment in the Cabrì Gèométre environment in order to identify regularities through measurements on the picture; - to transform the regularities in rules by use of Cabrì simulation; - to go back to the original experiment and interpret it.

Furthermore, we propose to use Cabrì Gèométre to estimate the refraction index of water and the incident angle at which total internal reflection occurs when a laser beam propagates in air and water, by means of digital photos made by students who carry out the experiment. In this way students can: - build up a simple model of how an optical fiber works; - identify and estimate the parameters (characteristic of a given material) which allow describing how a laser beam (i.e. the information to be transmitted) can be guided across space. Further modeling activities will be proposed mainly to help students: - learn that the same model can describe various phenomena; - become aware of power and limits of a model; - understand the different meanings, roles and scopes of a model with respect to a simulation of a given phenomenon.

The second choice is a laboratory-based inquiry approach. The reasons for the choice of such methodological framework can be summarized as follows: - inquiry is nowadays acknowledged as central in science learning (NRC, 1996; Lunetta, 1998); - research shows that deeper understanding can be achieved on behalf of students when they are involved in inquiry activities (Metz, 1995); - inquiry activities can be effectively supported by technology in order to provide authentic learning environments (Edelson, 2001); - it can foster young students' motivations (Mistler-Jackson & Songer, 2000) and scientific reasoning (Metz, 2000).

Scientific inquiry is defined as "*the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work*" (NRC, 1996, p. 23). As Krajicik et. al (1999) states: "*Inquiry involves making observations, posing and refining questions, seeking background information, planning and designing investigations, using tools to collect, analyze and interpret data, explaining and communicating findings*". Nevertheless, several different views about inquiry are held by researchers in science education (Schwartz & Crawford, 2006): often inquiry is intended only as "hands-on", "activity-based" or "student-originated activity" but such perspectives reveal only a teaching strategy or method and do not reflect the complex meaning of the term. Actually, a debate about what is "authentic scientific inquiry" and "school-based scientific inquiry" is still ongoing although in some cases authors may share the view that "authentic scientific inquiry" pertains to the practice of professional scientists and that school-based scientific inquiry may feature some similarities with the process experienced by scientists in their everyday practice. That means that essential features of scientists practice maybe translated into learners' school practice. Example of these features are (Bybee, 2006):

- learner is engaged in a scientifically oriented question
- learner gives priority to evidence in responding to the question
- learner gives priority to develop an explanation
- learner connects the explanation to scientific knowledge
- learner communicates and justifies the explanation

Put in other words, when learners are engaged in inquiry activities, they are faced with open-ended challenges wherein new scientific knowledge would be developed. Inquiry activities are essentially student-centered and focus on improving his/her abstraction, modeling and communication skills.

In the UoN Module scientific inquiry approach is implemented by means of both experiments and technology-enhanced activities (see paragraph below). The rationale of such choice is not only to extend the explorations carried out in the experiments to situations not easily reproducible in classroom but mainly to provide students with a modeling/simulation environment (Cabrì Géomètre) in which it is possible to investigate scientifically meaningful questions and facilitate the visualization of the mechanisms underlying the behavior of 'real' objects. In this way, the context of inquiry is widened as well as the possibilities to achieve a more authentic learning from the scientific viewpoint. Moreover, in doing so, it is possible to overcome a reported reduction of inquiry tasks to simple "get the right answer" attitudes (Wallace et al, 2000).

Finally, the inquiry approach had been interpreted and implemented in a way such that the teacher: -

suggests a scientific question to be addressed, encourages the students to express their ideas and formulate hypotheses; - suggests to perform a semi-guided experiment; - fosters students to test hypotheses and reflect on the initial scientific question/problem. For these aims to be transferred into teaching practice, as well as to minimize the risks that teachers in their class-use exploit the inquiry tools in ways that differ from those for which they were developed (Kim, Hannafin & Bryan, 2007), it is essential, in the overall development of the Module, to synergically integrate the participation to the design, the training and the feedback of teachers (see part E).

7. RELEVANT ICT TOOLS

The simulations proposed in the Module are integrated with hands-on laboratory activities. The rationale of this choice is linked to the fact that, usually, the Snell's laws of reflection and refraction are verified by means of low-cost experiments (light beams, mirrors and water tank, etc…) but often the experimental results are not sufficient for a deep clarification of these laws; moreover, experimental settings needed for precise measurements are not always easy to put up in school practice. Therefore, simulation and modeling activities are more and more used to complement laboratory work in optics, especially as far as more complex phenomena (lenses' behavior, interference and diffraction) are concerned. simulations of phenomena occurring when light interacts with matter (e.g., reflection, refraction, interference, diffraction, etc…) are nowadays widely diffused[5].The synergy of lab-work, simulation and modeling activities is powerful from an educational viewpoint since the competences that can be gained through both of them are diverse and complementary. Moreover, such threesome interaction can be useful to address the following issues: - perception, on behalf of the teachers, that the laboratory activities have more disadvantages than advantages from the educational viewpoint since unforeseen events may impair to reach the intended learning objectives; - distinction between simulation and model, which often are considered as synonymous

From the operative viewpoint, throughout the Module, experiments (performed by the teacher of by the students themselves) and ICT-enhanced activities essentially aim at actively engaging students in the "quest for the suitable materials' optical properties" to justify observed behavior of simple light guides (as a water jet) and optical fiber; the somewhat limited "hands-on" feature of inquiry here is enlarged by means of a thoughtful experience which promotes the development of formal thinking and higher level reasoning strategies. The activities allow students to gather 'clues' about the needed materials' properties (e.g. transparency, geometrical arrangement, specific relationships between refraction indices of two materials, etc…); the clues are enriched throughout the Module by means of experimental situations, investigated iteratively under different viewpoints/models (e.g. surface vs. bulk properties) to formulate hypotheses for the mechanisms at the basis of the observed behaviors. Plausibility of the hypotheses provided by the students is then tested in the modeling/simulation environment: in this case, students are prompted to write down sentences which summarize the observed regularities, in order to enhance rationalization, synthesis and own ideas' communication skills.

Simulations are designed using the Cabrì Gèométre environment to improve students' abstraction capabilities and modeling competences, especially in geometric optics. But mainly, there is the possibility given to teacher to choose which simulations are more suitable for the students and, consequently, which are the most meaningful activities to be proposed. The choice of Cabrì Géomètre as a flexible simulation (e.g., the teacher may design his/her own simulations) and modeling (e.g., the teacher may use digital photos of experiments obtained during class activities) tool may help teachers in overcoming traditional obstacles in implementing ICT-enhanced inquiry activities (Wallace, 2002) such as the lack of time to develop meaningful students' tasks. In particular.

Finally, since materials used for constructing optical fibers appropriate to telecommunications are expensive and not always easy to find, with Cabrì Géomètre we will design easy-to-use simulations which exploit the model of the optical fiber constructed in the experimental phase and which will allow to see how changes in the material structure (i.e. change in refraction index) can modify travelling light patterns.

5. *For example the NTNU JAVA Virtual Physics Laboratory by Fu-Kwun Hwang (http://www.phy.ntnu.edu.tw/ntnujava/) and The Physlet Project (http://webphysics.davidson.edu/Applets/Applets.html) which both provide a wide spectrum of "media-focused" critical thinking and problem-solving exercises, with interactive visual representations of the physical phenomena*

8. COMMON STUDENT DIFFICULTIES (WITH REFERENCES TO THE SCIENCE EDUCATION RESEARCH LITERATURE)

Research studies in science education about optics cover a range of students' instructional levels (1st - 10th grade). Roughly they can be divided in two groups dealing with: 1) the nature of light and its interaction with optical 'objects' (as lenses, mirrors, etc…) and with matter; 2) the mechanism of human vision. Here we briefly resume the most salient findings of this extended body of knowledge.

- students use many different models to explain vision: some students hold the Pythagorean view that vision is an active process, the origin being the subject himself (Guesnè, Tiberghien & Delacôte, 1978). This result, plausibly related to phrasing of common language ('look that kills'; 'piercing eyes'; 'X-ray vision'), has been well confirmed (Andersson & Karrqvist, 1982; La Rosa et al., 1984; Palacios, Cazorla & Madrid, 1989). In another model, the light first hits the eye, which either reflects or emits kind of a beam which finally reaches the 'seen' object (Crookes & Goldby, 1984; Ramadas & Driver, 1989). In other cases, there may be no direct connection between eye and object, provided it is luminous (Osborne et al., 1990).
- the ideas about the nature of light have been addressed long ago by Piaget (1929, 1930) who also focused on shadows formation and projection. More recently it has been found that some students think that light is a 'material medium' (Palacios, Cazorla & Madrid, 1989) or a 'resident medium' (La Rosa et al, 1984) which fills the space "like a sea" (Selley, 1996) and does not propagate, remaining nearby the source (Stead & Osborne, 1980). Only for a minority of students, light propagates along a rectilinear path (Andersson & Karrqvist, 1982; Guesnè, 1984);
- although students' ideas about propagation of light have been thoroughly researched (see also Tiberghien et al., 1980, Rice & Feher, 1987), much more common are studies about difficulties in understanding image formation by lenses and plane mirrors. First, these studies indicate difficulties with image's constructions via the 'rays' diagram' (Selley, 1996) unless a sound understanding of the rules to use when tracing such diagrams (e.g., draw only few emblematic rays) has been reached. The ray model can be misleading and confusing, students can think of rays as real entities (Viennot et al., 2005). Secondly, some students think that mirrors reflect all the incoming light and that the image is resident on the mirror or just behind it (Goldberg & McDermott, 1986). Another naïve conception is that the object's image travels to the mirror in presence of light (Galili, Bendall & Goldberg, 1993); a very similar one is held with respect to lenses (Goldberg & McDermott, 1987; Galili, Bendall & Goldberg, 1993). It has also been found that some students think that: - the image always remains focused independently of the distance between lens and screen; - half a lens produces half an image (Galili & Hazan, 2000); - a lens can also increase the velocity and energy of light passing through it (Palacios, Cazorla & Madrid, 1989);
- as far as reflection and refraction are concerned, some students do not recognized them as due to the interaction of light with matter and/or materials but think of them as two mutually exclusive properties: when there is reflection no refraction can take place, and vice-versa (Palacios, Cazorla & Madrid, 1989). In the same study, confusion between refraction and diffraction is also reported; another study (Singh & Butler, 1990) has shown that students have difficulties in drawing refracted rays in not standard situations (as, e.g., rays hitting an oblique face of an equilateral prism and a semi-circular glass block) and in recognizing conditions necessary for total internal reflection (e.g., unless the angle of incidence appeared very large most students do not consider total internal reflection).

Most of these results have been confirmed by studies involving prospective primary teachers (Bendall, Galili & Goldberg, 1993; Heywood, 2005). Galili (1996), within the theoretical framework of the facets of knowledge (Minstrell, 1992) states that, in this content area, "naïve ideas of cardinal importance, though modified, remain different from scientific schemes". This viewpoint justifies the plenty of research efforts to address conceptual difficulties in optics.

9. MONITORING STUDENT LEARNING

INSTRUMENTS FOR ASSESSMENT OF LEARNING OUTCOMES

The assessment tasks are designed to validate the module's activities, probing if the intended learning objectives have been substantiated in suitable students' learning outcomes. Mainly it is expected from students a sound understanding of the addressed concepts, as the mechanism of vision, basic geometric optics laws and the behavior of optical fibers. Moreover, the assessment task are aimed at investigating students' acquired skills in: - exploiting materials' optical properties to explain phenomena involving e.g., reflection, refraction and total reflection; - explaining and interpreting the observed phenomena building up simple models using Cabrì Géometrè or other similar computer tools (GeoGebra); - designing and setting up simple experiments with common materials; - designing simple light-guides satisfying suitable criteria.

Student assessment also focuses on the transfer of acquired knowledge and skills in contexts that were previously unfamiliar to the students.

The designed assessment tasks can be proposed as homework to be discussed by the teacher in classroom during the following teaching sessions, or they can be used by the teacher during classroom time.

In document D the assessment tasks and rubrics are reported.

MONITORING STUDENT ENGAGEMENT AND MOTIVATION

To investigate Students' engagement in the proposed inquiry activities and motivation towards learning science, we adopted three common investigation tools:

- using the Self-Determination Theory by Ryan and Deci (2002) the Finnish team has developed a 24-items questionnaire (Q1) to identify 3-4 students with different motivational orientations towards the study of physics and scientific school subjects. The questionnaire Q1 requests the students to evaluate how well each item corresponds to the reasons why they learn science.
- on the basis of the questionnaire Q1 data, 3-4 students are chosen and interviewed according to a semi structured protocol. The data are categorized using categories used also to analyze the content of the designed Module solution. The data will be organized according to the following categories: *- autonomy-supporting activities; - support to students' social relatedness; - support to students' feeling of competency; - support to interest and enjoyment; - material science content and context;*
- a second questionnaire (Q2) has been developed to investigate the features which arouse, maintain and channel students' behavior towards the science inquiry activities. This investigation is performed before and after the teaching. In this way it is possible to compare the inquiry activities carried out in the Module with laboratory activities usually carried out at school. The students are asked to evaluate how well 29 items correspond to their perception of inquiry/laboratory activities. From the comparison it can be plausibly inferred how motivating the designed module's activities were.

10. RATIONALE OF EXTENSION ACTIVITIES

Refer to document C.

11. OTHER USEFUL INFORMATION – LIST OF RELEVANT ARTICLES, LINKS TO WEB SITES ETC.

BRIEF SUMMARIES OF RESEARCH STUDIES ABOUT STUDENTS' DIFFICULTIES IN OPTICS[6]

- **Jung (1981) [Italian translation by Michelini & Ossicini (1986)]**

  Different interpretative frames in optics are analyzed in relation to context. Naive ideas about seeing, light, colour, darkness are investigated. Need to restructure naive conceptions in optics is encouraged.

- **La Rosa et al. (1984)**

  Ideas about light, colour, and geometrical optics were explored through interviews with teachers and open-ended written questions administered to high school students. On the basis of their observations, the authors propose a progression of stages in student thinking about light.

- **Watts (1985)**

  A detailed description is given of the views of a high school student on the nature of light. Many of the common misconceptions are represented in the discussions quoted.

- **Goldberg & McDermott (1986)**

  During interviews, university students were shown an object in front of a mirror and asked what an observer at various locations would see. Many students could not make correct predictions either before or after instruction.

- **Goldberg & McDermott (1987)**

  Even after instruction, many students could not apply the formalism of geometrical optics to predict or account for the image formed by a converging lens or concave mirror.

- **Palacios, Cazorla & Madrid (1989)**

  The topic of geometrical optics is chosen to diagnose preconceptions of trainee teachers in order to explore the existence of a possible quantitative relationship between constructivist and Piagetian models. A useful summary of experimental studies up to year 1987 about students' conceptions on light phenomena is presented in Table 1. Many misconceptions are presented in Table 4.

- **Singh & Butler (1990)**

  15 to 19 years old students' conceptions about refraction are investigated. The questionnaires addressed quantitative relationships between incident and refracted rays, refraction at plane and curved interfaces, refraction and reflection at plane surfaces, refraction in lenses and in prisms. The results show the lack of a deep knowledge structure about refraction (p. 440). As implication for teaching an alternative conceptual framework encompassing refraction is proposed to influence the content oriented knowledge structure of the students (p. 441)..

- **Saxena (1991)**

  This article reports the results from a multiple-choice test that was administered to both secondary school and undergraduate students in India.

- **Bendall, Galili & Goldberg (1993)**

  This article reports on a study that was designed to describe prospective elementary teachers' prior verbal and diagrammatic knowledge about various aspects of light, seeing, shadows, and mirror images. Data were collected through individual interviews using simple experimental apparatus. Included are some inferences about how students' ideas may have emerged from their interpretations of everyday experiences.

- **Galili, Bendall & Goldberg (1993)**

  Individual demonstration interviews have been conducted to study the knowledge about image formation exhibited by students (n=27) following a college physics course in geometrical optics in an activity-based college physics course for prospective elementary teachers. Student diagrams and verbal comments indicate their knowledge can be described as an intermediate state: a hybridization of pre instruction knowledge and formal physics knowledge.

- **Osborne et al. (1993)**

  Describes the results of an intervention which makes use of a set of open-ended strategies designed to elicit 5-10 years old students' ideas about: - sources of light; - representations of light; - nature of vision. Data collected were both written

6. *What we present here is a selection from the document Review of the literature about the topic: Optical Properties of Materials. Some of the comments are as they appear in McDermott & Redish (1999) and at http://www.eric.ed.gov/*

tasks and drawings. Results show that after the intervention significant changes in various aspects of students' understanding about light have been detected.

- **Galili (1996)**

  The author discusses how students' conceptual models in geometrical optics change with instruction. A representation of students' ideas as clusters of 'facets of knowledge' is proposed: in this framework, students' conceptual change after instruction is represented by a transformation of these facets resulting in a kind of 'hybrid' knowledge. Activities are suggested to help students reach a more scientific view. Moreover, the author argues that the conceptual change which students undergo appears to be similar to the development of optics knowledge in the history of science.

- **Langley, Ronen & Eylon (1997)**

  This study explored the ideas about light propagation and image formation of Israeli 10th graders. Results show that students' responses to a range of tasks looking at their conceptions of light often had little internal consistency and varied widely depending on contextual factors, such as whether an observer was present.

- **Viennot & Chauvet (1997)**

  The impact of the French curriculum for optics at grade 8 is investigated for a teaching sequence about diffuse reflection and light and vision. A sequence on colour is used to illustrate how cognitive conflicts and search for consistency may combine

- **Ambrose et al. (1999)**

  This article identifies specific difficulties that many students have in selecting and applying an appropriate model to account for the pattern produced on a screen when light is incident on one or two narrow slits. It is also reported that students at introductory and more advanced levels have seriously mistaken beliefs about photons and the wave model for matter.

- **Galili & Hazan (2000)**

  Explores high school students' and pre-service teachers' knowledge of light, vision, and related topics before and after commonly practiced instruction. Suggests a hierarchical structure to represent the collective conceptual knowledge of students and teachers in terms of facets and schemes of knowledge. Makes suggestions for designing instruction to more effectively address patterns of alternative knowledge about opticsk

- **Viennot & Kaminski (2007)**

  The case of image formation with a thin lens is used to evaluate a potentially critical detail. The distance between students' actual and targeted levels of comprehension is proposed as the key to understand when teaching a critical detail may influence understanding.

WEBSITES

http://www.corning.com/opticalfiber/discovery_center/
The Optical Fiber Discovery Center provides educational resources and tutorials in the fiber optics area and applications in telecommunications. Among other, the tutorials address: - Discover NexCor® Optical Fiber; - Discover why optical fibers are suitable to meet bandwidth needs of today and tomorrow; - Discover how fibers in a home change the way we live, work and play.

http://www.orc.soton.ac.uk/OSA/lightwave/experiments/experiments.html
Two experiments allow understanding how optical fibers work and how one can 'guide' the light using a water tank as a model of an optical fiber.

http://www.umoncton.ca/genie/electrique/cours/hamam/Elearning/Telecoms/Fib_net/Fibnet_en.htm
Twelve java applets simulate different physical situations with optical fibers, lenses, and prism

http://informando.infm.it/html/corpo.asp?NomeSezione=scuola/multimedia
This is a complete course (in Italian) that has been funded by the Italian Ministry of Public Education and the INFM (Institute for Matter Physics) that addresses matter science and contains also tutorials about optical properties of materials.

http://matse1.mse.uiuc.edu/~tw/home.html
Materials Science and Technology Teacher's Workshop (Department of materials science and engineering University of Illinois Urbana-Champaign). The site contains eight modules to introduce both teacher and student to the world of Materials Science and technology. The modules were designed for high school students; they address metals, ceramics, polymers, semiconductors, composites, concrete and

energy. Each module includes an introduction, a historical timeline, future trends, scientific principles, laboratory activities, references, resources, videos, a glossary and a quiz.

SELECTED ITALIAN SECONDARY SCHOOL TEXTBOOKS

Optics

- **Amaldi (1999)**
  This textbook is published in different versions according to various types of curricula: vocational and technical school (14-15 years students), scientific 'lyceum' (16-18 years students), classical 'lyceum' (17-18 years students). The main difference amongst the different versions concerns the mathematics used and some additional topics proposed to the scientific lyceum students. Here few notes about the classical 'lyceum' textbook, where optics is addressed in the chapter 'The main properties of light'. Main sources of light and its and propagation are firstly discussed; contextually, the ray model is briefly introduced. After a digression on the speed of light, reflection and refraction laws, index of refraction and total internal reflection are discussed. Image formation by lenses and mirrors are also addressed by means of the conjugates points law. Finally, dispersion of light is discussed.

- **Amaldi (2004)**
  In this renewed version for the first two years of the vocational and technical schools, light is addressed in the second volume. First, the wave/particle duality is presented, then the ray model is clearly described: within this framework, after a discussion about light sources and rectilinear propagation, reflection and refraction laws are qualitatively addressed. Some applications of total reflection as optical fibers are briefly described. When mirrors and lenses are described, the rules to draw the ray diagrams are explained and then applied to various example. It is worth noting that only the first figures of the module feature the observer's eye, while when discussing real and virtual images obtained by means of the ray diagrams, neither the observer's eye, nor a screen are draw. The final part of the module is devoted to phenomena as dispersion, diffraction and interference. An appendix devoted to tunnel effect-based microscopes (also treated in the Advancing Physics project), X and infrared rays is also featured.

- **Caforio & Ferilli (2000)**
  Also this textbook has been published in different versions, initially only for classical and scientific lyceum, then also for vocational and technical schools. Here few comments on the version "Experimental Physics" for the latter types of schools; it presents also some experiments' description sheets. Optics is addressed in two chapters; in 'Propagation and Reflection of light', the propagation of light and the ray model are addressed. Then the image formation by mirrors is thoroughly discussed by means of reflection laws and the ray diagrams method. In 'Refraction and instrumental optics' refraction laws are discussed, together with a geometrical method to determine the refracted ray .

- **Di Fiore (2001)**
  Light is extensively addressed in five units of this textbook for classical and scientific lyceum. After an introduction devoted to the historical conceptions about light and the particle vs. wave model issue, the main characteristics of plane and concave mirrors (bending radius, optical axis, focal distance) are introduced. Refraction of light is also addressed not only by means of Snell' s law but also presented via a mechanical analogy. Finally, image formation by lenses is addressed by means of conjugate points' law. It is worth noting that in the figures where image formation by mirrors is described, the observer's eye is also draw.

- **Panella & Spalierno (1995)**
  Optical Fibers is a core topic addressed in the fourth year of technical schools within the 'Telecommunications" course. The focus is on the principles of functioning, the main characteristics and the way to transmit data through optical fibers. The way of presenting the topic is common to almost all the textbooks used in this kind of schools (see also, e.g., Bertazioli, 1999, Cecconelli & Tomassini, 2000; Tomassini, 2004). First, light propagation in an optical fiber is discussed, focusing on total internal reflection and on the formula for the maximum angle (acceptance angle) at which such phenomenon happens for optical fibers. Then the various types of optical fibers are introduced (mono-modal, multi-modal, step- and graded-index) and their characteristics discussed. Finally, dispersion and attenuation of the travelling signal are addressed, focusing on technical

parameters as chromatic dispersion and band-pass coefficients. A presentation of the most used and commercially available opto-electronic transmitters' and detectors' parameters is also provided.

- **PSSC (1995)**
  What we review here is the fourth Italian edition, based on the seventh American edition. This edition is subdivided into three volumes for the last three classes of scientific lyceum. Light is addressed in the two first chapters of the third volume. Description of light propagation is addressed first, enriched by the now "classic" black and white pictures of the original American course. Reflection/refraction phenomena and index of refraction are addressed by means of examples and exercises which focus mainly on students' conceptual understanding. Image formation by mirrors and lenses is addressed in the subsequent chapter, stressing the rules to draw ray diagrams in specific examples. When addressing virtual and real images' formation (for example from parabolic mirrors), the observer's eye is always draw.

- **Ruffo (2006)**
  This renewed edition for the first two years of the technical and vocational schools features one unit (comprising six lectures) about light. The first lecture is an introduction to light propagation and ray model. In the second lecture, reflection and refraction are treated as separate phenomena; image formation from plane mirrors is also briefly discussed. When refraction is addressed, the definition of the sine of an angle is introduced in order to formalize the Snell's law. Finally, lenses are addressed by means of the conjugated points law (here called thin lenses formula) and magnification coefficient. Some hints to set home-made experiments are featured at the end of each chapter.

- **Tonolini (1997)**
  This textbook is addressed to students of the first two years of vocational and technical schools (13-15 years old). After an introduction about the electromagnetic spectrum, reflection, refraction and internal reflection are qualitatively described. Then, diffraction from an obstacle and polarization are addressed. More quantitative descriptions about mirror and lenses can be found: - rays diagram method is presented, but a clear explanation of the rules to draw such diagrams is not provided; - conjugate points law and dioptres are introduced without any demonstration. All the figures featuring light rays propagation do not show the observer's eye. At the end of the chapter, the human eye and rainbows are described. One experiment to determine the focal distance of a convergent lens is briefly presented.

- **Violino & Robutti (1995)**
  This textbook is no more available for use in the schools. It was addressed to scientific lyceum only and deeply covered all basic physics topics plus several issues of modern physics including relativity and quantum mechanics. Optics is extensively addressed in eight chapters, starting from electromagnetic radiation and ending with spectroscopy and polarization. All the main topics (reflection, refraction, lenses and mirrors) are treated at a deep formal and conceptual level. Ray diagrams are addressed but rules for drawing them are not clearly stated; also observer's eye and screen are not draw in the figures where image formation by lenses is reported. A chapter is explicitly devoted to vision (human eye, colors, glasses). Finally, some spectroscopy measurements by means of prisms and interferometers are also briefly described.

RESEARCH BASED CURRICULA

- **French curriculum for Optics at grade 8th (excerpt from Viennot & Chauvet, 1997)**
  Between 1993 and 1995 a new curriculum was drawn up in France for grades 8 to 12. Curriculum for grade 8 (six months course) is a first approach to: - how one sees objects and optical images; - how images are formed in thin converging lenses. Teaching goals are: - to convey visual information, light has to enter the eye; - light travels in straight lines (in a homogeneous medium). "Guided construction" is the idea at the basis of the teaching-learning process

- **Advancing Physics**
  The Project Advancing Physics, set up in the UK Institute of Physics by a group directed by Jon Ogborn, represents an innovative proposal for changing the physics curriculum at the "A-level", for students aged 16-18 years. The work began in 1997, and now about 10000 students take this course. One main objective for this change was to

attract more students to physics. In Advancing Physics, aspects of classical optics, and in particular geometrical optics are tackled in the chapter "Imaging and visualization", as one of the new topics serving to update the curriculum. For example, rather than go through the ray-model, the authors propose to regard a lens as a tool that changes the curvature of the wavefronts passing through it

- **Salters Horners Advanced Physics**
  The Salters Horners Advanced Physics (SHAP) Project is an interesting curriculum proposal, by York University and Nuffield Centre, UK. The choice has been a context-driven approach; for the AS level (16 years students) the contexts are Music, Sport, Food, Space technology, Surgery, Archaeology. For the A2 curriculum (17-18 years students) the chosen contexts are Transports, Communication, Matter, Travel, Building. For instance, to address the basic physics of electric circuits, a typical resistivity measure of the soil is used. The context-driven rationale is used also to help motivating students, together with experiments and visits to local industries and activities. The teachers who choose to use SHAP in their classes are supported by voluntary short training courses and, if needed, Math materials since in the UK it is possible to have secondary school physics courses without attending Math courses. To cope with the evolution of interesting/motivating contexts SHAP plans appropriate updating. More specifically, as far as optics is concerned, in one of the units of the AS level course, students learn how correcting lenses are designed and selected for use in spectacles, contact lenses and implants .In the A2 level, e.g., optical fibers and coaxial cables, their advantages and disadvantages, how different types of optical fiber can reduce the effects of dispersion, and the exponential nature of attenuation are addressed

- **The Activity Based Physics Suite**
  In 1997, the Activity Based Physics Group, composed by researchers involved in curriculum development and educational reforms, began the assembly of the Activity Based Physics Suite (ABPS) which includes a broad array of physics curriculum materials integrated with results from research in physics education. About 10 'elements' are included in ABPS: amongst the others, 'Understanding Physics' by K. Cummings, P. Laws, E.F. Redish & P. Cooney, 'Physics by Inquiry' by L. McDermott, 'Workshop Physics' by P. Laws and 'Teaching Physics with the Physics Suite' by E. F. Redish. In 'Understanding Physics' textbook, geometric optics and the ray model are discussed in chapter 35. Reflection and refraction phenomena, including total internal reflection, are firstly addressed; then, the issue of image formation by lenses and mirrors is tackled using ray diagrams; finally more complex optical devices as microscopes and telescopes are discussed. The optical fibers are briefly discussed in the paragraph devoted to total reflection.

TEACHING LEARNING SEQUENCES

- **Goldberg, Bendall & Galili (1991)**
  The authors describe an instructional strategy to increase student understanding of real images formation. Two demonstrations are used: a real image formed on a screen by a converging lens and a "screen reproduction" produced by a pinhole.

- **Goldberg & Bendall (1995)**
  The study of light provides a context in which prospective elementary teachers develop conceptual understanding and an awareness of their own learning.

- **Grayson (1995)**
  Proposes an alternative approach aimed at locating the image formed by a lens. Two special rays are used to locate the image, then a number of other rays are drawn in to indicate that light from the object passes through every part of the lens. Having students draw many rays from each point on an object appears to help them understand why covering half a lens doesn't block half the image. In a class of 35 South African university students, improvement in the post-test compared to the pre-test indicated that this strategy was effective.

- **Wosilait et al. (1998)**
  The article describes the iterative process through which a tutorial to address student difficulties in geometrical optics was developed and assessed. Moreover, evidence that university students at the introductory physics level and beyond often cannot account for simple phenomena involving light and shadow is presented.

- **Michelini & Stefanel (2001)**
  In the framework of an Italian National Research Project (SECIF, Spiegare e Capire In Fisica, To explain and Understand In Physics), the University of Udine Physics Education Group proposed a teaching approach to physics optics aimed at introducing 17-18 years old students to basic elements of quantum mechanics. The focus is on polarization phenomena, interpreted in terms of interaction between photons and matter. The Malus' law is addressed from a probability viewpoint to give meaning to the concept of quantum state of a single photon. The didactic path towards polarization starts from the analysis of interaction between light and matter with a major emphasis on reflection, refraction and absorption phenomena, then interference and diffraction phenomena are introduced and discussed. From a methodological viewpoint, the proposed approach helps the students to familiarize with the process of expressing and supporting hypotheses in order to interpret observed physical phenomena.

- **Gagliardi & Giordano (2001)**
  In the framework of an Italian National Research Project (SECIF, Spiegare e Capire In Fisica, To explain and Understand In Physics), the University of Milan and Bologna Physics Education Groups jointly proposed a teaching sequence (for 11-14 years old student) about three main areas in optics: light and vision; interaction of light with macroscopic objects; reflection, refraction and diffusion. Three descriptive and interpretative models are introduced: the source-object-eye model; the rectilinear propagation model and the ray mode. The didactic path proceeds from common sense knowledge towards scientific knowledge throughout the analysis of both qualitative observations and quantitative experiments. Specific topics addressed are: - the relationships amongst objects, light and human eye, - light and space; interaction of light with material media; - light and colors; - nature of light; - eye as a detector of light signals. Viewpoints from biology, neuroscience, arts and literature are also discussed.

- **Chauvet (2001)**
  The conceptual content that frames this proposal is the idea of a chain of transformation carried by light to the observers' eye. Emphasis is thus on the role played by the visual system

- **Rebmann & Chauvet (2001)**
  The role of the ray-diagram, as an independent frame, is stressed, the main idea being "to give sense to properties using dynamic ray-diagram". A specific software ASOG (Atelier Schema d'Optique Geometrique) designed by one of the authors allows to dynamically construct, e.g., images formed by lenses, mirrors etc…

EDUCATIONAL SOFTWARE

- Ray

This software has been developed by M. Ronen and O. Rivlin at the Weizmann Institute of Science and has been designed purposely to address students' difficulties in understanding the geometrical description of light behavior. A description can be found in Eylon, Ronen & Ganiel (1996) where the authors also report about the effectiveness of the software.

The environment offers a ray-tracing functionality and includes:

- an editor tool to create and manage properties of mirrors, lenses, and prisms;
- an interactive tool to communicate ideas and hypotheses;
- a ray simulation system simulating light behavior when interacting with objects created by the user
- a set of interactive demonstration files that introduce the main concepts, principles, and phenomena related to geometrical optics
- about 100 students' tasks and activities
- a task editor to create new instructional tasks and activities

A typical screenshot is shown in Figure A12.

- Looking Glass

Looking Glass™, developed by Shawn Leclaire and Peter Zion (www.livingGraphs.com) is a geometric optics simulation environment which allows/help students to create and explore the effects of lenses, mirrors and images on light rays. It has been designed for use by high school and college physics students.

The software offers a convex and concave lenses and mirrors editor tool allowing to investigate both virtual and real images. An online help and tutorial are provided to help teachers integrate Looking Glass™ into the curriculum. A typical screenshot is shown in Figure A13.

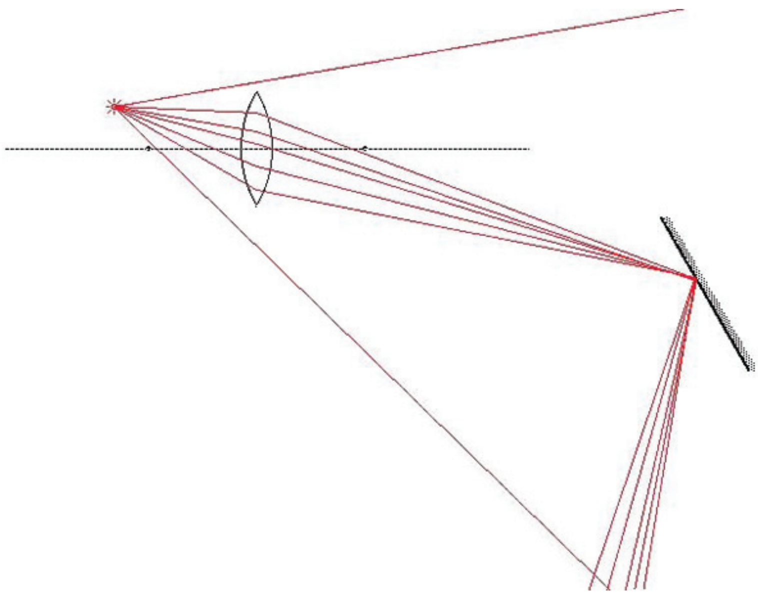

FIGURE A12: SCREENSHOT OF THE SOFTWARE RAY

- Geometric Optics

This software has been developed by David A. Alexander, Svetlana G. Shasharina and John R. Cary for Tech-X Corporation.

Geometric Optics addresses high school and introductory level-college students and uses Java applets. The program features simulations to study point and extended source shadows, refraction and reflection scenarios, dispersion, prisms, concave and convex lenses and mirrors, virtual and real images, thin lens equations, spherical and chromatic lens aberrations. It also includes a representation of a pinhole camera.

Key features of this software include: an interactive Living Graph Paper™; an editor of object, lens and mirror properties; a display of geometrical optical rays. It allows the user to export the created files as bitmap, plain text, web page or movie. Online help and tutorials are also available.

A typical screenshot is shown in Figure A14.

- Dynagrams

The Optics Dynagrams (shorthand for Dynamic Diagrams) Project deals with geometric optics by means of an interactive simulator environment. The software features can be classified as being between those of an interactive construction program and a simulation. The aim is to stimulate qualitative scientific argumentation mainly through POE (prediction-observation-explanation) cycle and collaborative learning environment.

The focus is on refraction, reflection and absorption phenomena: in particular, the students can easily manipulate one or more scenes made up of objects of different shape (circular, triangular and rectangular) characterized by user-defined light absorbance, reflectance and transmittance. The software deals also with image formation by lenses and mirrors.

Example of software's use and the results of an experimentation with 11th grade (about 16-17 years) students are discussed in Reiner, Pea & Shulman (1995).

- SILHOUETTE and CORNEA

Silhouette and Cornea are essentially a collection of geometric optics simulations to be used by 15-16 years old students. The basic concepts addressed are: lenses' focal length, refraction index, real and virtual images, magnification. Simulations included are: creation of shadows; Snell's laws of reflection and refraction; total internal reflection; creation of image by the eye; plane mirrors, lenses and dependence of focal length on refraction index (Lens maker's formula); the lens equation.

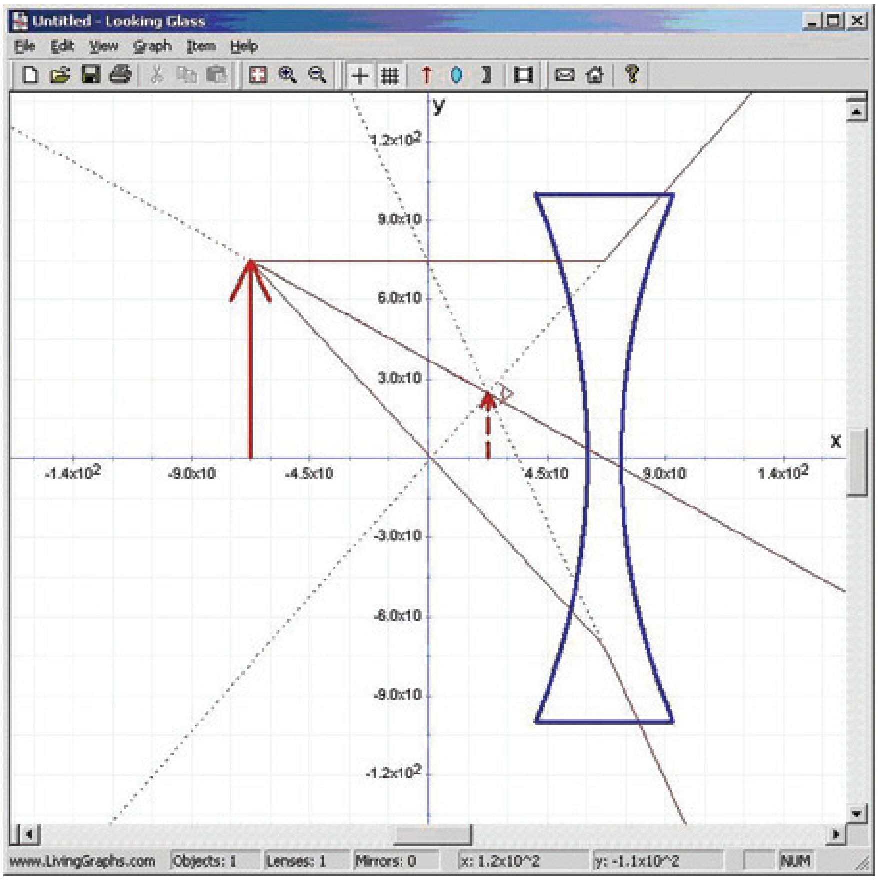

FIGURE A13: SCREENSHOT OF THE SOFTWARE LOOKING GLASS™

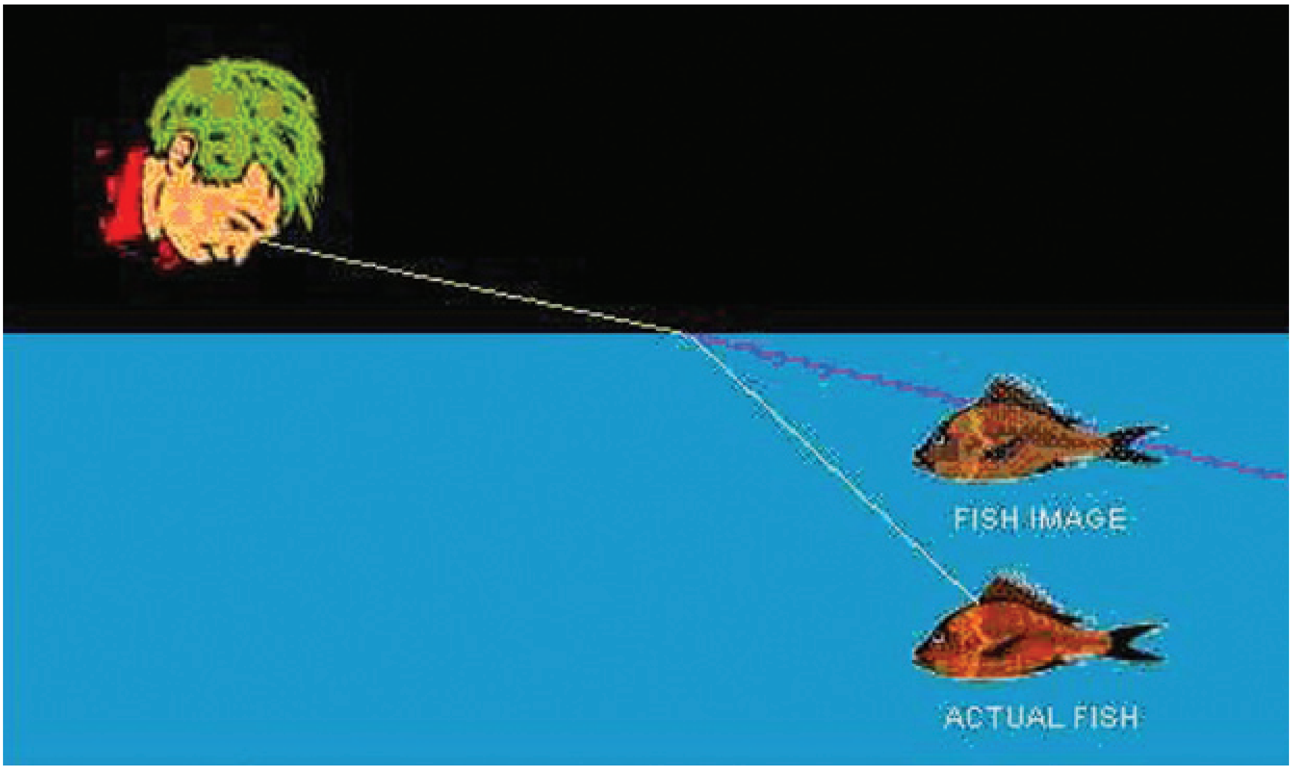

FIGURE A14: SCREENSHOT OF THE SOFTWARE GEOMETRIC OPTICS

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B: DESCRIPTION OF TEACHING AND LEARNING ACTIVITIES

B: DESCRIPTION OF TEACHING AND LEARNING ACTIVITIES

UNIT 0: VISION

0.1. HOW DO WE SEE?

Student level / age group
14-16 years old

Learning Objectives

Understand that we see because some light arrives at our eye

Understand that light that enters the eye can be either emitted by a light source or diffused by objects

Understand that the object and the observer have to be in a transparent medium

Recommended settings and pedagogical approaches
- students work in small groups (3-4 each);
- class discussion

Material resources including ICT tools
- bulbs;
- laser pointer;
- cardboard box

Inquiry-oriented activities including driving questions
The activity concerns the mechanism of vision. Students are engaged in hands-on experiments with bulbs, lasers, cardboard boxes, etc… trying to find out a scientifically reasonable answer to the question: how do we see"?

Hints and Tips
See "teachers notes"

UNIT 1: LIGHT GUIDES

SCENARIO

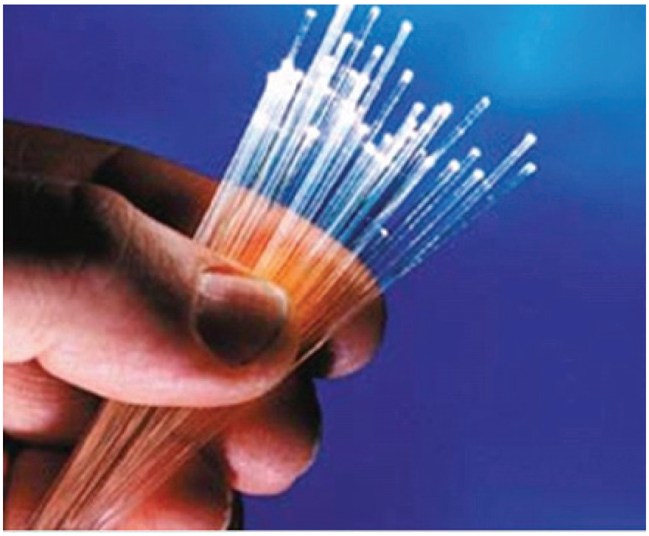


FIGURE B15: A BUNDLE OF OPTICAL FIBERS

At the beginning of the Module, some situations related to the use of optical fibers (Figure B2) in telecommunications are presented. The teacher may provide the following internet news to trigger the class discussion :

1Gbps Fiber-Optic Service Arrives in Japan on October 1

Near-instantaneous **** downloads will soon be possible in Japan thanks to a speedy new, widely available, fiber-optic service from ISP KDDI. The service will offer upload and download speeds (each way) of up to one gigabit per second

(source: http://gizmodo.com/5055965/1gbps-fiber+optic-service-arrives-in-japan-on-october-1)

"In a move that could reduce telecom costs, Indian Ocean countries are planning to replace satellite links with less-expensive fiber-optic cable for linking the countries to each other as well as intercontinental networks. The Indian Ocean Commission had recently approved this fiber-optic project at the Information and Communication Technology (ICT) Forum in Ethiopia. The aim of this project is to encourage

telecom/economic development in the Indian Ocean nations"
(source
http://findarticles.com/p/articles/mi_hb6530/is_/ai_n25884051)

NAIROBI, Kenya (AP) -- Plans to lay an undersea fiber-optic cable off eastern Africa could be the beginning of the end of crackling long-distance calls, slow dial-up Internet connections and universities without e-mail.

Four projects are in the works to link 22 eastern, central and southern African countries to the world's network of submarine cables and 21st century communications. They would enable cheaper international calls with no static and fast Internet access.

The first cable could be finished as early as March.
At the moment, the Indian Ocean's eastern African seabed is the only one in the world without a submarine fiber-optic cable, forcing the region to rely heavily on limited and expensive satellite links. As a result, countries along the coast and in its hinterland have some of the highest communications costs in the world.

Even though fiber-optic links would drive down communication costs for businesses and consumers, it also could be a big opportunity for entrepreneurs.
(source
http://www.technologyreview.com/Wire/18814/?a=f)

The break in a key undersea cable link between Australia and Singapore this week underlines the vulnerability of global telecommunication networks and the need for access to alternatives in case of emergencies, executives said Wednesday.

With communication satellites offering Asian and Pacific economies only a fraction of the capacity they need, the region is dependent on increasingly powerful fiber optic cables laid on the seabed to meet the surging demand for high-speed Internet access.

While the new cables may suffer from temporary breaks, such as the one that caused considerable disruptions in Internet traffic this week, the growing number of cables that are being put in place should help ensure reliable backup, analysts said.

A specially equipped ship is due to leave Singapore Thursday to locate the broken section of cable in Indonesian waters and repair it — an operation that is expected to take "some days," said Ivan Tan, director of corporate communications at Singapore Telecommunications Ltd.
(source
http://www.iht.com/articles/2000/11/23/cable.2.t_2.ph)

Internet services in Qatar have been seriously disrupted because of damage to an undersea telecoms cable linking the Gulf state to the UAE, the fourth such incident in less than a week. Qatar Telecom (Qtel) said on Sunday the cable was damaged between the Qatari island of Haloul and the UAE island of Das on Friday. The cause of damage is not yet known, but ArabianBusiness.com has been told unofficially the problem is related to the power system and not the result of a ship's anchor cutting the cable, as is thought to be the case in the other three incidents. It is expected to take at least "a few days" to fix, according to one person with knowledge of the situation. The damage caused major problems for internet users in Qatar over the weekend, but Qtel's loss of capacity has been kept below 40% thanks to what the telecom said was a large number of alternative routes for transmission. It is not yet clear how badly telecom and internet services have been affected in the UAE. Etisalat is expected to release a statement on Monday.
(source : http://www.arabianbusiness.com/)

1.1. OPTICAL FIBERS

Learning Objectives
Understand how and by means of what materials one can guide the light along curved paths.

Student level / age group
14-16 years old

Recommended settings and pedagogical approaches
- students work in small groups (3-4 each);
- class discussion

Material resources including ICT tools
- Semitransparent, rubber or plastic tube (diameter 5-10 mm)
- Optical fiber
- Optical fiber lamps
- LED
- Fishing-lines
- Small torch bulb
- Battery 4.5 V
- Black cardboard or tissue (as screen)
- Black Tape

Inquiry-oriented activities including driving questions
The behavior of fiber glass lamps, plastic rods, glass rods etc with respect to light is initially observed in order to find the answer to the question:
- which are the similarities and differences between optical fibers and other transparent objects that may guide the light?

Hints and Tips
See "teachers notes"

1.2. IS IT POSSIBLE TO MAKE A LIGHT GUIDE?

Learning Objectives
Understand the role of the interface between two homogeneous materials;

Student level / age group
14-16 years old

Recommended settings and pedagogical approaches
- four-five student groups performing the same experiment
- class discussion

Material resources including ICT tools
- A transparent container (about 30 cm length; 18 cm height; 16 cm depth; e.g. a low-cost plastic aquarium easily found in a pet shop)
- Low-cost laser pointer
- Support for the laser (a piece of wood is ok)
- Tap water
- Black paper or fabric as screen
- Something to dry spilled water (if any)

Inquiry-oriented activities including driving questions
An intriguing experiment[7] with an illuminated water jet triggers the discussion about how to build a light guide (Figure B16). Analysis of this experiment allows to address the following questions:
- What is the light behavior in an homogeneous medium?

7. *This experiment was actually carried out in 1842, by Daniel Colladon.*

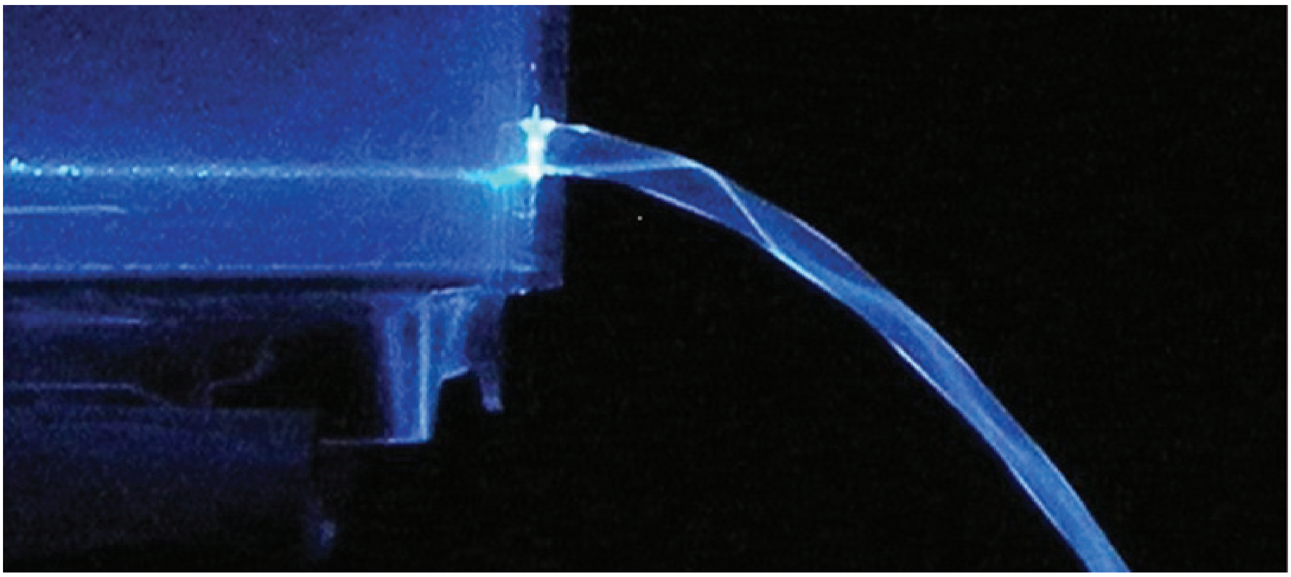


FIGURE B16: WATER JET EXPERIMENT

- What is the light behavior when it encounters an interfaces between homogeneous media?

Hints and Tips
See “teachers notes”

1.3. OBSERVING THE LIGHT PATH

Learning objectives
Distinguish simple different ways for deviating the light; Identify qualitative characteristics of light beams propagating in materials

Student level / age group
14-16 years old

Recommended settings and pedagogical approaches
- four-five students groups performing the same experiment
- class discussion

Material resources including ICT tools
- A transparent container (about 40 cm length; 20 cm height; 16 cm depth)
- Low-cost laser pointer
- Tap water
- Incense candle (to make some smoke)

Inquiry-oriented activities including driving questions
In the experiment of this activity, students are guided to observe the path of a laser beam in a tank half-filled with water by mean of diffusing particles (Figure B17). Students’ attention is guided on both the phenomena of reflection and refraction, through the following question:

- Which are possible ways to deviate the light from a rectilinear path?

Hints and Tips
See “teachers notes”

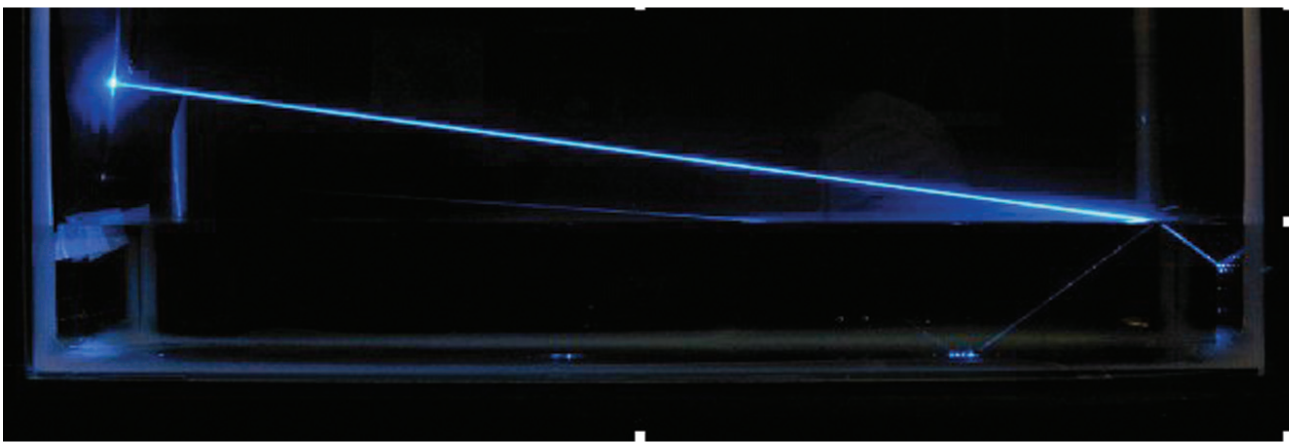


FIGURE B17: WATER TANK EXPERIMENT

1.4. WHEN AND HOW DOES LIGHT DEVIATE? REFRACTION

Learning objectives

Interpret optics phenomena by means of the ray model
Interpret the regularities: constant ratio sin r /sin i.
Measure and calculate the refraction index of a material

Student level / age group

14-16 years old

Recommended settings and pedagogical approaches

- four-five students groups performing the same Cabrì activities
- class discussion of the obtained values for the refraction index
- law of refraction discusses by teacher

Material resources including ICT tools

- Photos of experiment 1.3.1 (The water tank)
- Cabrì files

Inquiry-oriented activities including driving questions

By means of the Cabrì environment, refraction is formalized (Figure B18). The index of refraction of an homogenous medium with respect to another is introduced as the optical property which allows to answer the following question:

- Can we predict the light path deviation when light hits the interface between two media of given refraction indices?

Hints and Tips

See “teachers notes”

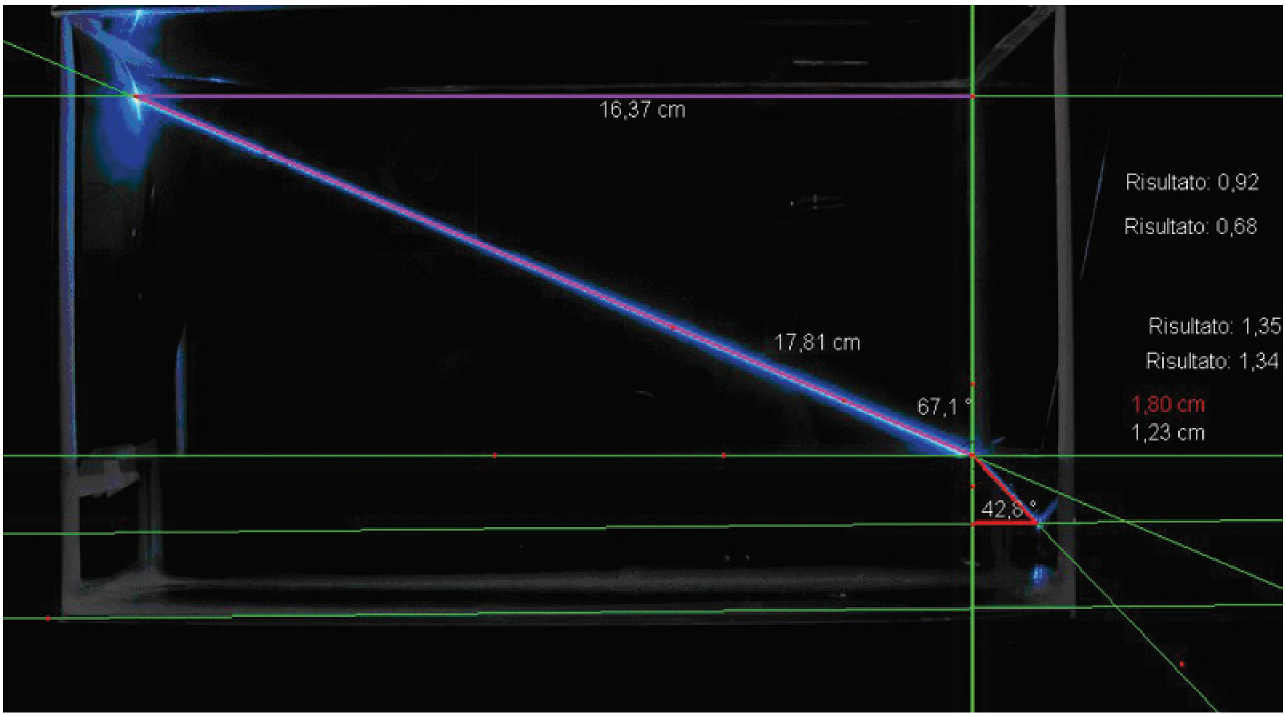


FIGURE B18: MEASUREMENT OF LIGHT REFRACTION WITH CABRÌ

1.5. WHEN AND HOW DOES LIGHT DEVIATE? REFLECTION

Learning objectives

Interpret optics phenomena by means of the ray model
Understand that refraction and reflection always occur at the interface.
Measure and calculate critical angle between two media

Student level / age group

14-16 years old

Recommended settings and pedagogical approaches

- four-five students groups performing the same Cabrì activities
- class discussion about the values of incident and reflected angles determined by each group.
- law of reflection and critical angle discusses by teacher

Material resources including ICT tools

- Photos of experiment 1.3.1. (The water tank)
- Cabrì files

Inquiry-oriented activities including driving questions

In this activity, the reflection law is quantitatively introduced when total reflection conditions are met (Figure B19)

The following questions are addressed:

- What happens when light goes from more refractive to less refractive media?
- Which are the conditions under which total internal reflection occurs?
- Which is the relationships between the critical angle and the two media relative refractive indices?

Hints and Tips

See “teachers notes”

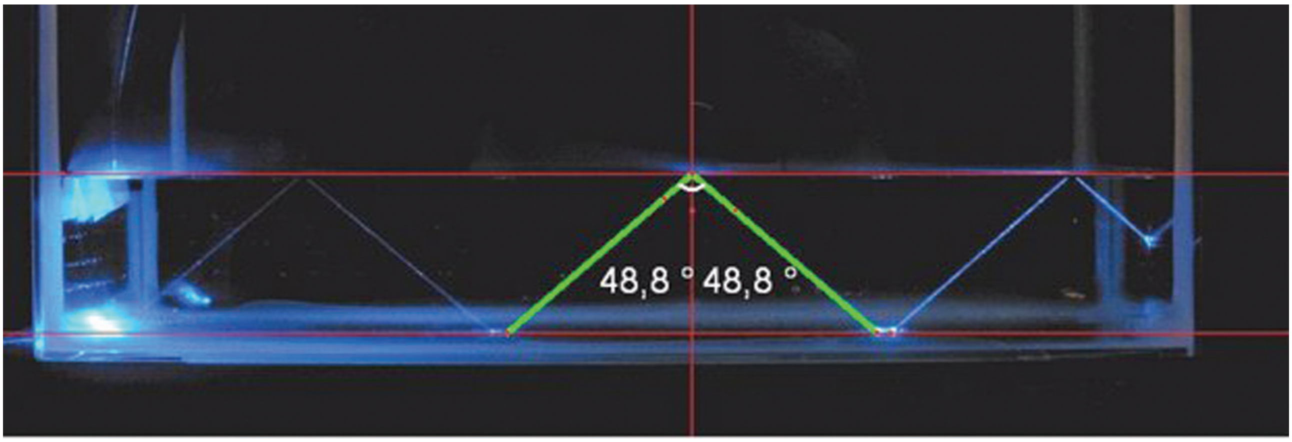


FIGURE B19: MEASUREMENT OF LIGHT REFLECTION WITH CABRÌ

1.6. How is an optical fiber made? First clues

Learning objectives
To resume the main results from previous activities

Student level / age group
14-16 years old

Recommended settings and pedagogical approaches
- four-five students group work with pictures of the previuos experiments, or the teacher may repeat the experiments
- class discussion

Inquiry-oriented activities including driving questions
In this activity, all information gathered during the previous ones are discussed. Then the teacher goes back to the objects that initially were observed to guide the light with the aim of discussing the following question:
- Which are the main issues to be taken into account when designing a light guide?

Material resources including ICT tools
- Photos of experiments 1.2.1 (The water jet) and 1.3.1 (The water tank)
- Cabrì files

Hints and Tips
See “teachers notes”

UNIT 2: FROM LIGHT GUIDES TO OPTICAL FIBERS

2.1. DO WE WANT TO SEE THE LIGHT PATH IN THE FIBER?

Student level / age group
14-16 years old

Learning Objectives
Identify correct light paths in a fiber
Understand the role of transparency of a fiber’s materials
Understand the role of fiber’s cladding surrounding the core

Recommended settings and pedagogical approaches
- four-five students group work with paper tissue and optical fiber
- class discussion

Material resources including ICT tools
- Optical fibers
- Laser pointer
- Paper tissue

Inquiry-oriented activities including driving questions
In this activity, careful observations of the images of the experiments performed with different water tanks and a laser pointer in diverse situations are discussed with the students. Further qualitative experiments are proposed to collect evidence to answer the question:
- where does attenuation in a fiber come from?
- how an optical fiber is actually made?

Some preliminary “clues” can be offered as, e.g., the fact that a cladding is necessary to “protect” the core.

Hints and Tips
See “teachers notes”

2.2. OPTICAL FIBERS' CHARACTERISTICS

Student level / age group
14-16 years old

Learning Objectives
Establish quantitative relations between refraction indices of core and cladding and optical fibers' characteristics

Recommended settings and pedagogical approaches
- four-five students group work with optical fiber lamps, plastic bars, glass bars
- two students group work with Cabrì simulations
- class discussion

Material resources including ICT tools
- Glass bar (diameter 5-10 mm)
- Water tanks
- Laser pointer
- Black cardboard or tissue (as screen)
- Cabrì files

Inquiry-oriented activities including driving questions
The regularities observed so far are transformed in some rules by means of the simulation activities with Cabrì.

In particular the proposed simulations allow answering the following questions:
- Can all the rays sent into a fiber on one end travel to the other end?
- Have the refractive indices of core and cladding any influence on the rays travelling along the fiber?

Hints and Tips
See "hints and notes for teachers".

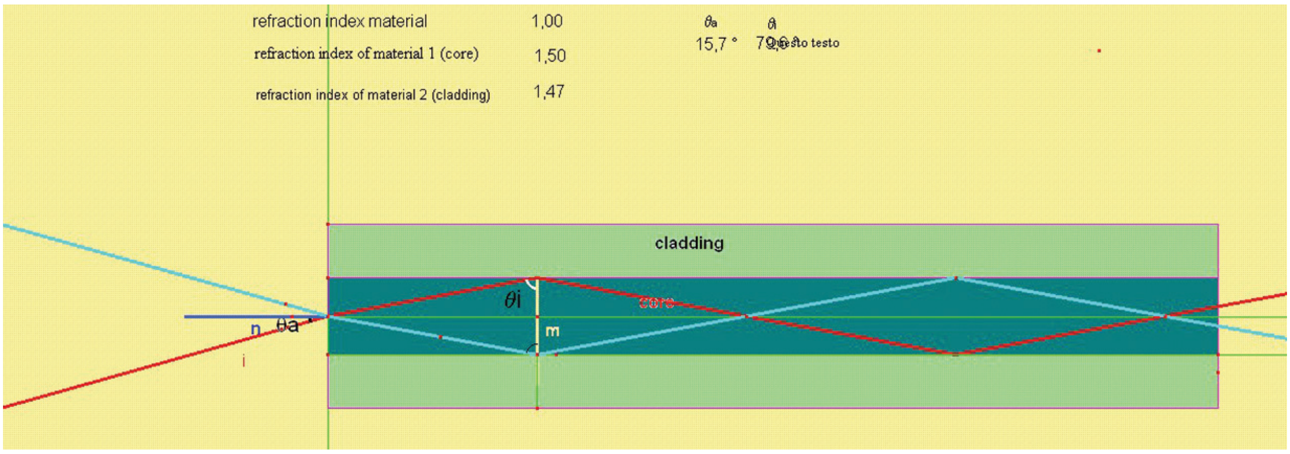


FIGURE B20: SIMULATION OF AN OPTICAL FIBER WITH CABRÌ

TEACHERS' NOTES

UNIT 0: VISION

0.1. HOW DO WE SEE?

Duration: about 1 hour

Didactical Notes

Experiment 0.1.1 (Light in the box) and 0.1.2 (Laser sword)
Smoke particles or chalk dust act as light diffusion centers and thus allow "seeing" the path of the light beam. It is part of common experience that some times one can see light beams entering through the window's shadows. Also in water it is possible to see the light path if the water is not so "clean". Adding few milk drops allows making the light path visible. The mechanism is the same as that for the dust particles or smoke in air. Even in distilled water one may see a feeble light path because there are diffusion centers, but fewer than in "dirty" water or tab water.

Activity 0.1.3: Diving in clear waters
This Activity aims at helping students to understand that in order to be able to see, both the object and the observer (the eye) must be in a (at least partially) transparent medium.

Main Conclusions
The observations carried out in these experiments allow understanding that:

- we see because some light arrives at our eye, which is the apparatus for detecting visible light.
- we see light emitted by a source or light diffused by objects. The first is named "direct light" and the latter "diffused light"
- we see because there are material particles that diffuse the light. In the activities with the laser pointing at the wall through air one sees only a spot on the wall, while if some particles are added in air, as smoke or chalk dust, one can see the light path.

UNIT 1: LIGHT GUIDES

After introducing the "Scenario" about the FLAG network or about the disaster that occurred when an underwater fiber optics cable was interrupted, leaving many Asian countries unable to be connected to Internet, one may introduce the activities in the Unit saying that:

"… In the articles you read many times the word "optical fibers" has been mentioned. The systems that allow far-distance connections for signal transmission are based on optical fibers. They allow transferring light at very large distances, without appreciable attenuations…We would like to know how this can be done and what we have to know about optical fibers in order to design them".

1.1. OPTICAL FIBERS

Questions as:

"Have you ever heard about optical fibers? Do you have an idea on how they are made? Have you ever seen them?"

can trigger this activity. Otherwise, it is possible to introduce optical fibers lamps:

"Likely you have seen those interesting lamps that seem to be made of strings, sometimes also used for Christmas decorations. A light spot appears only at the end of the "string"… [8,9]*".*

Duration: about 1 hour

Didactical Notes

1.1.1. EXPERIMENT: FIBER OPTICS LAMP

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
In order to understand the functioning of an optical fiber lamp, one can put together a number of optical fibers and find out that a LED is present at the lamp's base. Take a bundle of optical fibers and connect one extremity of the bundle to the light bulb. So, you have made an optical fiber lamp. Usually, LEDs of different colors light the common optical fiber lamps.	You may call attention on the fact that the path of light may be very strange, if you knot the wire and observe that nothing changes.

There are optical fibers with rough surfaces and ends. In such a case you may see light also in all the rough part of the fibers used to make the lamp. One may obtain this effect by removing part of the fiber's cladding. This is an indication that the fiber has an external part that plays an important role as far as light transmission is concerned, as we shall explore later.

8. *In the ancient Egypt, the slaves that built tombs or pyramids needed to light long curved tunnels. To solve this problem the builders used a series of copper mirrors placed in such a way that the sun light , by multiple reflections, lighted the tunnels. However, the set of metal mirrors was not an handy system also because of the attenuation of light intensity . Nowadays, there are telecommunication systems that guide the light along transoceanic distances. Obviously, it could not be realized by using a mirror system! Such systems, which allow, for instance, to make a call from New York to Tokyo without suffering any sensible delay, are based on the propagation of laser light in optical fibers. Let's try to understand how an optical fiber works.*

9. *In order to open the discussion, it can be useful to start from another issue connected, but different, and belonging to commonsense knowledge: Is it possible to bound the lighted region of space, given a specific light source? For instance, in everyday life, the need for a proper lighting to read or write calls for the use of a lampshade or any other device that can reduce the solid angle of emission of the light source at our disposal. A stimulating question can be: Which everyday objects, at home and outdoors, do you know that allow to bound the lighted region of space for a given light source?*

1.1.2. EXPERIMENT: BENDING A FIBER

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Place an optical fiber straight on the table, a piece of black cardboard or tissue (as screen) at one end of the fiber and a small torch bulb at the other end; connect one end of the fiber to the 4.5 V battery. Describe what you observe on the screen. Curve the fiber using e.g. a thin wire loop placed almost at the free end of the tube Pull the loop gently so that the fiber bends gradually.	Optical fibers of different diameters can be used. While one student bends the fiber, another takes care of the contact between bulb and fiber.

When the optical fiber is bent gradually, the light spot keeps its brightness. When the fiber breaks, the end of the fiber is still lighted. This makes plausible to infer that the optical fiber is a guide of light. Help your students to observe that no light passes through the outer surface of the fiber, i.e. what happens inside the fiber is not visible.

One can stimulate questions about the material whose the fiber is made. It is transparent? Is the fiber made of glass? Can we bend a piece of glass?

Additional activities

It may be useful to perform also the following activities (not indicated in Students' Worksheet 1)

1.1.2A. EXPERIMENT: RUBBER TUBES AND TRANSPARENT PLASTIC WIRES

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Arrange the rubber tube straight on the table. Connect one end of the tube to a light bulb by means of the black tape. Place the black screen about 2-3 cm from the other tube end . Light the bulb by powering it with the battery (4.5 V). Curve the tube using a thin wire loop placed almost at the free end of the tube. Pull the loop gently so that the tube bends gradually.	Keep the tube on the table in a straight position. - tourniquets (length about 8 cm) can be used. Such tubes allow a good connection with small flashlights. Do the experiment in a darkened room. Alternatively, use any blackened box (cardboard or whatever) around the setup.
The optical fiber experiment is repeated using a transparent plastic wire lighted at one end	Fishing-lines (length about 10 cm) can be used.

When the rubber tube is bent gradually, the light spot dims and finally disappears. This allows inferring that the rubber tube is not a good candidate for guiding the light. Help your students to observe also that some light entering goes out through its outer surface.

The experiments with optical fibers could lead to believe that the optical properties of the fibers are due to their small thickness and to the solidness.

The experiment with the fishing-line helps the students to observe that the optical fibers evidently are not ordinary plastic wires but they are designed with some special material.

Encourage a comparison between the experiments with plastic wires or rubber transparent tubes and optical fibers. The way of bending the material is the same, but the result is different. The outer surface of the rubber tube is lighted, while that of the fiber is not. The fiber breaks, the rubber tube not. Moreover, call attention on the spots produced on the screen by the tube (low brightness and blurred boundaries) and the fiber (high brightness and sharp boundaries).

If you try to scrape an optical fiber (sand paper is ok), you see that the light passes through the scraped surface. Thus, the coating (cladding) of the fiber surface is a crucial ingredient for its peculiar optical properties.

1.1.3. EXPERIMENT: SENDING SIGNALS

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Signal transmission A couple of students hold a piece of optical fiber. One student lights one end of the fiber and the other students is in a place where he cannot see his fellow student (behind the door for example). The second student is asked to recognize what signals the first student sent him: long-short etc)	The best way to perform the experiment is to have the student who sends the signal to do so by creating an interruption of the light beam with a piece of cardboard.

The activity aims at making students aware that an optical fibers is a good candidate for transmitting signals. One may also introduce what "coding" signals means.

1.1.4. Activity: What optical fibers are for?

At the end of this Activity students should be able to claim that "optical fibers are pipes (not hollow) made of a transparent medium. These objects allow to: guide the light; transmit signals".

Main conclusions:

- By means of suitable devices it is possible to guide the light along curved paths and direct it towards zones unreachable or difficult to reach by rectilinear propagation of light
- By means of optical fibers, it is possible to direct the light towards a precise spot and, at the same time, to bind the illuminated region of space, even if the fiber has been bended.
- Optical fibers are light pipes
- Optical fibers allow to transmit signals

What next?

The students have been helped to become aware that the main property of an optical fiber is to guide the light. They have also made a nice optical fiber lamp. But up to now it is not known how the fiber works and which are the properties allowing the fiber to guide the light. To understand what happens inside a fiber *"…we need a guide of light where we can* ***see*** *how the light propagates within it"*

1.2. IS IT POSSIBLE TO MAKE A LIGHT GUIDE?

This activity can be introduced by saying:

"Back in 1841 in a classroom of Geneva University in Switzerland, the physicist Daniel Colladon, observed by chance and for the first time that the light travelling in a water jet was guided within the jet. We'll reproduce that experiment using a techno-object not available at that time, namely a laser pointer. We'll observe carefully that strange effect"

Duration: about 1 hour

Didactical Notes

1.2.1. EXPERIMENT: THE WATER JET

The core of the activity is an experiment showing that it is possible to guide the light with a water jet which thus is taken as a good candidate for studying the basics of how an optical fiber functions. In this context, the law of rectilinear propagation can be stated; observations of what happens at the interface between two media are also carried out. The experiment can be introduced by saying:

"The light travels in an optical fiber, but we can not see its path. Let's try to make a light guide where it is possible to see the light path"

FIGURE T-1

PART I & II

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Drill a small hole (about 5-6 mm diameter) in one of the small faces of the aquarium, about 3-4 cm from the bottom and close it with some tape. Use a drill point to get a hole with rather regular contour. Fill the aquarium with tap water up to about 10-15 cm height. Open the hole and use some container to collect the water coming out as a parabolic shot. The laser pointer is placed on its support near the aquarium face opposite the hole. The laser beam is horizontal, parallel to the table plane and lined with the hole. To better see both the laser beam and its path in the water, the classroom is darkened or the whole setup is in a box (any cardboard box is ok) whose walls are black (lined with black paper or fabric).	To better see the laser beam (especially when it is not much powerful), it may be needed to work with “dirty” water, i.e. water with some chalk powder or “dirty” air i.e. air polluted with some hair spray or cigarette smoke. The students must stand laterally with respect to the laser beam, in order to avoid any direct view of the laser light. To allow all students see the details of the laser light beam path in the water shot, it may be convenient to give each of them a printout of a digital photo of the lighted water shot, done previously by the teacher.

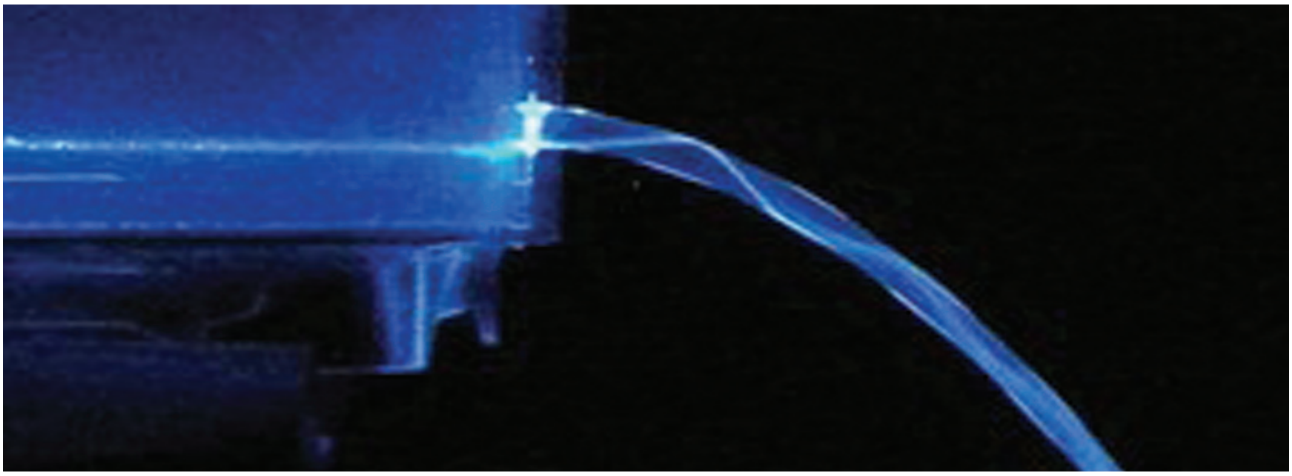


FIGURE T-2

This experiment, easily performed in class, is an appropriate emblematic example to help students understand under which conditions the light can be "guided".

Once the experiment has been done, the teacher calls attention on the path followed by the laser beam: firstly a rectilinear path (segments AB and BC) in an homogenous material (air then water); secondly the path within a zone where there is an interface between two different materials with different optical properties.

Observation and analysis of these two types of paths allow introducing two notions:

- Homogeneous and inhomogeneous material
- Interface between two different materials and to check the
- Law of rectilinear propagation of light, when it moves in an homogenous material

Part III

It is useful to distribute a copy of the picture of the illuminated water jet for each group of students.

Hence, go back to the experiment and ask to observe very carefully the water shot and the internal reflections in the water. What is more intriguing is the propagation of light in the shot. It has "guided" the laser beam. This property reminds what has already been observed in the optical fiber, but with a crucial difference. In the water shot the light is guided and its path is seen because of some light diffused by impurities always present in the water (dust or similar stuff). In the case of the fiber we do not see the path of the light. One may say that "the fiber traps the light". If it were trapped also in the water jet, this would mean that no light escapes from the jet and no beam would reach our eyes, producing no images of the internal reflection zig zags (one can here recall briefly what studied about vision and diffused light).

Looking carefully at the water jet one notices that light "bounces" at the interface water-air and one can "see" internal reflection of light, therefore the water shot can be thought, with good approximation, as a curved cylinder full of water whose walls (the lateral surface) are made of air. It is important, from a didactical viewpoint to point out the air-water sequence encountered by the light along its path. Recall the results of the curved fiber experiment. Since here the analogous result of guiding a light beam along a curved path, it is reasonable and plausible the assumption that what has been observed in the water shot is analogous to what happens in the fiber.

The fiber's material is yet unknown, here the jet material is known: water surrounded by air

Main Conclusions

- First observations of a special light guide allow to say that it is made of two different materials and an interface between them and that light is reflected at the boundaries between the two materials. If possible, it would be useful to anticipate the idea that a fiber should be made of a material surrounded by a different one, similarly to water and air, in the water shot experiment. This can help the comprehension of the basic of how a fiber functions: the internal total reflection on the interface between the two fiber materials (later called core e cladding).
- This activity has also addressed some topics taught in almost all basic physics courses: the law of rectilinear propagation of light, homogeneous materials, interfaces between two diverse media. A medium is homogeneous when its properties are the same everywhere within the medium. From the experiments we conclude that the laser light paths in an homogeneous medium are straight lines. Such a result holds every time light travels in an homogeneous medium. This is known as the first law of the geometrical optics.
- Interfaces have also been introduced: the surface dividing two uniform (homogeneous) media is called "interface" or boundary. For instance, the flat surface of the table is the interface between wood (of which the table is made up) and the air. The water surface in the tank is the interface between water and air.

What next?

In the performed experiment the students have observed a light guide where the light path is visible. It is appropriate to explore why, when ad under which conditions the light does not travel a rectilinear path and when it bends as in the light guide.

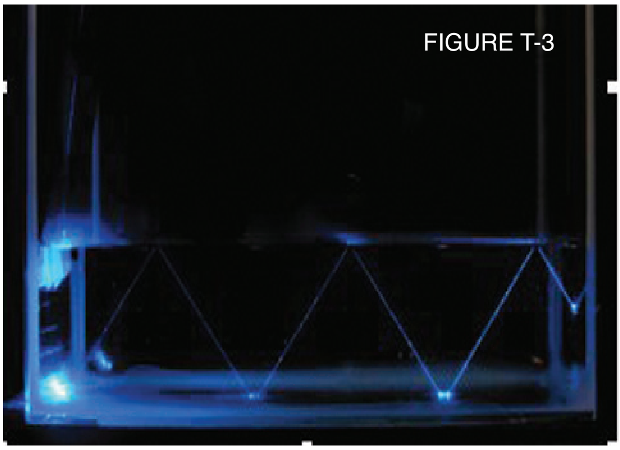
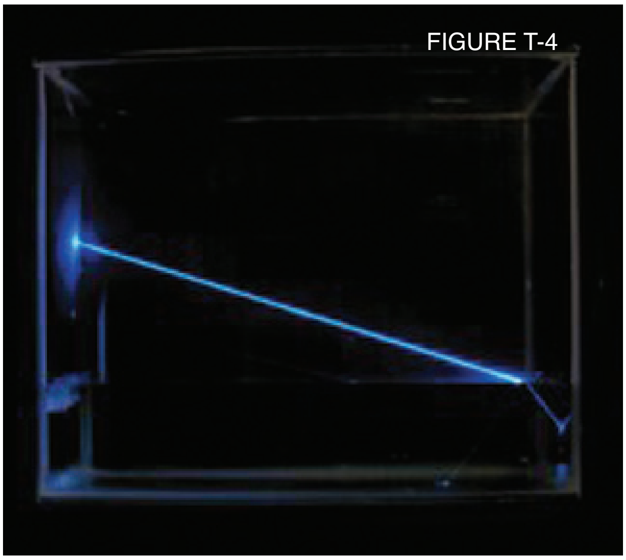
1.3. OBSERVING THE LIGHT PATH

One may go back to the original problematic envisaged in the “Scenario” and introduce this activity by saying:
“We have observed the water jet gushing from the hole in the tank. In the jet, the light follows kind of zigzag trajectory. We have to perform some measurements aimed at understanding why this can occur. In this activity we will set up a suitable situation to this aim”.

Duration: about 2 hours

Didactical Notes

1.3.1. EXPERIMENT: THE WATER TANK

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Hitting the hole C with the laser. Fill the tank with water (about half way) and introduce smoke with the incense candle in the air above the water. Place a transparent cover on top of the tank. The hole C can be hit either orienting the laser pointer downwards, so that light goes through air first and then through water, or vice versa orienting the laser upwards from water to air. When the laser inclination is changed, one may observe refraction, reflection and also total internal reflection, if the light hits the water first. In this latter case one observes reflected and refracted beams and it is possible also to notice that, at a certain entrance angle of the laser beam, the refracted beam disappears and total internal reflection takes place.  FIGURE T-3	To better see the laser beam (especially when it is not very powerful), it may be needed to work with “dirty” water, i.e. water with some milk drops. The incense candle allows to introduce easily smoke in the air above the water. Once this is done, you should close the tank with the cover in order also to avoid too much smoke to fill the air of the lab. The table where you place the water tank should be perfectly horizontal. The students must stand laterally with respect to the laser beam, in order to avoid any direct view of the laser light  FIGURE T-4

One may focus students’ attention on the role of the interface water-air or air-water. Water acts as a reflecting surface (recall students’ experience about mirrors).

This experiment allows to see, (e.g. in the figure on the right) in many situations both the reflected and refracted beam and therefore allows to address a common difficulty induced in the schematic representations used in geometrical optics that the reflected and refracted beams are always present together, but they can have different appearance in the bulk due to absorption.

Observe also that this condition ceases when the limit angle is reached and the refracted beam disappears.

Further observations and questions:

- the visibility of the reflected and refracted beams are different. How does this depend on the amount of diffusing particles?
- light is attenuated as it proceeds in the water, by multiple internal reflections

The latter observations allow gathering information about the role of the bulk.

Main Conclusions

- When light hits an interface deviates from its rectilinear path. One can observe, in such cases incident, reflected and refracted beams, that are always present together.
- Light deviation through reflection and/or refraction may be useful to orient a light beam towards a specific point.

What next?

After having performed qualitative observations that allow recognizing regularities in the observed behaviors, we proceed with measures, which will be performed in a virtual environment.

1.4. WHEN AND HOW DOES LIGHT DEVIATE? REFRACTION

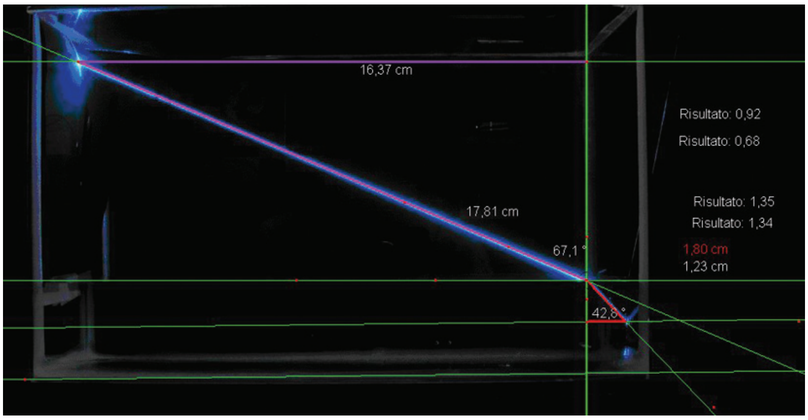
One may introduce this activity by saying:

"We have observed in the experiment what happens when a light beam hits the water surface propagating from air to water. Let's now focus on this light beam"

Duration: about 2 hours

Didactical Notes

1.4.1. COMPUTER ACTIVITY: MEASUREMENT OF THE REFRACTION INDEX

CABRÌ PHOTO AND CONSTRUCTION	OPERATIVE SUGGESTIONS
 FIGURE T-5	The students may notice that the light beams in air and water have different visibility. They could in this case vary the width of the segments with the function "width" of the menu, to account for what they observe (see below). The construction of the triangles is reported in the file "**refraction_image.fig**"

It is suggested that students identify the incidence and refraction angles and define the sine of the angle by means of the ratio cathetus/ hypotenuse.

If different pictures of refraction are distributed among the groups, then each group can determine a value of the relative water/air refraction index. Sharing all values and discussing allows to compare the value they have obtained with the one indicated in tables of refraction index for common substances.

The ratio

$$\frac{\frac{BE}{AB}}{\frac{DF}{CD}} = 1.33$$

is indicated thus as the relative water/air refraction index.

The ratio

$$\frac{BE}{AB}$$

can be called "sine of the incident angle" (in the construction it is implicit that the angle is measured with respect to the normal to the water surface).

The ratio

$$\frac{DF}{CD}$$

can be called "sine of the refracted angle" (in the construction it is implicit that the angle is measured with respect to the normal to the water surface).

As the students become familiar with the construction, they can notice that many aspects of the real phenomenon are not represented in the Cabrì modeling: mainly the light beam is modeled as a **"ray"** and all rays are represented by segments of the same width. The different appearance of the beam in water and air should be noticed and (as suggested above in "Operative suggestions") marked in the Cabrì construction. A discussion about such aspects allows to relate the difference between **the phenomenon and its (abstract) representations.** The proposed construction (use of pictures of the observed phenomenon imported in Cabrì) is a very straightforward way to do so.

1.4.2. COMPUTER ACTIVITY: REFRACTION INDEX AS A MATERIAL'S PROPERTY

CABRÌ APPLET SIMULATION	OPERATIVE SUGGESTIONS
Open the file "**refraction_index.fig**"	In order to vary the inclination of the laser beam one has to select the pointer in the menu In order to vary the refraction index of medium 2 it is advisable to use the small arrows. In order to vary the water's height you must select (with the pointer) the point H and drag downwards or upwards Even if the height of the liquid in the tank is reduced to a minimum value, it is impossible to reduce it to zero and thus there is always refraction.

Different measures of the ratio

$$\frac{\sin(\alpha)}{\sin(\beta)} \equiv \frac{n_2}{n_1}$$

allow to deduce that n_1/n_2 does not vary with the inclination angle of the laser beam (incident angle) nor with the height of the water in the tank, therefore

$$\frac{\sin(\alpha)}{\sin(\beta)} \equiv \frac{n_2}{n_1} = \text{constant}$$

and n_1 and n_2 are constants that depends on the material.

A range of possible values for n_1 and n_2 is useful for the students to know. The possibilities offered by the simulation applet allow hence to address the dependence of the refraction index on the type of material..

1.4.3. Activity: Snell's law of refraction

The law of Refraction of Geometric Optics (Snell law, 1621) can be introduced. The angle α between the incident beam and the normal to the interface of media 1 and 2 and the angle β between the refracted beam

$$\sin\beta = \frac{\sin\alpha}{n_{12}}$$

and the normal are related by the following relation: ,

$$n_{12} = \frac{n_1}{n_2}$$

where

is a constant which is related to the optical properties of both media, 1 and 2.

Main Conclusions

- light travels through a homogeneous medium (say medium 1) in a straight path. When the light reaches the boundary with a different medium (say medium 2) light, some light will be reflected on the boundary and some light will be transmitted into the medium 2. When light hits the boundary at a certain angle with respect to the normal to this boundary (in the previous experiment it was called α), the light path bends from the original direction, i.e., it follows a "new" direction characterized by an angle β with respect to the normal to the boundary. The transmitted light undergoes refraction, which is modeled by the Snell's law.
- in the case of the experiment 1.3.1, depends on water and air and is called refractive index of water relative to air. In the experiment, this constant should be about 1.33, $n_{1,2.}$ The refracted beam in this case approaches the normal to the boundary.

What next?

Before going back to study the light guides, we must understand what happens to the reflected beam…

1.5. WHEN AND HOW DOES LIGHT DEVIATE? REFLECTION

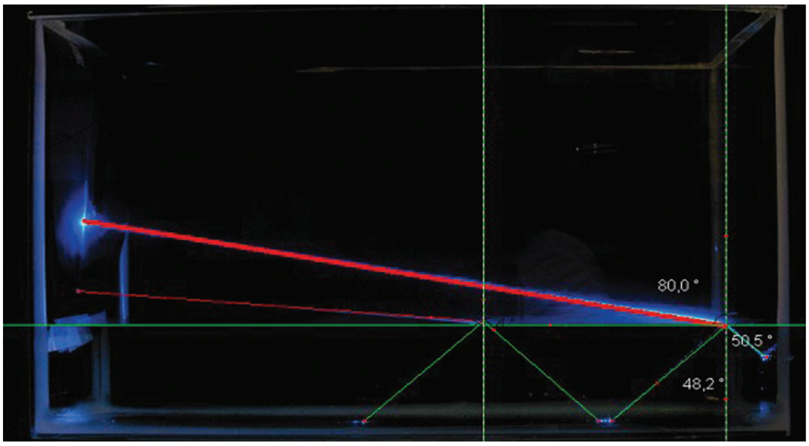
One may introduce this activity by saying:

"…we will now focus on the light beam that is reflected at the surface water-air or vice versa..."

Duration: about 2 hours

Didactical Notes

1.5.1. COMPUTER ACTIVITY: REFRACTION AND REFLECTION PART I & II

CABRÌ PHOTO AND CONSTRUCTION	OPERATIVE SUGGESTIONS
Open the file "**reflection_refraction.fig**"  FIGURE T-6	The students may notice that the light beams in air and water have different appearance. They could in this case vary the width of the segments with the function "width" of the menu, to account for what they observe (see below).

1.5.2. COMPUTER ACTIVITY: MEASURING INCIDENT AND REFLECTED ANGLES

CABRÌ PHOTO AND CONSTRUCTION	OPERATIVE SUGGESTIONS
Open the file **"multiple_reflection.fig"**  FIGURE T-7	This image is obtained when the laser beam enters the water tank from water to air and total internal reflection can take place.

One may notice that the reflected beams are not well visible while the spots at the water surface are very bright. This is also true for the spots at the bottom of the water tank.

An explanation for the different appearance of the light spots at the water-air interface and at the (bottom) interface water-glass is provided in “Teacher’s Notes 6”.

The bright spots at the top and at bottom may be well taken as the segments’ extremes that model the light beams.

The values of the angles obtained by each group can be shared with the whole class.

Here again one may focus students’ attention on the differences between the physical phenomenon and the model.

1.5.3. COMPUTER ACTIVITY: MEASURING THE CRITICAL ANGLE

CABRÌ APPLET SIMULATION	OPERATIVE SUGGESTIONS
Open the file “**critical_angle.fig**” Let the refraction index of medium 1 be 1 and 1,33 the refraction index of medium 2. On the normal n’ trace the semi ray a that represents the entering beam. Rotate the semi ray a until you don’t see any more refracted rays in air. Measure the incidence θi and reflection θr angles of the laser beam on the interface water-air.	By rotating the semi-ray a which represents the incident beam it is possible to observe that at a certain angle the refracted beams disappear. This allows to focus on the particular angle (limit or critical angle) for which this is achieved.

When performing activities with the Cabrì applets it is wise to go back frequently to the experiment, in order to connect what the students are doing in this phase with what they have observed, and also explain that the use of the virtual environment of the simulation is a useful tool to perform measures. In this case one can measure the incident, reflected and refracted angles.

Students can work on photos (one for each group and different ones) where they can trace the incident, reflected and refracted rays. With the Cabrì construction each group can determine the relation between the incident, reflected and refracted angles.

The **Reflection Law** of geometrical optics can be formalized at the end of these activities. As a matter of fact, focusing on each pair of adjacent angles θ_i and θ_r allows to claim that $\theta_i = \theta_r$

Total internal reflection
The smallest angle for which there are no more refracted “rays” (or light beams in general) is called $\theta_i = \theta_L$ “limit, or critical angle”.

The existence of a “critical” angle follows from Snell’s law, when the ratio

$$\frac{\sin(\alpha)}{\sin(\beta)} = \frac{n_2}{n_1}$$

is greater than 1.

This can happen when light propagates from a medium that has larger refractive index to one with smaller refractive index. In our case from water ($n_1 = 1{,}33$) to air ($n_2 = 1{,}00$).

Since the refracted beam moves away from the perpendicular, at the value π/2, the refracted beam will cease and all the light is reflected. This phenomenon is called total internal reflection.

By Snell’s law this happens for the incident angle $\theta_i = \theta_L$ = critical angle, such that $n_1 \sin \theta_L = n_2$ ($\sin \pi/2 = 1$) or

$$\theta_L = \arcsin\left(\frac{n_2}{n_1}\right)$$

In our case $\theta_L = \arcsin(1 / 1{,}33) = 48{,}75°$

Main conclusions

- The Reflection Law of geometrical optics: $\theta_i = \theta_r$
- The definition of the critical angle for total internal reflection

What next?

Going back to the water jet we will see that it is indeed total internal reflection the basic physics phenomenon that allows guiding the light

1.6. HOW IS A LIGHT GUIDE MADE? FIRST CLUES

One may introduce this activity by saying:

"Let's go back to all the experiments we performed up to this moment and look at the objects we have observed first and then investigated: optical fibers, rubber or plastic tubes and the water jet. Let's look again at the experiments with the water tank. All these experiments will serve to gather the clues which will allow us to understand a light guide's characteristics.."

Duration: about 1 hour

Didactical Notes

1.6.1. ACTIVITY: INTRODUCING CORE AND CLADDING OF A LIGHT GUIDE PART I

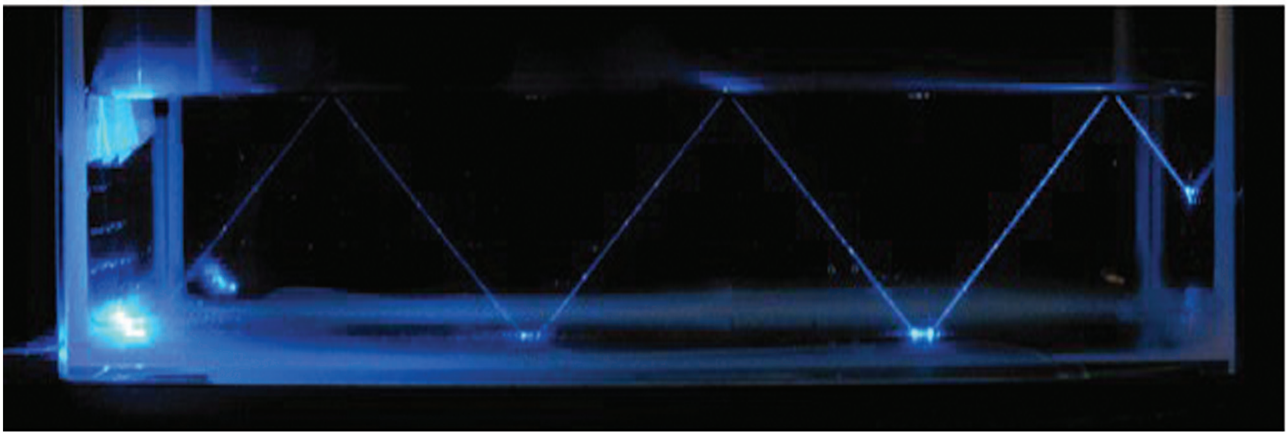


FIGURE T-8

In Experiment 1.3.1 (The water tank) one observes that the interfaces are water-air (on top) and water-glass (on bottom).

At the upper interface, at the critical angle, there is total internal reflection. This is not true for the other interface water glass (at bottom) since light propagates from water (lower refraction index) to glass (greater refraction index) and thus the condition for total internal reflection does not hold.

A schematic representation of what happens at the lower surface, which takes care of the glass width, is here represented.

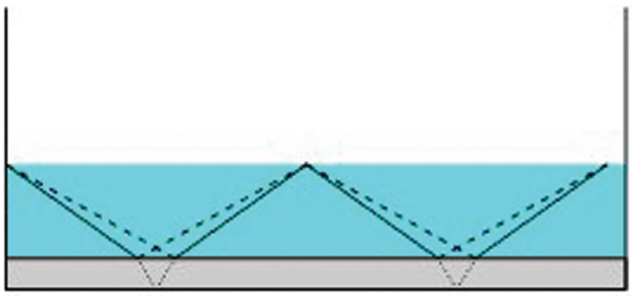


FIGURE T-9

This model well fits what one observes in the experiment where the light spots are very bright

PART II

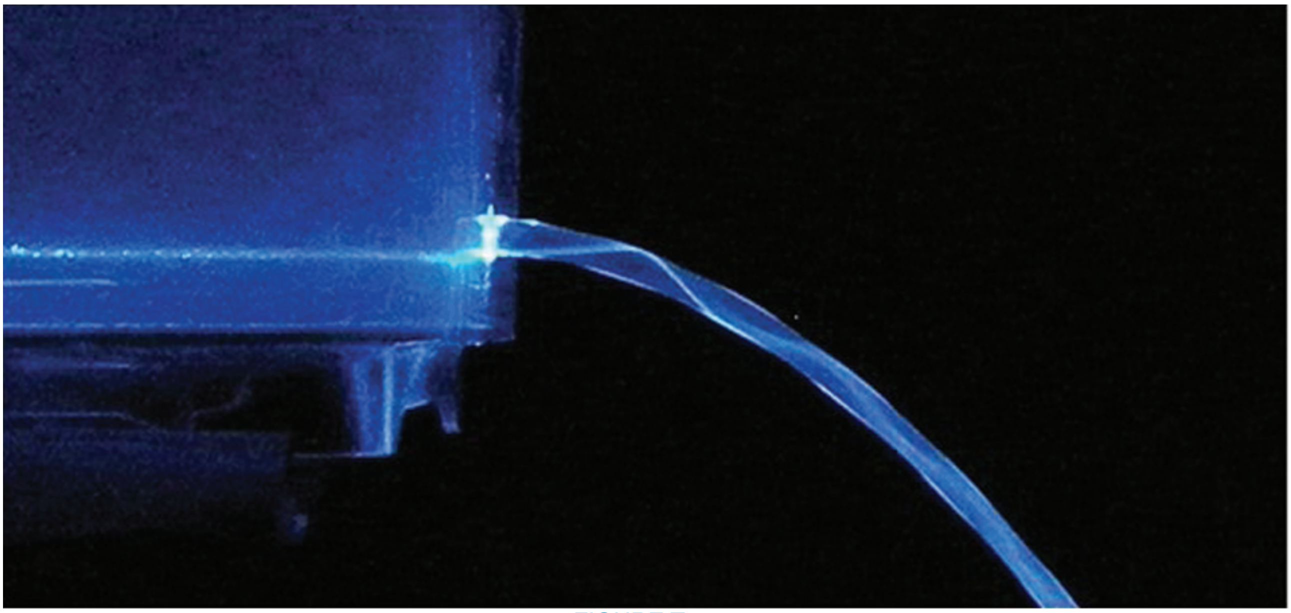


FIGURE T-10

In Experiment 1.2.1 (The water jet) the interfaces of the water jet are always water-air and the laser beam is undergoes total internal reflection, on both surfaces which allows the light to bend along its path. The same happens in the optical fiber.

One may thus conclude that a sandwich of two media, one with lower refraction index surrounded by another of greater refraction index, allows guiding the light through total reflections, if light is sent in the inner medium.

The inner material is named “core” and the outer material is named “cladding”. In the water jet the core is water and the cladding is air.

Part III

All the objects of the first experiments (1.1.1 – 1.1.3) can be re-examined, in order to synthesize the properties of a light guide. All transparent tubes as glass plastic Plexiglas are potentially light guides. Of course their lack of flexibility impairs the possibility to orient the light as it is done in the optical fiber.

Main conclusions

In 1.1 we concluded that light guides are *transparent tubes (not hollow)*. Now we add more clues to construct an optical fiber, having understood that the main mechanism for guiding the light is *total internal reflection.* That is:

- in order to guide the light one must have a transparent medium surrounded by another transparent medium of lower refraction index. When light is sent into the inner medium it undergoes total internal reflection at the interface between the two media.
- we name “core” the inner material and “cladding” the outer material

What next?

Let’s look for more clues... We want to construct an object that looks more like an optical fiber….

UNIT 2: FROM LIGHT GUIDES TO OPTICAL FIBERS

You may go back to the Scenario where different uses of the optical fibers were explored and compare the optical fibers with the water jet. For instance it is possible to ask:
"For what purposes could the water jet light guide be used for? Which liquid would you choose then? Could the water jet be suitable for transmitting signals? What are the possible drawbacks?"

Actually, it is not possible to use the water jet for signal transmission due to the attenuation of light travelling into it.

2.1. DO WE WANT TO SEE THE LIGHT PATH IN THE FIBER?

Possible questions to introduce the activity are:
We have investigated about an optical fiber's main characteristics and we have also seen that in an optical fiber we don't see the light travelling in the fibers' core. Do we want to see this light path? What advantages might this have? What drawbacks?

To be able to see the light path is an indication that light is attenuated (some of the emitted light enters the eye). But, where does attenuation come from?

Duration: about 1-2 hours

Didactical Notes

2.1.1. ACTIVITY: TRANSPARENT MATERIALS

Main factors that affect light attenuation in an optical fiber are related to bulk (as in all materials) and also to surface properties.

Bulk properties: relate to the nature of the core and of the cladding. It is true for all materials that intensity attenuation depends on the material's properties for a fixed radiation.[10]

Surface properties relate to the nature of the core-cladding interface .
Since light in the optical fiber hits (is reflected) many times the interface core-cladding we can ask if these reflections affect light attenuation
In order to do so we examine the Surface properties i.e. the nature of the interface core-cladding.

10. *Optical fibers… (bulk properties). The process of light transmission in an optical fiber is not 100% efficient: power leaving the fiber is less that that entering the fiber. Attenuation takes into account of this phenomenon. These pictures illustrates attenuation in a schematic way*


FIGURE T-11: SIGNAL ENTERING THE FIBER


FIGURE T-12: SIGNAL AT THE FIBER'S EXIT


FIGURE T-13: SCATTERING (PARTICLES)

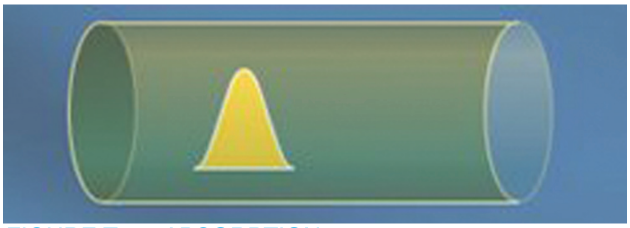


FIGURE T-14: ABSORPTION

2.1.2. EXPERIMENT: INFLUENCE OF MATTER ON TRANSPARENCY

Does attenuation depend on the amount of matter that light encounters? How can we convince ourselves of this? The experiment with the tissue allows addressing the dependence of attenuation on the amount of matter encountered.

How does attenuation relate to colour? What are possible effects of this?
Absorption can be addressed with the water jet colored liquids or recalling the common experience of warm black clothes exposed to light versus white clothes. The main effect produced by light absorption is warming.

What happens when there is (ideally) NO attenuation in a material,?
All the light that enters in a material comes out of it. We call "transparent" materials the ones that let the light pass through them without appreciable attenuation.

Which transparent materials do you know?
Observe also that materials that can be transparent with respect to some e.m. radiation and not to other, and that attenuation has to do with the interaction matter-radiation.

Attenuation is an important factor limiting the transmission of light across far distances.

2.1.3. EXPERIMENT: SCRATCHING THE SURFACE

When one scratches an end of a fiber (for example in the optical fiber lamp) one may see diffuse light, where the cladding has been removed. Since "to see the light means intensity reduction", students can understand that the core-cladding's interface properties are important in determining light attenuation.

2.1.4. ACTIVITY: IDENTIFYING A GOOD CLADDING

One can become aware of the fact that the interface core-cladding must be straight and smooth, otherwise one observes diffuse reflection, as the scratched fiber shows. The schema below allows understanding the reasons for such behavior.

In figure T-15 A, where the surface of glass is rough, one may say that some rays that hit the surface could be not at the critical angle, while in figure T-15 B, they are alla parallel due to the smoothness of the surface.

When the interface core-cladding is rough light is no more trapped within the fiber's core and one sees diffuse light arriving at the eye.

Main conclusions

- Transparency means that light is not attenuated when it travels in a material
- Scattering and absorption in the bulk are factors that determine light attenuation.
- Diffusion at a rough interface can affect loss of intensity
- In optical fibers, attenuation is the rate at which the signal light decreases in intensity. For this reason, glass fiber (a transparent material which has low

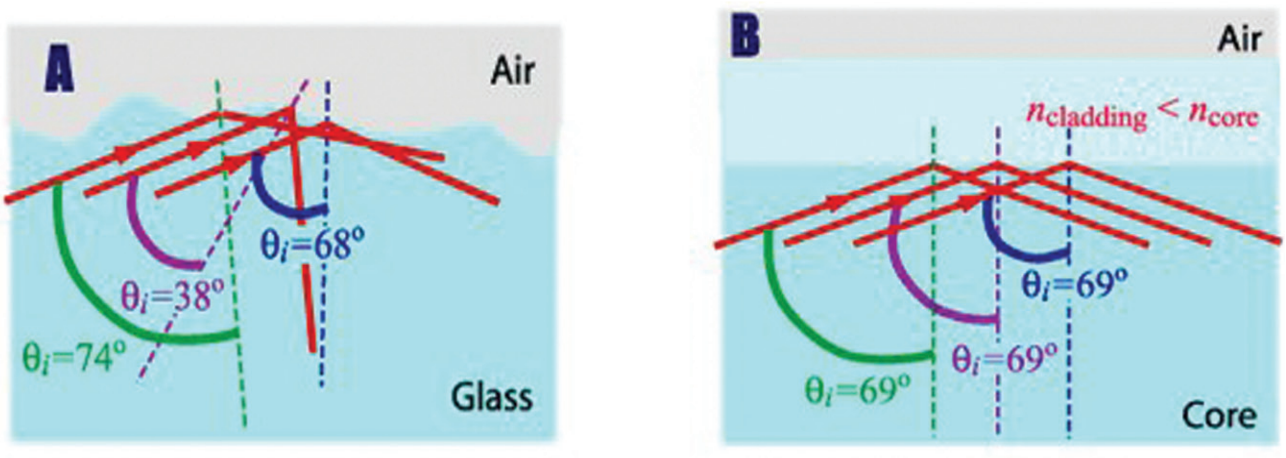


FIGURE T-15

attenuation) is used for long-distance fiber optic cables; plastic fiber has a higher attenuation and hence shorter range. The latter are used in clinical endoscopy.

What next?
Let's look more carefully at the core – cladding refraction indices in order to see what is the experimental setup we need to have light travel in the fiber …

2.2. OPTICAL FIBERS'' CHARACTERISTICS

One may introduce this activity by saying:
"Lets' look at a picture of an optical fiber where its real dimensions are indicated… We want to better understand how to construct an optical fiber…"

Duration: about 1 hour

Didactical Notes

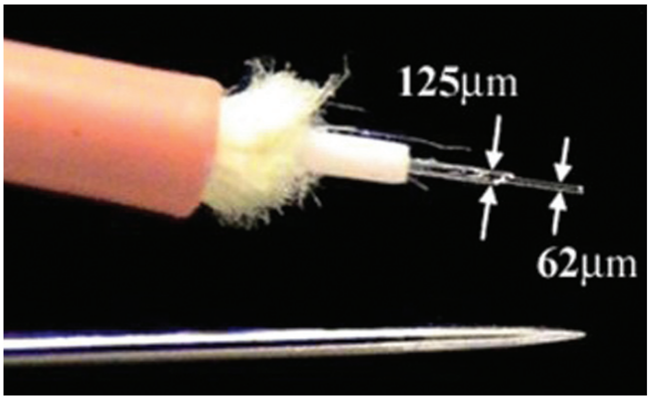


FIGURE T-16

2.2.1 EXPERIMENT: INTRODUCING THE ACCEPTANCE ANGLE

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Glass bar Send the light of the laser at one end of the fiber and look if the opposite end is illuminated or not. Turn around the laser light. When you don't see anymore the bright spot of light at the opposite end you have passed the acceptance angle.	It is necessary to hold the laser pointer real close to the fiber's end otherwise you see only diffused light.

The simple experimental observations can lead to say that not all entrance angles of light in the fiber, allow light to arrive at the opposite end of the fiber. Therefore there is an "acceptance angle": i.e. light reaches the opposite end if it enters at an angle smaller (or equal) than it. Evidence for this is provided by the proposed activity above.

2.2.2 EXPERIMENT: ROLE OF THE CLADDING IN DETERMINING THE ACCEPTANCE ANGLE

EXPERIMENT DESCRIPTION	OPERATIVE SUGGESTIONS
Acceptance angle and cladding's refraction index Insert the glass bar in water (refraction index of water greater than that of air) and observe that the acceptance angle is smaller than in the air-cladding case.	It is necessary to hold the laser pointer real close to the fiber's end otherwise you see only diffused light.

The activity allows determining an order relation between the cladding's refraction index and the acceptance angle.

When the glass bar is introduced in water it is quite clear that, when the refraction index of the cladding increases, the acceptance angle decreases.

Main conclusions
Cladding's properties
As we learned in the previous activity the cladding allows protecting the core and defines a smooth interface with the core in order not to have diffuse reflection and thus loss of intensity at interface.

As far as the *geometrical setting* necessary to have light propagation within the fiber one can conclude that there is a maximum angle for which light sent in the fiber propagates within it. We call this angle: the "acceptance angle" .

The value of the acceptance angle depends on the relation between the refraction indices of core and cladding. As the refraction index of the cladding increases with respect to the core's, the acceptance angle decreases.

2.2.3. COMPUTER ACTIVITY: CALCULATING THE ACCEPTANCE ANGLE

Having **fixed the values** of the core and cladding's refraction indices, one may define the acceptance angle, and the numerical aperture.

The maximum value of the entrance angle of light in the fiber θ_a for which you have total internal reflection in the core is called
θ_{amax} = acceptance angle

The angular aperture of the fiber is $2\theta_{amax}$, and all light beams that propagate within this angular aperture propagate only in the fiber's core.

PART I

CABRÌ SIMULATION	OPERATIVE SUGGESTIONS
Open the Cabrì file "**optical_fiber.fig**" Select the refraction index of material 1 (core) n_n = 1,5 and n_n = 1,47 for material 2 (cladding). Two rays i and i' are superimposed and parallel to the fiber's axis and θ_a=0°. Increase θ_a by rotating the semiray i counter clockwise until you don't see total internal reflection in the fiber (by construction i' moves symmetrically).	A three dimensional picture can be imagined by rotating around the fiber's axis the plane containing i and i' and the section (in Cabrì) of the fiber. Rotating i and i' one obtains the *acceptance cone of the fiber.*

PART II

Fix a value for the core's refraction index n_n = 1,50. Fix initially the cladding's refraction index n_m = 1,10 and fill the table.

The above simulation allows understanding that θamax depends on the difference n_n- n_m between the refraction indices of the core and cladding.

Main conclusions
The fiber's main properties are hereafter indicated.
- An optical fiber is a vitreous filament made of two concentric cylinders made of two materials with different refraction indices; the inner one is called core and the outer one is called cladding
- The refraction index of the core is larger than that of the cladding and light is sent in the core. This is

the condition for total internal reflection in the core

- Total internal reflection takes place only if the angle at which light enters the fiber is smaller than an angle θ_{amax} named acceptance angle. And the angular aperture is $2\theta_{amax}$.

What next?

The question now we could ask is
"do we want a large or small acceptance angle?"

The answer to this question is related to what we want to do with an optical fiber. But here we have learnt that if we want to change for some reason the angular aperture, we can act on the difference n_n- n_m between the refraction indices of the core and cladding. In the next activity we shall consider the fibers used as cables for telecommunications and understand what characteristics they must have.

C: DESCRIPTION OF EXTENSION ACTIVITIES

C: DESCRIPTION OF EXTENSION ACTIVITIES

UNIT 3: OPTICAL FIBERS AS TRANSMISSION CABLES

3.1. HOW CAN WE RECOVER INFORMATION?

Student level / age group
14-16 years old

Learning Objectives
Understand relationships between numerical aperture and the number of beams travelling in a fibers
Introduce fibers' signal transmission

Recommended settings and pedagogical approaches
- two students group work with Cabrì simulations and PowerPoint presentation
- class discussion

Material resources including ICT tools
- PowerPoint files
- Cabrì files

Inquiry-oriented activities including driving questions
In this activity, the students are guided to answer the following questions:

- what is a signal?
- what are the problems of signal transmission with optical fibers?

The teacher guides the students to understand that when a signal travels along the fiber and modal dispersion occurs, one may have a not desirable result for transmission: the distortion of the information carried along with the signal. It is possible to design two different types of optical fibers to reduce modal dispersion: single mode and graded index.

Hints and Tips
See "hints and notes for teachers".

3.2. A GRADED INDEX OPTICAL FIBER

Student level / age group
14-16 years old

Learning Objectives
Investigate the relationship between modal dispersion and refraction indices of core and cladding
Design a graded index optical fiber

Recommended settings and pedagogical approaches
- the teacher performs the experiment
- class discussion
- two students group work with PowerPoint presentation and internet applets

Material resources including ICT tools
- transparent container (80cm length, 15cm height 5cm depth);
- low-cost laser pointer (638 nm, 20mW);
- dropper
- tap water
- denaturized alcohol
- PowerPoint files

Inquiry-oriented activities including driving questions
The graded index optical fibers are introduced by means of an experiment in which a laser beam propagates within a mixture of water and alcohol. The mixture has variable index of refraction resulting in a curved path of the light beam (Figure C21).

Possible questions to ask to drive class discussions are:
- How is it possible that light makes a curved trajectory?
- How can you relate this with the water refraction index?

Hints and Tips
See "teacher's notes".

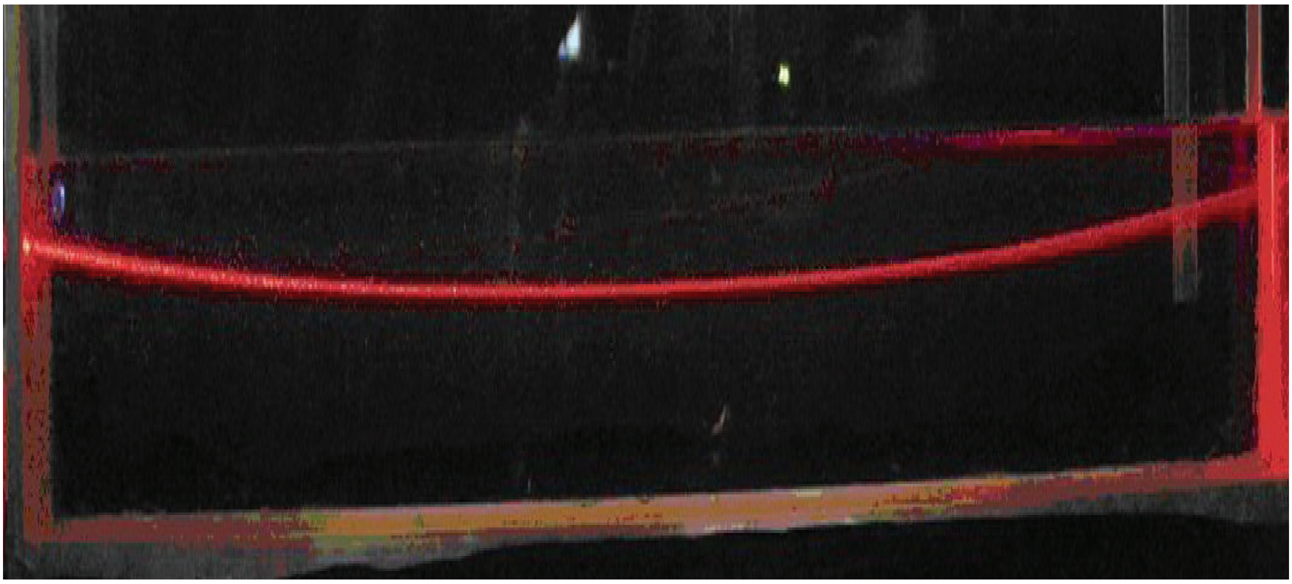


FIGURE C21: WATER TANK EXPERIMENT WITH ALCOHOL AND WATER

TEACHERS' NOTES

UNIT 3: OPTICAL FIBERS AS TRANSMISSION CABLES

3.1. HOW CAN WE RECOVER INFORMATION?

One may introduce this activity by saying:

"What happens when the angular aperture is large? What use may such a fiber have? Let's go back to the activity we did when you were trying to communicate with your peer by sending light signals in a piece of fiber. There we learned that a light beam can be thought as a signal. Up to now we have studied what happens when one signal travels in an optical fiber and we have always simulated this with one ray…But is such a fiber useful? Would we want more of it? If we want to use the fiber for transmitting signals how could we do this? With one light beam? More?

Duration: about 2 hours

Didactical Notes

Before looking at the Cabrì simulations students should be led to understand that large numerical aperture allows for MANY signals with very different paths to travel along the fiber. Each signal will follow a quite different path in terms of length and in terms of TIME interval that it takes to arrive at the opposite end. It is intuitive that rays that travel parallel to the core axis (enter the fiber at θ_a=0°) arrive at the opposite end in the shortest time interval. The rays that enter the fiber at an angle different from θ_a=0° take more time to arrive at the opposite end of the fiber.

Assuming thus large angular aperture, we can consider two different signals (here two rays) and measure the length of the path for each of them and the time interval it takes for each of them to go through the fiber.

Activity 3.1.1 (Signals' pathway) and Activity 3.1.2 (Which signal travels faster?)

The answer to the questions of these activities are intuitive IF students can understand that light is a wave phenomenon travelling (in vacuum) at constant speed.

It requires students to be able to go from the model light propagation used up to now, of the optical geometry, to the wave model of light.

3.1.3. COMPUTER ACTIVITY: INTRODUCING MODAL DISPERSION

The idea behind the simulation is that a light beam can carry information. Here the simplified idea of signal as a set of different light beams can be introduced.

With this idea, one can convince students that a signal travels in an optical fiber as simple light beams do. The simulation uses such an approximation. It allows visualizing the problems in information transmission within the step-index fibers.

Open the slides "modal_dispersion.ppt" one at a time and let the students observe what happens

1) the three parts travel at same speed along different paths; two parts hit the surface (reflect) while one part travels along the axis. They arrive at the end of the fiber (right hand side) with a time delay that does not allow to recompose the image (information is not recovered).
2) the three parts arrive at same time but the image transmitted is not correctly received (the three parts travel with very different speeds).

How should the three parts of the image travel in the fiber in order to avoid the time delay at the arrival?

One solution is that the three parts travel all parallel to the axis and recompose correctly the image (single-mode optical fiber). You can show slide 3) for a possible solution.

3.1.4. COMPUTER ACTIVITY: EVALUATING THE MODAL DISPERSION

Open the file **"times.fig"** .
Select a value for the core's refraction index $n_n = 1{,}50$ and cladding's refraction index $n_m = 1{,}47$.

Observe the rays **α** and **β**, that are superimposed respectively at θa=0° and θa=17,3°.

Δt is the difference between the times needed by the two rays a and b to reach points Q and P.

The fiber considered in the simulation is **step-index**.

If the students can grasp some elementary algebra it is possible to arrive to the exact form of the relation between (L_2-L_1) and (t_2-t_1) and (n_2-n_3)
This relation shows that if the difference nn-nm is

$$\Delta t = t_{max} - t_{min} = \frac{L \cdot n_2}{c \cdot n_3}(n_2 - n_3)$$

small, (therefore nn/nm is close to 1) then the two signals arrive at the fiber's opposite end with small time delay.

Main conclusions

- *Large numerical aperture = rays can enter the fiber at different angles and arrive at fiber's end with time delay.* Rays of light enter the fiber with different angles with respect to the **fiber axis**, up to the fiber's **acceptance angle**. Rays that enter with a smaller angle travel through a more direct path, and arrive sooner than rays that enter at a steeper angle (which **reflect** many more times off the boundaries of the core as they travel the length of the fiber). The time delay between two (or more rays) is called **"modal dispersion"**
- When different rays constitute a signal travelling along the fiber, and modal dispersion occurs, one may have a not desirable result for transmission: the distortion of the information carried along with the signal.
- In a homogeneous material light travels at constant speed that depends on the material's refraction index, therefore a difference in path length means also a time delay. Modal dispersion is this time delay and it is the basic limiting factor for an efficient transmission. In order to limit modal dispersion, one may act on n_n-n_m. If this difference is small the rays propagate in a direction almost

parallel to the fiber's axis. In this kind of fibers the only signals that can propagate are those that enter at a very small acceptance angle (in the limit only one angle of entrance is allowed). Such fibers are called single-mode optical fiber.

Design facts

Finally… how can we design an optical fiber that has little modal dispersion?

One way to do this is to use the same material for both core and cladding and "doping" the cladding in order to have it a refraction index slightly smaller than that of the core.

What about making the diameter of core very small?

Such a fiber will propagate necessarily signals parallel to its axis.

The usual optical fibers for telecommunication are very thin (core about 5 μm). The cost for producing very tiny diameters is less than that of doping the cladding. Other problems?

What next?

We want to investigate about the design of another type of optical fiber.

3.2. A GRADED INDEX OPTICAL FIBER

One may introduce this activity by saying:

"So we now know that modal dispersion is not desirable. We have seen that when modal dispersion occurs, information can be distorted. Let's see how we can design an optical fiber that has low modal dispersion in order to limit signal distortion…".

Duration: about 2 hours

Didactical Notes

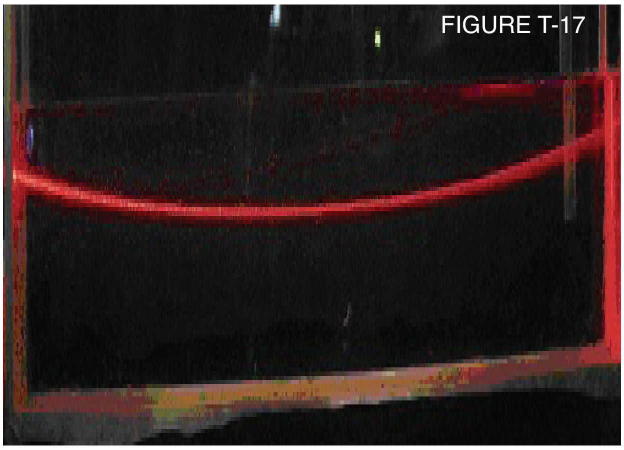
3.2.1. COMPUTER ACTIVITY: ADDRESSING MODAL DISPERSION

The three parts of the image arrive at the same time because the fiber is graded index.

3.2.2. EXPERIMENT: LIGHT TRAJECTORY IN VARIABLE REFRACTIVE INDEX MATERIALS

The experiment with the water tank analogy for the graded index optivcal can be performed by the teacher

<table>
<tr><th>EXPERIMENT DESCRIPTION</th><th>OPERATIVE SUGGESTIONS</th></tr>
<tr><td>

Water and alcohol mixture
The photo below shows a typical result of the experiment
FIGURE T-17


</td><td>

Use 3 l of water and add very carefully 200 ml of alcohol with the dropper in order to let the alcohol mix gradually with water. The water tank has to be longer than the one you used in the experiments before because otherwise you will not be able to see light bending.

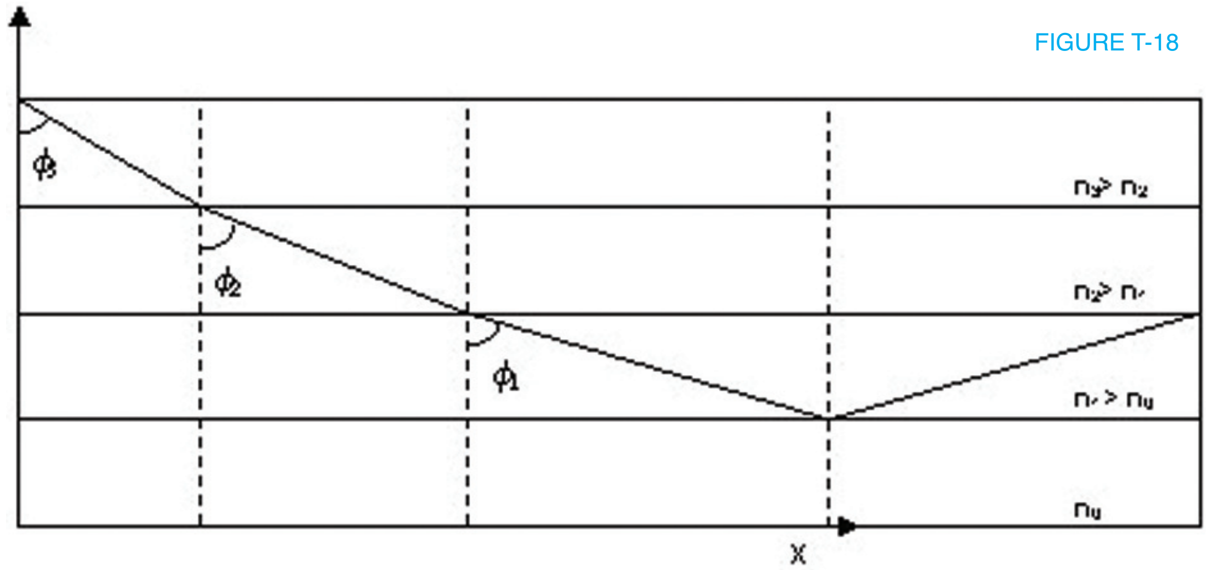
Other solutes as sugar, salt or honey can be used. They do not give the same results because of light scattering and absorption.

After about 2 hours the water-alcohol solution has a significant gradient in the refraction index.

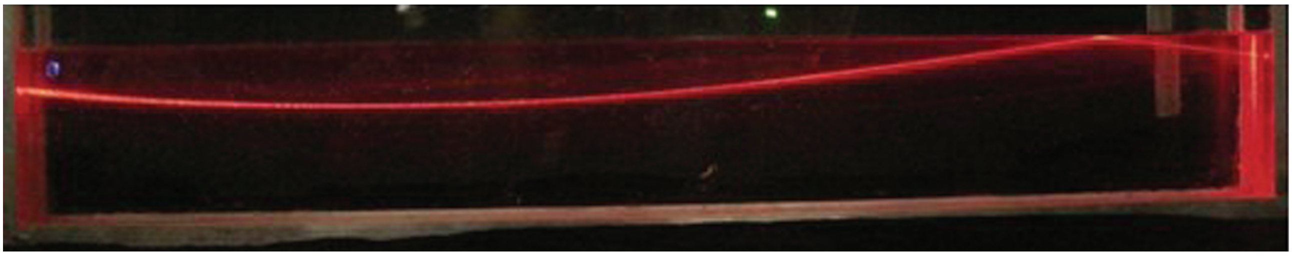
</td></tr>
</table>

The alcohol “floats” in the water and the refraction index decreases as one approaches the bottom of the tank and therefore bends the light beam, as the schema below suggests.

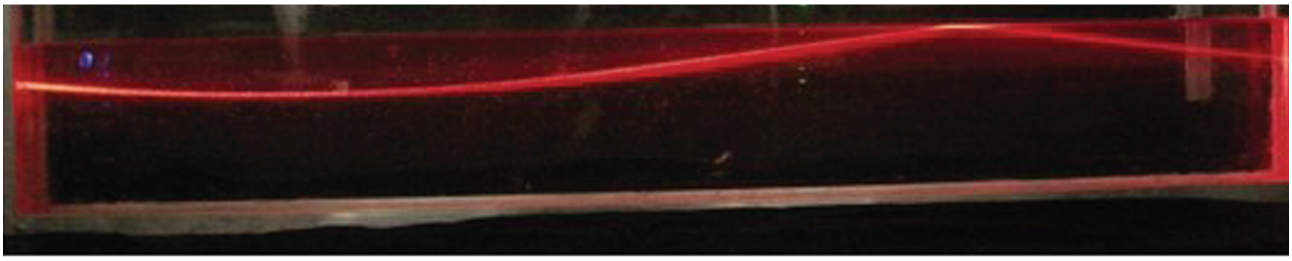
FIGURE T-18



Notice that the beam goes up again when the total reflection condition is reached at a certain height. Adding more alcohol allows to see another bending of the light path.



225 ML OF ALCOHOL - FIGURE T-19



250 ML OF ALCOHOL - FIGURE T-20

3.2.3 COMPUTER ACTIVITY: STEP AND GRADED INDEX OPTICAL FIBERS

The URL gives a pictorial representation of the different situations and different signals travelling in fibers

Main conclusions

- Optical fibers for telecommunication are made with many cables that are step index optical fibers (usually they have different colors) and each of them carries a signal.
- Graded index optical fibers can in principle carry different signals…but they are seldom used for telecommunications for cost reasons due to the fact that the material has to be doped in a proper way.

D: EVALUATION TASKS FOR INDIVIDUAL ACTIVITIES OR INDIVIDUAL UNITS OR WHOLE MODULE (INCLUDING ASSESSMENT RUBRICS)

D: EVALUATION TASKS FOR INDIVIDUAL ACTIVITIES OR INDIVIDUAL UNITS OR WHOLE MODULE (INCLUDING ASSESSMENT RUBRICS)

1. OVERVIEW

To evaluate the UoN Module are designed the following:

- pre-test to investigate prerequisites needed to students
- three interim tasks
- post test

We also include rubrics to evaluate all the designed tasks.

PRE-REQUISITES

PART A

1. Express in words what is

A ray:

A segment:

A semi-ray:

2. Two rays intersect when:

a) They have only one point in common
b) They have at least one point in common
c) They don't have any point in common

Explain briefly

3. **Given a ray r, in which of the pictures below is represented a ray that is perpendicular to r?**

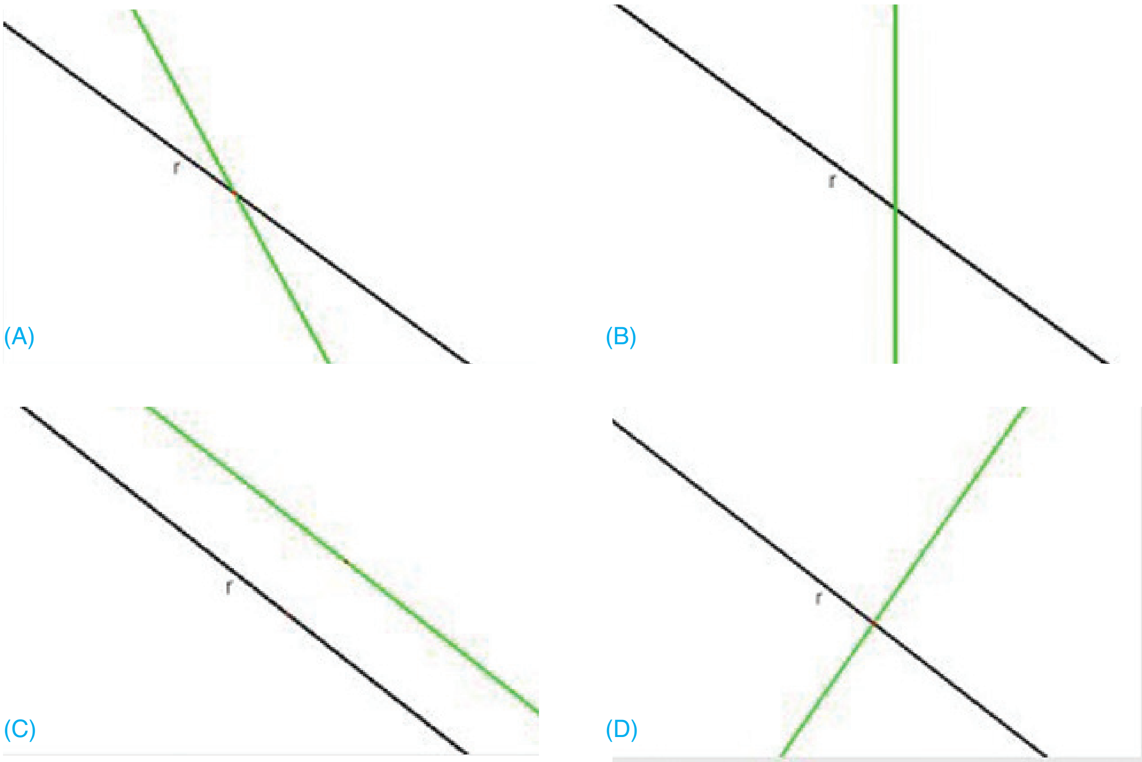


FIGURE PRE-1

Explain briefly

4. **The rays r and s are parallel to each other, therefore the angles α and β:**

a) Are equal
b) Their sum is 90°
c) Their sum is 180°

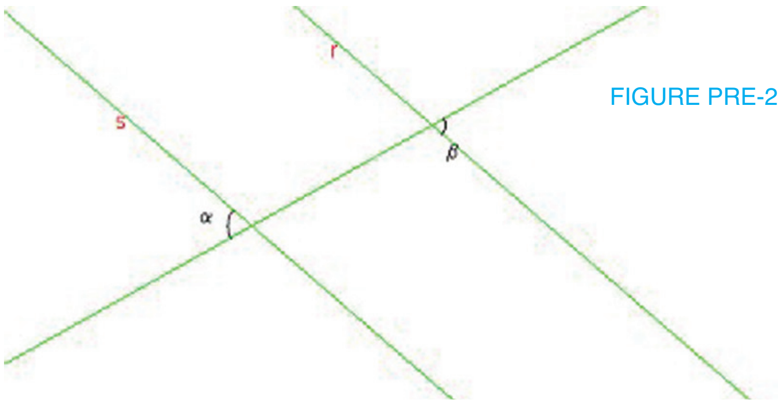


FIGURE PRE-2

Explain briefly

5. Trace the perpendicular to the ray s, and through point P.
Trace counter- clockwise the angles that segments AP and PB form with such a perpendicular.
Which of the two angles is greater?

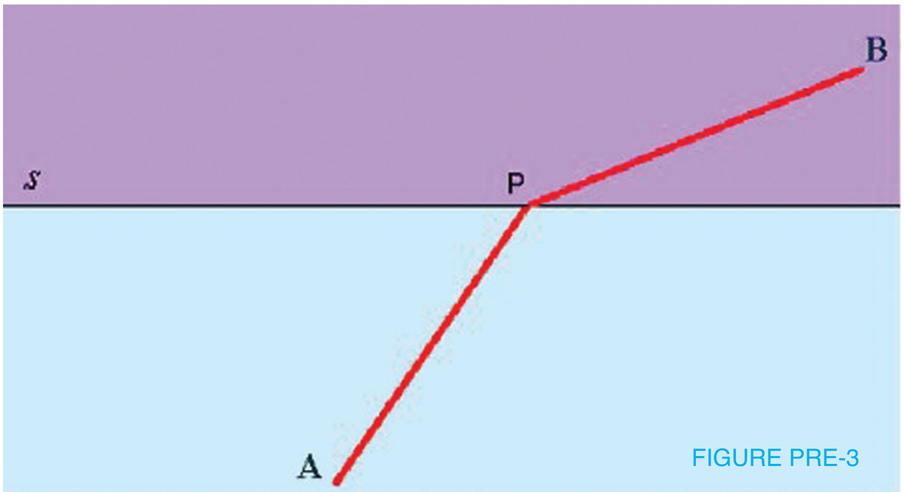


FIGURE PRE-3

Explain briefly

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6. In figure 2 ray s is rotated counter-clockwise by 20° with respect to figure 1. The segment AB in fig 1 is parallel to AB of fig 2. Draw, in both figures 1 and 2, the angles clockwise between segment AB and the perpendicular to ray s, and compare them. The angle you have drawn in figure 2 is

a) greater than that in figure 1
b) lesser than that in figure 1
c) same in both cases

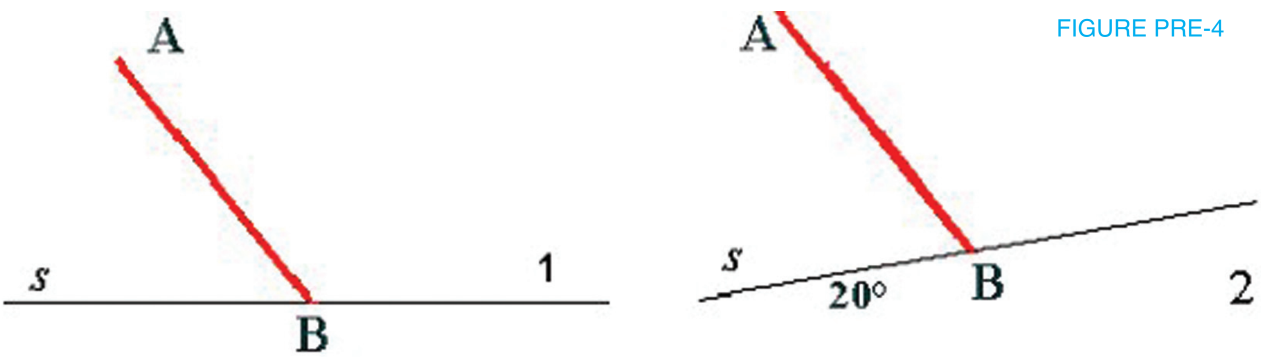

FIGURE PRE-4

Explain briefly reporting your calculations

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7. **Suppose you have measured six times the time interval that is needed for the pendulum to make a complete oscillation The six values are reported in the table**
The mean value of such measurements is:

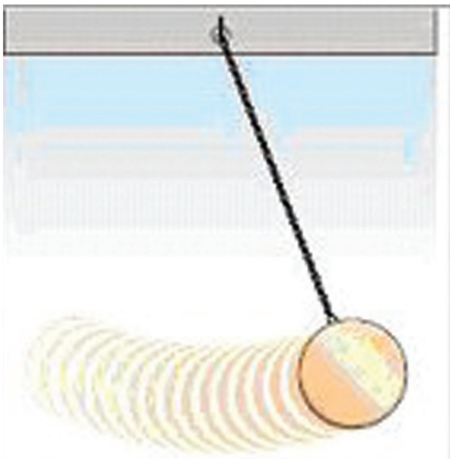

FIGURE PRE-5

Measure	Period (s)
1	2,5
2	2,7
3	2,4
4	2,6
5	2,5
6	2,3

Explain briefly

PRE-REQUISITES

PART B

1. Explain briefly why we don't see objects in a dark room

2. Which of the pictures below better represents the mechanism for which we see objects around us?

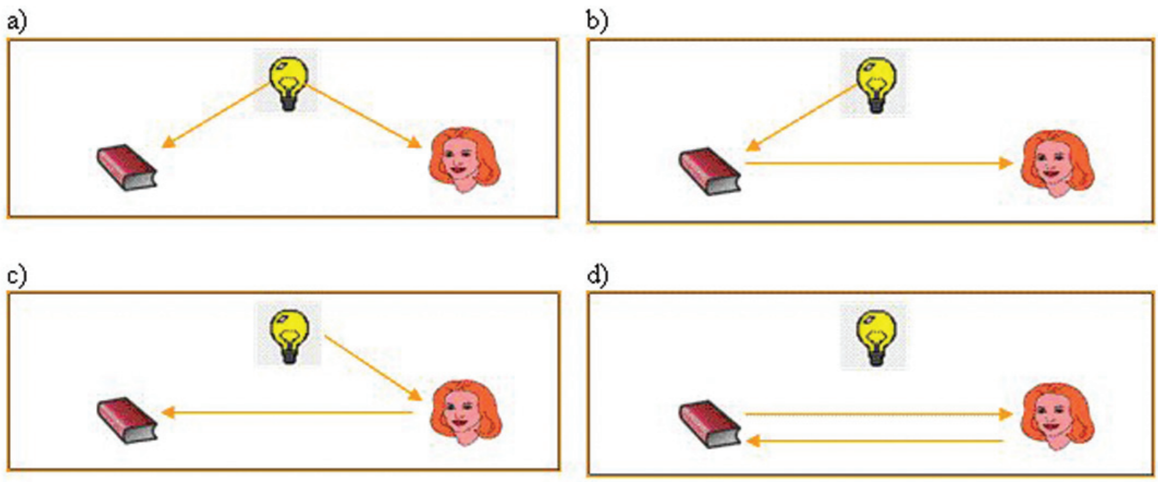

FIGURE PRE-6

Explain briefly

3. Why sometimes you can see light beams filtering from the clouds?

INTERIM QUESTIONNAIRE 1

1. You want a laser beam hit a surface and go back. What object would you choose?

a) A window's glass
b) A concrete wall
c) A glass containing still water
d) A mirror
e) A wood tablet

Explain briefly

2. Why, according to your idea, some rooms in a house have frosted glass window pane (see example in the figure)?

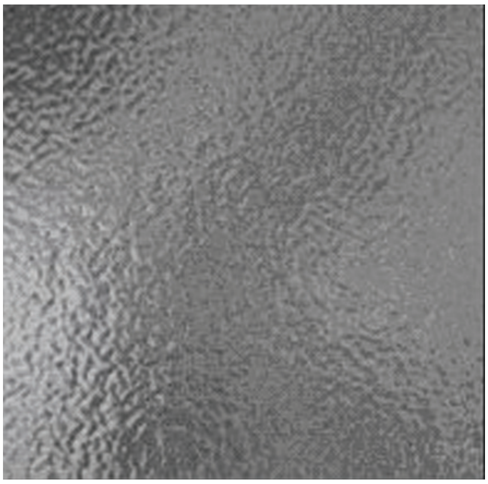

FIGURE I1-1

Explain briefly

3. When a laser beam propagates in a room's air, its trajectory is:

a) Always rectilinear
b) Always curvilinear
c) Part is rectilinear and part is curvilinear
d) Rectilinear until the beam hits an obstacle that deviates or absorbs the light
e) Rectilinear until the beam curves in order to pass the obstacle

Explain briefly

4. If you were an ancient Egyptian and you had to light up a long tunnel with many curves inside a pyramid how would you guide the light within such tunnels?

Explain briefly

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5) The picture below depicts a fountain in a square of Moscow. How is it that only the water jets are lighted while the surroundings are dark?

FIGURE I1-2

Explain briefly

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INTERIM QUESTIONNAIRE 2

1. **The picture represents a laser beam travelling from the water contained in the tank to the air above the water surface. The beam is more visible in air than in water because:**

   a) Air captures more light than water
   b) There is less water in the tank than air
   c) Air is less dense than water
   d) Air particles are smaller than the water particles
   e) Some particles that diffuse light more than the particles in the water tank have been added in the air

   Explain briefly

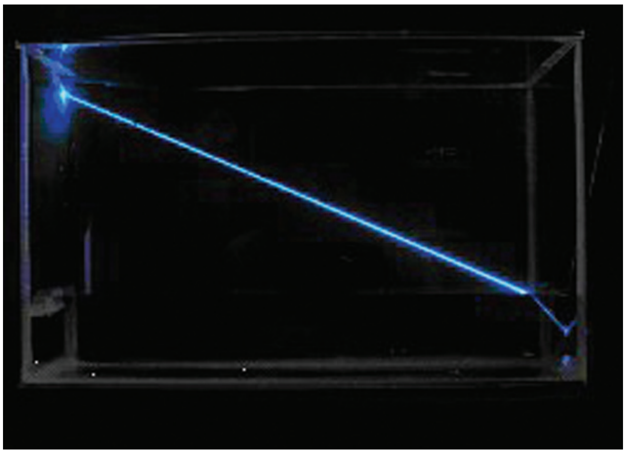

FIGURE I2-1

2. **The picture represents a laser beam travelling from the water container in the tank to the air above the water surface. Observe points the P and Q where the laser beam hits the water surface.**

In P there is reflection	YES	NO
In P there is refraction	YES	NO
In Q there is reflection	YES	NO
In Q there is refraction	YES	NO

   Explain briefly

FIGURE I2-2

3. **Open the file "unknown_reflection_index.fig" as background image. Draw the incidence (i) and refraction (r) angles and, using a suitable graphical representation calculate the ratio sen(i)/sen(r). Compare your result with what you have obtained in the class activity. The number is the same? Different? Why?**

   Explain briefly

4. Which of the following sentences is true? (Note that here the "refraction index" is relative to that of the air which for our purpose can be taken as 1)

A substance's refraction index depends on the quantity of substance	TRUE	FALSE
If two materials have different densities, then the material that is more dense has a greater refraction index	TRUE	FALSE
A materials' refraction index depends on the volume of the material	TRUE	FALSE
A laser beam is brighter in the materials with greater refraction index	TRUE	FALSE
A laser beam entering at the same angle into two materials with different refraction indices, is refracted more in the material with a greater refraction index	TRUE	FALSE

Explain briefly

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5. In the image below, draw the rays of light in air according to their propagation in the water

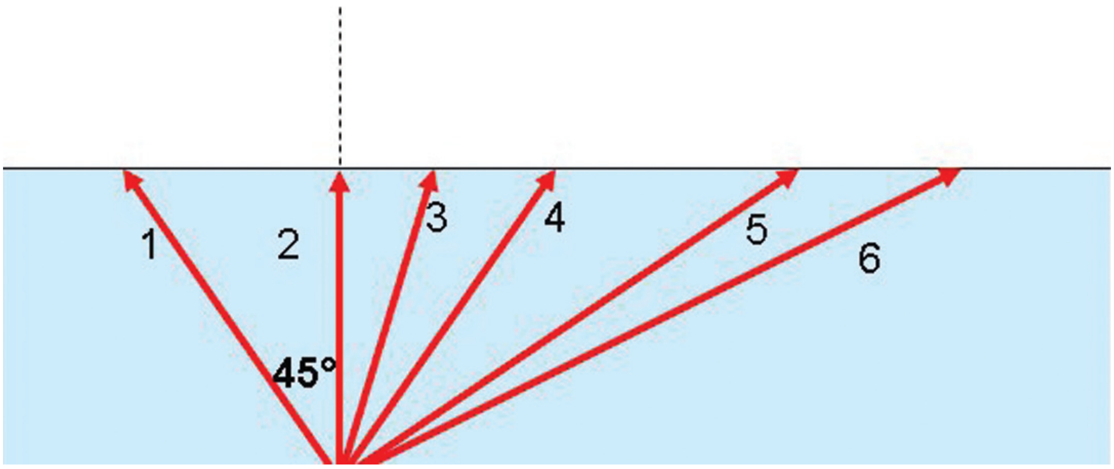

FIGURE I2-3

INTERIM QUESTIONNAIRE 3

1. **The picture shows an optical fiber made of a plastic transparent tube immerged in water. A light beam enters the fiber.**

   Observe what happens to the light when it enters the fiber at an angle θ_0 = 37.9° (fig a) and at an angle θ_0 = 52.3° (fig b). Briefly describe the differences between the two situations.

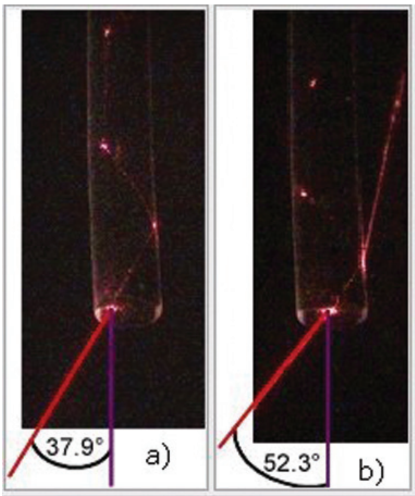

FIGURE I3-1

2. Is it true that:

A fiber's cladding must have refraction index smaller than that of the core in order to avoid refraction at interface	YES	NO
Light is sent in a fiber in a direction parallel to its axis in order to reduce reflections at the core-cladding interface	YES	NO
Total internal reflection is the phenomenon that allows light to travel along curved paths	YES	NO
Light must enter in a direction parallel to the fiber's axis to avoid that light refracts when the fiber is bent	YES	NO
A fiber's core must have refraction index greater than that of the cladding for total internal reflection to occur within the fiber	YES	NO

Explain briefly

2. Is it true that:

Light transmission with optical fibers is fast because light is fast	YES	NO
Optical fibers guide the light because there are small mirrors inside them	YES	NO
Light travels at zig-zag inside a fiber	YES	NO
The inner part of a fiber is covered with a thin aluminium layer to favour light conduction	YES	NO
When a fiber is bent, light which propagates within it does not loose significantly intensity	YES	NO

Explain briefly

POST INSTRUCTION QUESTIONNAIRE

1. **Explain briefly why we cannot see the objects around us in a dark room.**

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2. **Why sometimes you can see light beams filtering from the clouds?**

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3. It is possible to guide the light within:

a) a whole plastic tube surrounded by air	YES	NO
b) a whole plastic tube surrounded by water	YES	NO
c) an hollow plastic tube	YES	NO
d) an hollow glass tube	YES	NO
e) a whole glass tube surrounded by air	YES	NO
f) a whole glass tube surrounded by water	YES	NO

Explain briefly

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4. What materials are made of the optical fibers of the lamps (see picture)

a) Plastic
b) Glass
c) Rubber
d) Ceramic

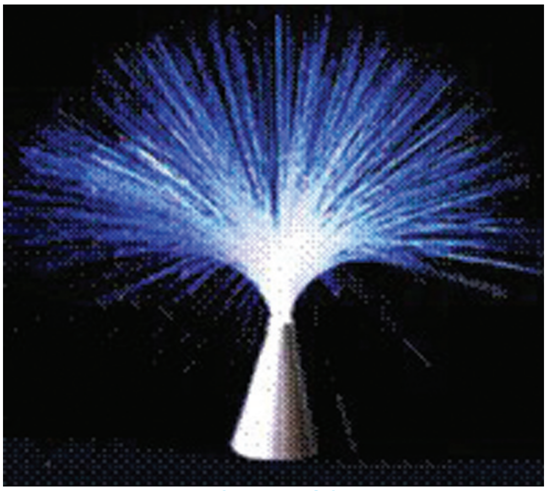

FIGURE POST-1

5. What happens when light hits a still water surface?

a) all the light comes back in the air
b) light will travel only in the water
c) some light will travel in water and some will come back in air
d) all the light is captured by water
e) we need more information about the nature of the water surface

Explain briefly

6. According to your idea, is it true that

a) index of refraction is a property of materials	YES	NO
b) the refraction index of the water influences the brightness of a light beam propagating in the water	YES	NO
c) the value of the refraction index of a substance depends on the quantity of substance (Yes / No)	YES	NO
d) to measure the refraction index of a substance with respect to another, it is sufficient to know the critical angle between them	YES	NO
e) to measure the refraction index of a substance it is necessary to know its density	YES	NO

Explain briefly

7. **Open the files "oil_water.fig" and "water_oil.fig".**
   Draw the laser beams as they travel through the media (n_{water} =1.33 ; n_{oil} = 1.67).

8. According to your idea, is it true that

a) Light travelling from water to air can undergo total reflection	YES	NO
b) The critical angle between two materials depends only on the refraction index of the material in which the light is totally reflected	YES	NO
c) Light travelling from air to water can undergo total reflection	YES	NO
d) Total reflection is a phenomenon which occurs when light travels from a less refractive to a more refractive material	YES	NO
e) Given a light beam travelling from material 1 to material 2, the critical angle of material 1 with respect to material 2 is the smallest incidence angle for which there is no refraction in material 2	YES	NO

Explain briefly

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9. In the figure, θ_0 is 45°. According to your idea, is it true that

a) if n_2 >1.40 there is refraction between core and cladding	YES	NO
b) after entering the fiber, the beam deviates towards the fiber's axis	YES	NO
c) to know how the beam deviates after entering the fiber it is necessary to know n_2	YES	NO
d) after entering the fiber, the beam deviates towards the upper part of the fiber	YES	NO
e) it is sufficient that n_2 < 1.40 to have always total reflection between core and cladding	YES	NO

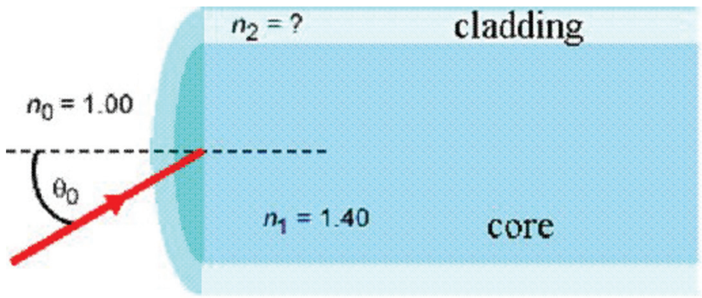

FIGURE POST-2

Explain briefly

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10. According to your idea, is it true that

a) The numerical aperture of a fiber depends on the fiber's diameter	YES	NO
b) The acceptance angle is the largest value of the entrance angle in the fiber which allows total reflection between core and cladding	YES	NO
c) The numerical aperture of a fiber depends only on the core and cladding refraction indices	YES	NO
d) If the difference between the core and cladding refraction indices increases, the acceptance angle of a fiber increases	YES	NO
e) If the difference between the core and cladding refraction indices become zero, the acceptance angle is the largest possible	YES	NO

Explain briefly

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CORRECT ANSWERS

PRE-TEST

PART A (max = 10 pts)

1. (1 point) A ray is an infinite sequence of points along a rectilinear path; a segment is a part of a ray between two points; a semi-ray is a part of a ray with a point as origin and a fixed direction
2. (1 point) a)
3. (1 point) d)
4. (1 point) a)
5. (2 points) Angle formed by segment PB is greater than that of AP
6. (3 points) b) Angle formed in figure 2 is 20° degree less than that in figure 1
7. (1 point) Average value is 2.5

PART B (max = 3 pts)

1. (1 point) Objects diffuse the light (that enters our eyes) that reaches them from a light source. If there is no such source no light can enter our eyes
2. (1 point) b) Light source lightens up the object which reflects part of the light into our eyes
3. (1 point) Light is scattered and diffused by vapor molecules near the clouds

Interim Questionnaire 1 (max = 5 pts)

1. (1 point) d)
2. (2 point) Frosted glass allows light to enter, not going out to an observer behind it
3. (1 point) d)
4. (0.5 point) Ancient Egyptians used a sequence of mirrors to guide sunlight and enlighten up pyramids tunnels
5. (0.5 point) Water jets surrounded by air act as light guides

Interim Questionnaire 2 (max = 5 pts)

1. (0.5 point) e
2. (0.25 point) all YES. In P and Q light beams do not hit at the critical angle
3. (1.75 points)
4. (1 point) all FALSE. Refraction index is a property of the material. The last answer is a consequence of Snell law.
5. (1.5 point) Rays hitting the water surface at angles greater than 48.8° are totally reflected.

Interim Questionnaire 3 (max = 5 pts)

1. (2 points) When the light beam enters into the tube at 37.9°, the incidence angle at the plastic-water surface inside the tube is greater than the critical angle between these two materials. This is not the case when the entrance angle is 52.3 °.
2. (1. 5 points) All YES
3. (1. 5 points) NO – NO – YES – NO – YES

Post Test (max = 15 pts)

1. (1 point) Objects diffuse the light (that enters our eyes) that reaches them from a light source. If there is no such source no light can enter our eyes
2. (1 point) Light is scattered and diffused by vapor molecules near the clouds
3. (2 points) Yes – Yes – No – No – Yes – Yes
4. (0.5 point) a)
5. (0.5 point) c)
6. (2 points) Yes – No – No – Yes – No
7. (2 points)
8. (2 points) Yes – No – No – No – Yes
9. (2 points) Yes – Yes – No – No – No
10. (2 points) No – Yes – Yes – Yes – No

How to evaluate:

Global (whole class):

- If average of Part A of Pre-Test < 5, students' pre-knowledge does not match needed pre-requisites in Euclidean geometry
- If students do not answer to 2 questions of PART B of Pre-Test, vision mechanism needs to be addressed before the Module
- If average of an Interim Questionnaire ≤ 3 → low level of students' outcomes → Modules' objectives for that segment of Module are not being fulfilled.
- If average of Post Test ≤ 7 → low level of students' outcomes → some Modules' objectives have not been fulfilled

Local (for some selected students):

Overall Interim Questionnaires (1 + 2 + 3) and Post Test

AVERAGE (X)	LEVEL OF STUDENTS' ACHIEVEMENT
$0 \le x \le 2.5$	very low
$2.5 < x \le 5$	low
$5 < x \le 7.5$	medium low
$7.5 < x \le 10$	medium high
$10 < x \le 12.5$	high
$12.5 < x \le 15$	very high

RUBRICS

For all the questions, responses' categories are defined as follows:

CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
Scientific reasoning	*Answer correctly addresses the content issue from the physics viewpoint*
Partially scientific reasoning	*Answer reveals an incomplete knowledge about the content issue*
Incorrect reasoning	*Answer reveals naïve viewpoints or ideas which are incorrect from the physics viewpoint*

PRE-TEST

The questions in Part B address if the students have understood that:
- we see because some light arrives at our eye
- light that enters the eye can be either emitted by a light source or diffused by objects
- the medium and the observer have to be in a transparent medium

Question 1

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*"We see only if there is a source of light: objects around us diffuse the light which enters our eyes".*
2	Partially scientific reasoning	*"Because there is no light"*
3	Incorrect reasoning	*"The dark obscures our eyes"*

Question 2

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*b) "Light source lightens up the object which reflects the light into our eyes"*
2	Partially scientific reasoning	*a) "We see because light diffuse everywhere in the room"*
3	Incorrect reasoning	*c), d) "The light from our eyes reaches the book"*

Question 3

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*"Light is scattered and diffused by molecules near the clouds"*
2	Partially scientific reasoning	*"The light crosses the clouds"*
3	Incorrect reasoning	*"The clouds are not completely dark"*

INTERIM 1

Questions 1-3 address if the students have understood:
- how and by means of what materials one can guide the light along curved paths
- the role of the interface between two homogeneous materials;

Questions 4-5 address if the students have the capability to:
- distinguish simple different ways for deviating the light;
- identify qualitative characteristics of light beams propagating in materials

Question 1

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*d) "Because the surface of the mirror is very smooth"*
2	Partially scientific reasoning	*d) "Because it is made of a particular glass"*
3	Incorrect reasoning	*a) "Because the glass is transparent"*

Question 2

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*"Frosted glass is a material which allows light to enter, not going out to an observer behind it"*
2	Partially scientific reasoning	*"The glass captures most of the light"*
3	Incorrect reasoning	*"The glass obscures the room so the light does not enter"*

Question 3

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*“I would use a sequence of mirrors”*
2	Partially scientific reasoning	*“I would use something to curve the light path”*
3	Incorrect reasoning	*“I would use a torch”*

Question 4

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*“Water jets surrounded by air act as light guides”*
2	Partially scientific reasoning	*“Because there is the air around the water fountain”*
3	Incorrect reasoning	*“There are some lamps in the water”*

INTERIM 2

Question 1 addressed if the student have the capability to:
- intepret the ray model;

Question 2 aims at investigating if the students have:
- understood that refraction and reflection always occur at the interface;

Question 4 aims at investigating if the students can:
- interpret correclty the regularities (e.g. the constant ratio sin r /sin i);

Question 5 aims at investigating if students can:
- measure and calculate the critical angle between two media
- draw correctly refracted rays

Question 1

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*e) “For us to see, it is necessary that some particles diffuse light”*
2	Partially scientific reasoning	*e) “The air is more dirty than the water”*
3	Incorrect reasoning	*a) “The molecules in the air have the capability to absorb light so the ray is brighter”*

Question 2

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*“Refraction and reflection always occur together”*
2	Partially scientific reasoning	*“Refraction and reflection occurs only in one point”*
3	Incorrect reasoning	*“In point P the light disappears”*

Question 4

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*“None of the sentences is true. Refraction index is a property of the material”*
2	Partially scientific reasoning	*“None of the sentences is true because refraction index is a constant”*
3	Incorrect reasoning	*“Sentence a) is true since the more the quantity the more the light is refracted”*

Question 5

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*“Rays 5 and 6 are totally reflected since they hit the water surface at angles greater than 48.8°”*
2	Partially scientific reasoning	*“Ray 1, 3 and 4 are refracted and goes away from the normal”*
3	Incorrect reasoning	*“The refracted rays of 5 and 6 approach the normal”*

INTERIM 3

Question 1 aims at addressing if students can:
- identify correct light paths in a fibre

Question 2 and 3 respectively aims at addressing if students have understood the role of:
- transparency of a fibre's materials
- fibre's cladding surrounding the core

Question 1

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*"When the light beam enters into the tube at 37.9°, the incidence angle at the plastic-water surface inside the tube is greater than the critical angle between these two materials so total reflection occurs This is not the case when the entrance angle is 52.3° where there are both reflection and refraction"*
2	Partially scientific reasoning	*"In the first situation there is total reflection"*
3	Incorrect reasoning	*No answer*

Question 2

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*"All yes" with some calculations to support the answer*
2	Partially scientific reasoning	*"All yes" without any calculation*
3	Incorrect reasoning	*Third sentence is false since light can only follows rectilinear path*

Question 3

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*Only the third and fifth sentence are true since the light propagates by multiple reflections bouncing repeatedly on the core-cladding interface in a quasi-pure material.*
2	Partially scientific reasoning	*Only third is correct since light attenuation always occur*
3	Incorrect reasoning	*The second one is true because the core is made of silicon which is similar to glass*

POST-TEST

Questions 1 and 2 are the same of questions 1 and 3 of the Pre-Test.

Questions 3 and 4 address if students have:
- understood how and by means of what materials one can guide the light along curved paths.

Question 3

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*"The third and fourth statements are false. Air is good core since it has the lowest refraction index. So you can't use a tube with air inside"*
2	Partially scientific reasoning	*"The third and fourth statements are false, since all filled tubes can guide the light"*
3	Incorrect reasoning	*"None is true because only optical fibres guide the light"*

Question 4

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*a) "… because plastic has a refraction index which s higher than that of the air"*
2	Partially scientific reasoning	*a) "…because optical fibres are made of plastic"*
3	Incorrect reasoning	*b) "… because optical fibres are made of a material like glass"*

Question 5 aims at investigating if students have:
- understood the role of the interface between two homogeneous materials;

and are able to
- distinguish simple different ways for deviating the light

Question 5

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*c) "…because the water surface is not a completely smooth surface hence light is partially refracted and partially reflected"*
2	Partially scientific reasoning	*c) "… because refraction and reflection always happen together…"*
3	Incorrect reasoning	*d) "the particles of the water are greater than those of the air and hence they capture more light"*

Question 6 aims at investigating if students are able to:
- measure and calculate refraction index;

Question 6

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*a) and d). "Because the index of refraction is property of a material. Moreover we have seen that the critical angle depends only on the refraction indices of the two substances"*
2	Partially scientific reasoning	*a) "because the refraction index is a property of a given substance"*
3	Incorrect reasoning	*b) "in the water the light beam is more visible with respect to air"*

Question 8 aims at investigating if students are able to:
- measure and calculate critical angle

Question 8

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*a) and e) "…since total reflection occur only when light travels from a medium with higher refraction index to a medium with lower refraction index"*
2	Partially scientific reasoning	*e) "it is the definition of critical angle"*
3	Incorrect reasoning	*d) "Total reflection can happen whenever light encounter a separation surface"*

Questions 9 and 10 aims at investigating if students have the capability to:
- establish quantitative relations between refraction indices of core and cladding and optical fibres' characteristics

Question 9

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*"Only the first two sentences are true" [follow some calculations based on the reflection and refraction laws]*
2	Partially scientific reasoning	*"Only the second sentence is true since the refraction index of the core is greater than that of the air"*
3	Incorrect reasoning	*"For every calculation we need to know the refraction index of the cladding"*

Question 10

	CATEGORY OF RESPONSE	TYPICAL STUDENT RESPONSE
1	Scientific reasoning	*“The first and last sentences are false since the numerical aperture (and hence the acceptance angle) depends only on the difference between the refraction indices of the core and the cladding”*
2	Partially scientific reasoning	*“The first is not true because the numerical aperture does not depend on geometrical parameters”*
3	Incorrect reasoning	*“The numerical aperture of an optical fibers is a constant”*

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

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

1. THEORETICAL FRAMEWORK

In the construction of the UoN module, we have adopted a view in which "the development of instructional materials and activities as well as research on various issues of teaching and learning science is intimately linked" (Duit, Komorek & Muller, 2004). As a consequence, we have chosen as theoretical framework to develop our teaching-learning sequence about optical fibers the Model of Educational Reconstruction, developed by Kattman et al. (1995). This construct, fitting both instructional planning/design and Science Education Research (Duit, Gropengieber & Kattman, 2005; Duit, 2007), "draws on the need to bring science content related issues and educational issues into balance when teaching learning sequences are designed" (Duit, 2006, p.4-5). It historically refers to the German tradition of "Bildung" and "Didaktik": the main heritage of such tradition is that, in the ER framework, the teaching process is viewed as composed of two interrelated phases: "elementarization" and "construction of the content structure for instruction". In the first phase, key elementary ideas at the very basis of a given content are identified; then, in the second phase, on such set of key ideas, the content structure for instruction is constructed.

Epistemologically, the ER model refers to the constructivist viewpoint (Duit & Treagust, 1998, 2003). Main facets of constructivist epistemology considered are: - learning is a process in which students build their own science knowledge starting from their ideas, experiences, conceptions and previously gained knowledge; - (Driver, & Easley, 1978); - science is viewed as an human construction (Abd-El-Khalick & Lederman, 2000), i.e. "the science content structure is seen as the consensus of a particular science community" (Duit, 2006). Both these theoretical pillars lead to the essence of the ER model: "the science content structure has to be reconstructed from educational perspectives" (Duit, 2006). The key components of ER model are shown in Figure E22.

The first key component of the ER model is the "Analysis of Content Structure". It refers to subject matter clarification, identification of related key scientific ideas and to the analysis of educational significance of the content. Such analysis, which may be lead by questions as (Duit, 2007): "which are the main scientific theories/concepts about this specific subject and which are their limitations?"; "which ethical and social implications are implied with such scientific theories/concepts?". The main sources to conduct such an analysis are textbooks, historical and

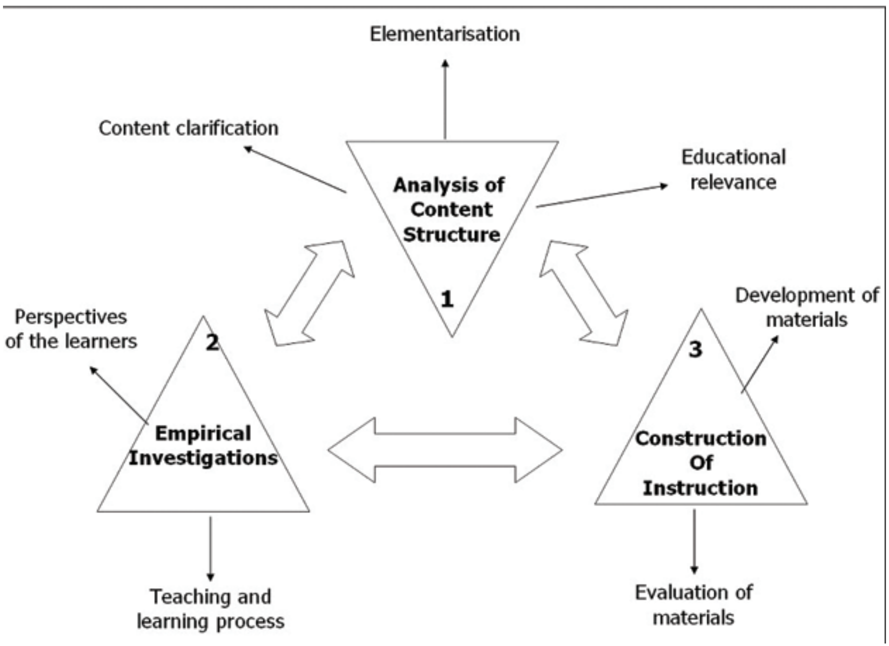

FIGURE E22: KEY COMPONENTS OF ER MODEL

epistemological studies, texts about the interplay amongst science, technology and society, etc…

The second key component of the ER model concerns “Empirical Investigations” and mainly refers to the analysis of students’ perspectives, pre-instructional conceptions, motivations, interests which are relevant for the particular instruction to be carried out. It is not limited to the analysis of existing literature on students’ alternative ideas about a specific ideas (although this is an important ingredient) but it also encompasses the analysis of data collected during the implementation of the designed educational intervention itself, as laboratory worksheets, portfolios, questionnaires, homework, as well as semi-structured interviews and video studies that will be used in the evaluation carried out in the next phase. Theoretical constructs such as self-efficacy come into play when analyzing affective issues of learning (e.g. motivation towards science) and hence research about these issues has to be taken into serious account in this phase.

Typical leading questions of students’ perspectives’ analysis could be (Duit, 2007): “how are the scientific concepts represented in students’ perspectives?”, “what are the interests and attitudes concerning the specific content?”, “which conceptions (conceptual frameworks) are used by the students?”, “which perspectives do students have about science itself?”, “how do alternative frameworks and conceptions of students correspond with scientific theories and concepts?” The main sources to conduct such analysis are, e.g., papers about students’ conceptions and the role of affective variables in the learning process.

Finally, the third key component is the “Construction of Instruction” phase which refers to the design of the educational materials and activities which build up the specific teaching learning sequence about the chosen content. Here the process of reconstruction of the content for instruction comes to an end by means of designing suitably sequenced instructional activities which should lead students to the scientific view. A major focus should be put also on evaluation of the materials and activities designed, using interviews with students and teachers, or questionnaires about students’ cognitive and affective variables or video-studies. Such an analysis can be performed drawing on questions such as: “which are the most relevant elements of the students’ conceptual frameworks and affective variables to be respected?”; “is the fundamental interplay of all variables determining instruction taken into account?”. Main sources to answer such questions are: papers about conceptual change and instruction evaluation.

2. THE ITERATIVE STRUCTURE OF EDUCATIONAL RECONSTRUCTION

The design of a teaching-learning sequence in the framework of the Educational Reconstruction model features an intrinsic iterative structure, similar to that of “Developmental Research” by Lijnse (1995) and “Design-Based Research” (Design-Based Research Collective, 2003). Such dynamic aspect is exemplified in Figure E23.

Only key stages of the development of a TLS in this framework are evidenced and here described:

- analysis of relevant literature triggers the TLS design; at this stage students’ difficulties and alternative frameworks about the content chosen are researched, as well as previous influential didactical proposals about the same content. Usual textbook presentations are also analyzed in order to infer significant trends and pitfalls to avoid. This stage can be carried out in strict connection with the next stage;
- if literature does not provide sufficient evidence about students’ perspectives (either about the disciplinary aspects as conceptual difficulties or about affective dimensions as motivation and attitudes), it is recommended to run a pilot study to collect useful information that inform the subsequent stage; the methods to carry out such study could be a questionnaire or semi-structured interviews
- clarification of basic contents is informed both from existing literature and pilot study; it aims at distinguishing between the disciplinary and the every-day life meaning of concepts as well as at establishing the main learning outcomes of the planned instruction;
- previous stages should have clarified also what

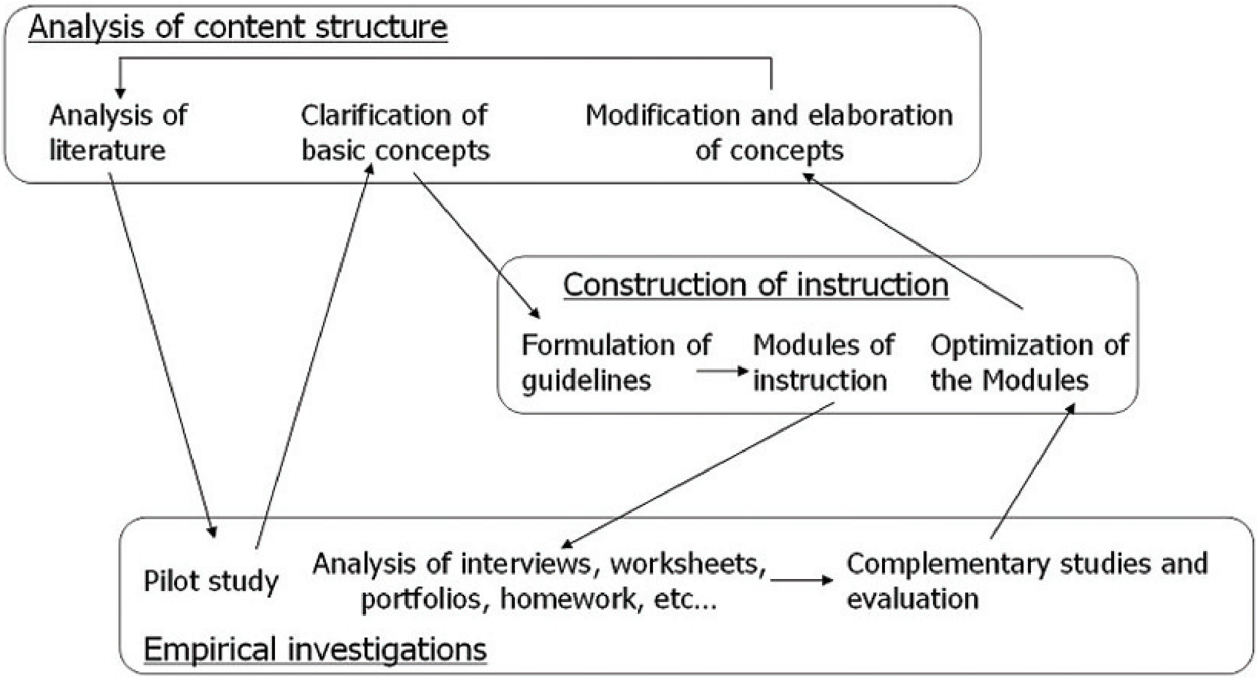

FIGURE E23: TYPICAL CYCLIC STRUCTURE OF EDUCATIONAL RECONSTRUCTION

constitutes in the specific case the 'scientific knowledge', the excepted outcomes of instruction including students' knowledge of concepts, attitudes, reasoning strategies, epistemological awareness as well as the methodological procedures to be used to achieve such results. In brief, the previous stage inform a set of guidelines which inspire the development of the specific materials for instruction;

- at this stage, drawing from the guidelines a preliminary version of the instruction materials (e.g. teaching modules, learning environment) is designed and implemented in a real context;
- during the implementation of the instructional materials various kind of raw data as, e.g., interviews, worksheets, homework, have to be collected in order to start the evaluation stage of the materials;
- on the basis of the data collected, the evaluation of materials includes the analysis of, e.g., students' learning pathway or reasoning strategies and mental models in order to inform the next stage;
- the optimization of the instructional materials concerns the re-shape and re-design of the instructional materials; such an operation drawn on reflection of the factors that promoted students' conceptual change or hindered students' conceptual understanding; context limitations and local constraints have to be deeply documented in order to facilitate the transferability of the instructional materials;
- the last stage features the modification of the content structure and the systematization of results and implications from all the previous stages of the empirical investigations carried out with the aim also to contribute to the body of knowledge of science education literature.

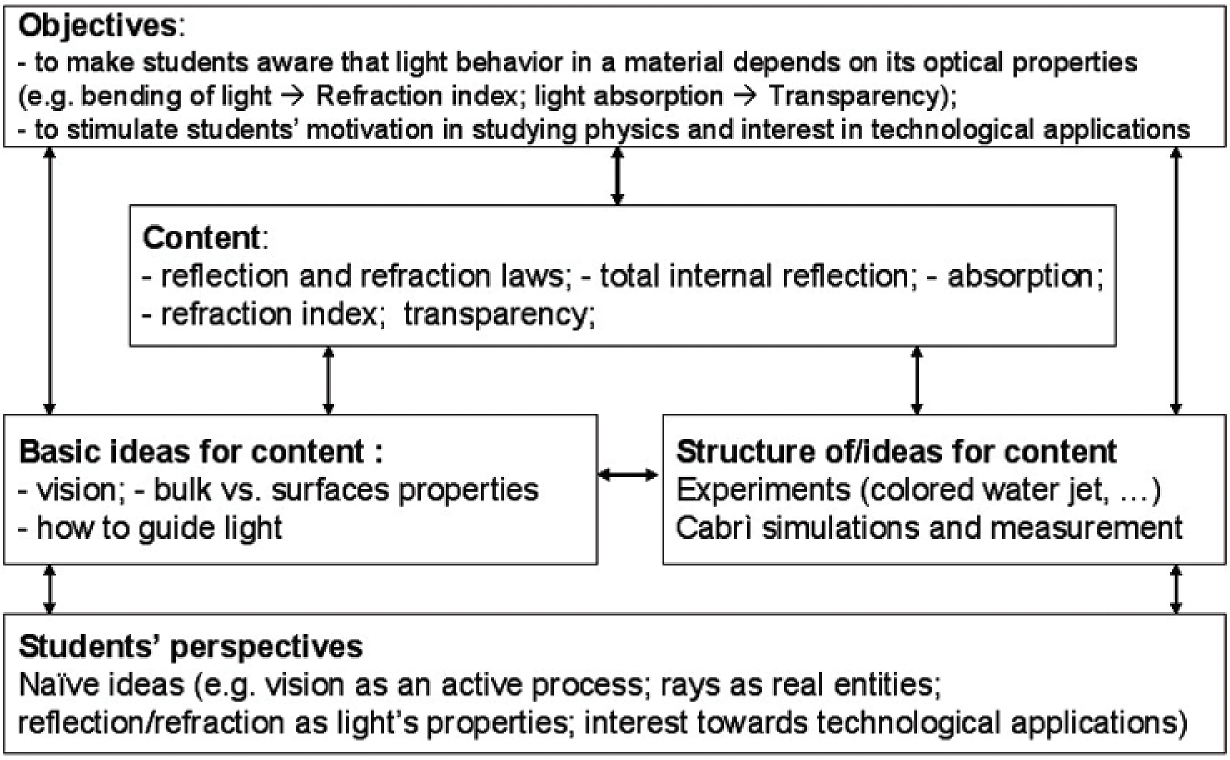

FIGURE E24: DEVELOPMENT OF THE UON MODULE ABOUT OPTICAL PROPERTIES OF MATERIALS

3. DESIGN OF THE UON MODULE

On the basis of the chosen theoretical framework, the design structure of the UoN can be schematically represented as in Figure E24.

In the following we describe specifically the design of UoN module in the framework of the ER model.

4. ANALYSIS OF CONTENT STRUCTURE

Initially, the main aims of the Module have been chosen according to relevant literature about students' difficulties and alternative conceptions in geometrical optics and about the role of affective variables in the learning process. To this latest concern, we focused on students' motivation/interest towards studying science.

Once clarified the main aims of the Module (see Document A, paragraph 5) as, e.g., to make students aware that light behaviour depends on optical properties of materials, to stimulate students' motivation in studying physics and to enhance their interest towards technological/social fallouts of science/physics research, the analysis of content structure led us to identify some "traditional" physics contents as well as "not traditional" (i.e. advanced) physics contents to be addressed in the module: amongst the first ones, we mention here light propagation, reflection and refraction laws, total internal reflection, refractive index; amongst the second ones we have chosen to address transparency, absorption, dispersion, etc… the basic ideas on which such conceptual knowledge is based are: vision (all the studied phenomena can be "seen" by students, hence the mechanism of vision is at the core of all the evidences studied in laboratory); bulk vs. surface properties (light behaviour depends on what it encounters, i.e. a medium or an interface between two media which differ from the optical viewpoint); light guide (the bending of light is at the core of every optical system, not last optical fibers which guide the light along a specific path). The analysis of the content allowed us also to identify motivating applications which exploit the physics principles addressed. In particular we identified optical fibers as a typical example of technological object which students 'could' know in term of everyday experience but not in terms of the basic physics underlying its functioning.

Some of the sources (mainly research papers, Italian textbooks and relevant websites which feature optical fibers tutorials) that have helped us in such analysis are reported in Document A.

5. CONSTRUCTION OF INSTRUCTION

The theoretical framework of ER model prescribes a rigorous and suitable design of the instructional environments supporting meaningful learning.

As far as the UoN Module is concerned, the collaboration between school teachers and University staff at the basis of the Project has driven the methodological choice of a guided inquiry teaching/learning approach (McDermott, 1996) supported by active students' engagement, collaborative learning, sharing of conclusions drawn from available evidence. The justification for such an initial choice is that guided inquiry preserves basic features of authentic scientific inquiry (Chinn & Malhorta, 2002) as, e.g., active participation, group work, active laboratory work, peer discussion and at the same time supports teachers who are not familiar with such innovative teaching approach. In particular, the teaching in the UoN module is inductivistic and activity-based, inspired to the scientific method: students investigate on a problem presented by the teacher which encourages them to express their ideas and formulate hypotheses. In particular, 1) the teacher: - suggests a scientific question to be addressed, encourages the students to express their ideas and to formulate hypotheses, - helps to perform a semi-guided experiment, - fosters students to test hypotheses and reflect on the initial scientific question/problem; 2) the students: - observe complex phenomena related to light propagation, - perform experiments, - import digital pictures of data from an experiment in Cabrì Geométre environment to recognize regularities and make measurements, - transform the observed regularities in as simple as possible rules by use of Cabrì simulations, - go back to the original experiment and interpret it.

The proposed module's teaching/learning activities include a balanced series of experiments and simulations. Experiments are mainly performed with every day materials. Simulations are designed using the Cabrì Gèométre environment. They are implemented through the following steps: observe a complex phenomenon of light propagation (in a water tank or in air) and perform experiment; import a picture of the experiment in Cabrì environment in order to recognize regularities by performing measurements on the picture; transform the regularities in rules by use of Cabrì simulation; go back to the original experiment and interpret it. Through these steps an inductive reasoning is fostered.

For a full description of the Module and underlying educational choices, refer to Document A.

6. EMPIRICAL INVESTIGATIONS

In the following we report about the investigations carried out to inform the process of design-trial-redesign of the teaching sequence. Two preliminary studies and two pilot studies have been up to now completed.

In the preliminary studies, two "special" class situations have been investigated:

- a pre-service teacher course context
- a school class context with selected students

The pilot studies have engaged in normal school contexts with whole classes.

Generally, the preliminary studies aimed more at investigating the feasibility of the overall rationale and the role of the teacher. The pilot studies aimed more at analysing students' learning outcomes about module's addressed contents and at constructing/validating appropriate assessment instruments.

PRELIMINARY STUDIES

First study

Sample
23 pre- service teachers of the Post Graduate School for Teacher Preparation, during one of the courses of Didactics of Physics. About 30% of the sample was graduated in Engineering, 70% had a physics degree.

Duration
The overall duration of the study was 12 hours.

Aims

- to test and improve the coherence of the teaching sequence;
- to train prospective teachers about innovative teaching sequences
- to discuss/compare the Module's contents with what is usually done in the Italian curriculum in the area of optics

Setting

Three University researchers and the two teachers-researchers involved in the design of the Module acted respectively as teachers and tutors (i.e., helped with practical issues as setting up experiments and computer simulations) during the activities.

Data collected

Pre-test about vision, portfolios of training activities including a conceptual map of their understanding of the teaching sequence; observers' notes.

Main conclusions

Many conceptual maps indicated that some main issues in the proposed rationale had not been well understood. In particular many pupils described the conceptual map as an innovative way to teach geometrical optics contents and laws whereas optical fibers had been intended as intriguing applications of such laws (as frequently done by some secondary school physics textbooks)

Main changes introduced in the teaching sequence after the implementation

More emphasis has been put on the not conventional presentation of geometrical optics of the Module. It has been decided to address the issue of modal dispersion in an extension activity. The activities have been redesigned according to a more inquiry-oriented approach where the role of optical fibers as the driving content to motivate students has been emphasized. As a consequence, more guidance about inquiry approaches has been included in the teachers' notes. One of the proposed experiment (the measurement of the water refraction index with low-cost materials) have been eliminated since procedure was considered too cumbersome and obtained results too inaccurate. Some minor changes have also been made to the activities with Cabrì.

Second study

Sample

9 selected students of a third class of secondary school (15-16 years old) from one class chosen on the basis of personal motivation to participate. All involved had very high grades in physics and scientific school subjects in general.

Context

Scientific Lyceum "L.B. Alberti", located in a residential district of Naples. The students belong on average to families of upper-middle employees' class. Usually they are motivated and interested in studying scientific school subjects, their general cultural background is a medium-good one. On average they are much interested to the scientific aspects of the proposed activities but have very little confidence with trying out possibilities offered by experiments and simulations.

Duration

12 hours in four sessions over a period of ten days

Aims

- to qualitatively investigate students' learning outcomes about some of the contents addressed in the Module
- to quantitatively investigate the feasibility and the enactment of the activities in a school context

Setting

The activities were held in the afternoon (extra-curricular period) by the teacher of the selected students. Three tutors were present during the activities to help in optimizing the experimental setting and in giving technical support, if needed: one was another advisor of the local working group, two were the teachers-researchers. In the last session, one University researcher substituted the teacher who acted in this case as tutor.

Tools

a) To collect data about students' conceptual understanding, we designed a set of questions to be answered at home after each of the sessions, as preliminary assessment tasks. The questions were about some problematic situations involving concepts addressed during the performed activities. After the instruction a small group of students (2-4) has been identified and interviewed, the aim being to clarify some answers they gave to the homework questions. Typical questions in the interview protocol were: "what do you mean when you say….?"; "can you explain in more detail your answer…?"; "can you describe how you would answer this question?" A grounded categorization has been adopted to analyse the interviews' transcripts.

b) To investigate the enactment of the teaching sequence we studied the impact of the teacher's practice adopting as measuring tools: - the Reformed Teaching Observer' Protocol (RTOP)[11] by Sawada et al. (2002); the Teachers' Beliefs Interview (TBI)[12] by Luft et al. (2003), and a modified version of two inventories about Teacher's Self-Efficacy and Epistemic Beliefs (TSEBI)[13].

The triangulation of the results obtained from the above three instruments has given an overall picture of the quality of the implementation of the Module in the classroom; it has been therefore possible to infer those plausible contextual factors related to teachers' practice which may have affected students' conceptual understanding[14]. Other data have been collected from observers' notes.

Analysis of collected data

a) Answers to the homework tasks indicate that the students have encountered some few difficulties in understanding basic concepts addressed during the activities.

   For instance, when asked if the refraction index of a substance depends on the quantity of substance, only 1 out of 9 students answered *"No, since it is a property of the substance", while 4 students related the refraction index to the laser beam intensity: "the index of refraction does not depend on the quantity of substance since we observed that the laser beam had the same intensity in two tanks with different quantities of water"*. It is plausible to infer

11. *The RTOP has been developed by the Evaluation Facilitation Group (EFG) of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) as an observational tool designed to measure "reformed" teaching. It seemed to us a very suitable instrument to investigate how the adopted inquiry methodological approach was actually implemented in an ordinary classroom, in ordinary contexts. The RTOP consists of 25 items divided into three subsets: Lesson Design and Implementation (5), Content (10), and Classroom Culture (10), both divided into two sub-groups of five items. The first subset aims at addressing if, during the lesson there was, on behalf of the teacher,: - the recognition of students' prior knowledge and preconceptions; - the engagement of students as members of a learning community; - the search for a variety of solutions to problems; - the tendency to follow the direction of ideas generated by students. The second subset addresses disciplinary issues, the quality of the lesson content and the degree of enactment of the inquiry methodology. The third subset addresses the overall climate of the classroom. The items are answered on a five-points Likert scale. Teachers who obtain high scores (above 80) with the RTOP instrument are plausibly keener to accept innovation and implement it coherently in classroom. Teachers who obtain medium scores (between 60 and 80) have partially accepted the innovation, whereas teachers with low scores (less than 60) have much transformed or not adopted at all the innovation.*
12. *The TBI, developed by J. A. Luft and G. H. Roehrig, aims at categorizing teachers according to their beliefs about and attitudes towards the teaching and learning processes, with a particular focus on how to optimize the students' understanding. We chose such instrument since it can detect the attitude of the teacher towards a student-centred approach as the inquiry methodology, allowing us to infer a plausible factor affecting the enactment and effectiveness of the Module's activities. The categories of teachers than can be identified by means of TBI are: - Traditional, Instructive, Transitional, Responsive and Reform-based. Traditional and Instructive label a somewhat teacher-centred attitude; Responsive and Reform-based represent more student centred beliefs, while Transitional reflects a view of students that primarily stresses their affective rather then cognitive involvement.*
13. *The TSEBI was constructed on the basis of a 20-item inventory called the Teacher Efficacy Inventory (Gibson & Dembo, 1984; Woolfolk & Hoy, 1990) and of a 25-item Epistemic Beliefs Inventory (Bendixen, et al., 1998). The Teacher Efficacy Inventory allows envisaging how a teacher score on two scales, each related to two factors, namely Personal Teaching Efficacy (PTE) and General Teaching Efficacy (GTE). The PTE scale measures the perception of a teacher to positively impact on students' learning on the basis of his/her own capabilities and skills. The GTE scale measures the perception of a teacher to impact on students' learning as a professional, with a certain cultural background and a given social role. We chose 18 items, twelve of which refer to the PTE scale, six to the GTE scale, to be answered on a seven-points Likert scale. A subject's score for Personal Teaching Efficacy can range from 12 (low level) to 84 (high level). Scores for General Teaching Efficacy range from 7 to 42. From the Epistemic Beliefs Inventory five different factors were developed by Bendixen et al. (1998) and based upon earlier work by Schommer (1990). The factors refer to the view of the nature of learning and to individuals' abilities in learning; they correspond to five basic beliefs, i.e. that: - exist a 'certain' knowledge that and will eventually be known; - knowledge is constituted only by 'simple' facts; - there is an omniscient authority which has the access to otherwise inaccessible knowledge; - learning occurs in a easy or not-at-all fashion; - the ability to acquire knowledge is innate. We chose 15 items, to be answered on a seven-points Likert scale, out of the five beliefs' categories, belonging to Simple Knowledge (5 items), Quick Learning (6 items) and Innate Ability (4 items). On the average, scores for each of the three subscales can range from 5 to 35.*
14. *Such results will also inform subsequent data collections and will be part of the research results that will feed the description of the mechanism to link collaboratively the efforts of science education researchers and school science teachers.*

that the observation of the remarkable different intensities of a laser beam in, e.g., water and air, has lead the students to overlook the deviation of the direction of propagation of the beam when crossing the interface of two media, focusing only on the possible factors that affected the intensity. This alternative conception could be related to the fact that the teacher did not spent much time in commenting neither on the experimental results nor on the role of the refraction index and the role/meaning of the 'ray' model of geometric optics.

As a matter of fact, during the interview, one of these four students clarified that: *"… I was not referring to the refraction [of the light beam] but only to the intensity"*. Nevertheless, such an evidence has led us to re-design the experiments in order to better distinguish when to focus on beam intensity and when on beam deviation.

When one of these students was asked during the interview to clarify his answer, he confirmed that he had seen *"…the light beam having the same intensity in the two tanks with different quantities of water…"* but this time he also clearly claimed that: *"…the index of refraction does not depend on the quantity of substance…"* Nevertheless, when prompted about a possible relationships between the intensity of the light beam and the index of refraction he said: *"… uhm… I think so… because when the light beam is not refracted but completely reflected it does not loose any intensity… instead when there is refraction the light beam looses its intensity".* Only after being prompted to compare the intensity of a beam after being refracted in two different media with different indices of refraction he finally claimed that: *"… no... the intensity is the same… maybe only the direction of propagation of the beam is different in the two media"*. These excerpts plausible show that in this case the mechanism at the basis of functioning of the fiber (i.e. the total reflection at the core-cladding interface) has shadowed a correct understanding of the basic geometric optics laws (e.g., the refraction law). This evidence suggested us to focus more on the formalization of the regularities found by means of the Cabrì activities.

Two students wrote that "*the more the quantity of substance, the more the refraction".* This alternative conception might be interpreted in terms of a di Sessa p-prim in which the refraction phenomena is seen as the result of the resistance opposed by a medium or a substance to the light propagation and hence the more the quantity of the substance the more the resistance opposed and hence the more the refraction. Such reasoning might be also related to a misinterpretation of the results of the applet offered to the students in order to predict, observe and explain what happens to a laser beam direction of propagation when the level of water in a tank is raised.

In the same way, the other students answered this question recalling only the observation that raising the water level did not affect the calculation of the

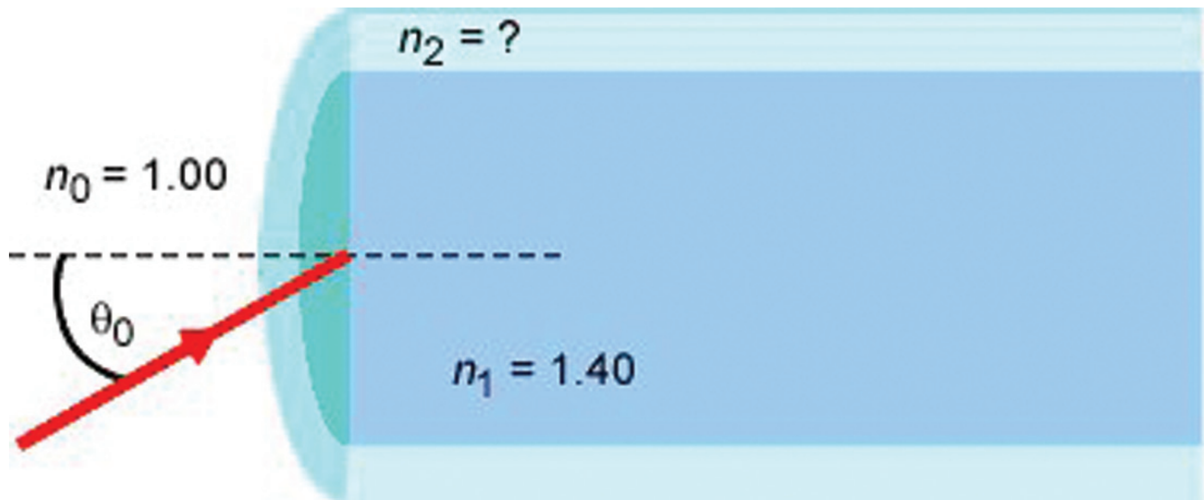

FIGURE E25: SITUATION USED AS HOMEWORK. THE STUDENTS ARE ASKED TO DRAW THE DIRECTION OF THE INCIDENT LASER BEAM WHEN ENTERING IN THE FIBER CORE refraction index, not trying to explain such an observation. This further evidence has leaded us to emphasise more the “predict” and “explain” phases in the proposed experimental activities.

Almost all students, when asked to explain why the phenomena of total reflection is responsible for light travelling along curved paths, answered correctly that otherwise *“there could be the refraction of the light beam and the light could loose its intensity”*. On the other hand, it emerged that the knowledge about the mechanism at the basis of the fibers’ functioning remained only qualitative.

For instance, when asked to draw the path of a laser beam in the core of an optical fiber when entering in the fiber at a given angle (Figure E25), almost all the students answered that they had to know the refraction index of the cladding as well.

During the interviews as well, none of the students was able to correctly predict the direction of the beam when refracted from the air to the core.

Finally, when asked for the reason why “we cannot use an hollow tube to guide the light”, only two students claimed that “we can not use it since the air has the lower refraction index and it is difficult to find a cladding with refraction index lower then the air to avoid the refraction of the propagating beam”. Two other students answered that “if I bend the hollow tube the light undergoes refraction”. The others did not explain their negative answer. Overall, we found the results of this first preliminary analysis of the students’ answers not completely satisfactory, especially as far as the geometric optics concepts are concerned.

b) To investigate the teacher’s practice, first two independent trained observers (Observer 1 and Observer 2) used the RTOP instrument to score the first two sessions lead by the observed teacher (T1). The Table shows the overall results:

RTOP RESULTS	OBSERVER 1	OBSERVER 2
Total score	57	68
Lesson Design and Implementation (total score)	15	18
Content (total score)	14	20
Propositional knowledge mean score (mean score)	0.8	1.2
Procedural knowledge mean score (mean score)	2.0	2.8
Classroom culture (total score)	28	30
Communicative Interactions (mean score)	3.0	2.8
Student/Teacher Relationships (mean score)	2.6	3.8

Pearson’s coefficient of correlation between the total score obtained by the two observers is 0.74, which is considered acceptable. The mean is 2,28 (st. dev. 1.28) for Observer 1 whereas it is 2,72 (st. dev. 1.28) for Observer 2. From the score obtained by this teacher it is possible to infer some plausible factor to justify the poor results of the students after the instruction: the total score obtained by Observer 1 indicate that T1 had not accepted the innovation and this has affected the implementation of the Module, whereas for Observer 2 the teacher barely accepted the innovation, however not succeeding in being effective;

The score in the propositional knowledge items is very low (Observer 1 mean = 0.8, Observer 2 mean = 1.2). Such items address, e.g., the emphasis put by the teachers on “fundamental” physics concepts at the heart of the lesson or the capability of the teacher to feel the potential significance of students' ideas as well as to relate the contents addressed with everyday students' experience. Therefore an inferable plausible factor hindering an effective understanding of some contents, as shown by the homework tasks, is related to the teacher' subject matter knowledge about unfamiliar topics as optical fibers. This evidence emerges also from the somewhat middle mean score obtained by T1 as far as procedural knowledge is concerned (mean is 2.0 for Observer 1, 2.8 for Observer 2), for example the students were not only actively doing things, but they were also actively thinking about what they were doing.

As far as the lesson design and implementation is concerned, the obtained score is quite high (Observer 1 mean = 3.0 for, Observer 2 mean = 3.6), as well as for the classroom climate (Observer 1 mean = 2.8, Observer 2 mean = 3.3), on all the 10 items of the subscale), in particular the relationships with students, the active participation, the production of hypotheses, or the teacher's listening attitude.

On the basis of the RTOP results, we investigated more in detail T1's beliefs and attitudes about teaching The results of the TSEBI questionnaire for T1 are reported in the following table:

T1 TSEBI RESULTS	TOTAL SCORE	MEAN SCORE
Overall	138	4,18
General Teaching Efficacy	23	3,83
Personal Teaching Efficacy	50	4,17
Innate Ability	19	4,75
Quick Learning	23	3,83
Simple Knowledge	23	4,60

Overall mean is 4.18 ± 1.07 (st. dev). The scores obtained by T1 do not support the hypothesis that her attitude in teaching practice can be related to any of the factors analyzed in the questionnaire. A quite high value for the IA factor suggests that T1 thinks plausibly that teaching practice is not effective if the students are not naturally skilled or gifted, as confirmed by the rather low value of the GTE factor which suggests a belief that teaching practice has a low impact on student's personality and habits.

Much more useful has revealed the TBI tool, whose results are synthetically reported in the following table:

TRADITIONAL	INSTRUCTIVE	TRANSITIONAL	RESPONSIVE	REFORM-BASED
***	**	**		

The 7 stars represent the seven questions of the interview. If we score each of the answers according to the following scale:

TRADITIONAL	INSTRUCTIVE	TRANSITIONAL	RESPONSIVE	REFORM-BASED
1	2	3	4	5

We obtained an overall score of 13 which reflect a rather teacher-centered attitude in the teaching practice of T1, as shown by the following excerpts from some of the answers to the interview:

I. *How do you maximize student learning in your classroom?*

T1: *… I use the textbook…*

I. *How do you describe your role as a teacher?*

T1: *… I guide their learning…*

I. *How do you know when your students understand?*

T1: *… If they are able to correctly solve an exercise… or if they are able to apply what they have learnt before to the new content*

I. *In the school setting, how do you decide what to teach and what not to teach?*

T1: *…it depends on time… I cannot address some topics since there is no time*

I. *How do your students learn science best?*

T1: *… it should be the laboratory… they like it very much…but it is too much time consuming…in this Module we made two physics laws in twelve hours… for me it would be impossible during a regular teaching*

I. *How do you know when learning is occurring in your classroom?*

T1: *…when they do the homework…*

From such excerpts it clearly emerges a tendency of T1 to rely on curriculum and textbook as main source for her teaching practice. When she shows a more "transitional" attitude, i.e., somewhat in between a traditional and a reform-based attitude, she is more focused on content and not on students' perspective. Such results confirm those obtained from the RTOP tool, where it emerged that the practice of T1 was weakly directed towards a reform- or inquiry-based teaching.

Main conclusions

The results seem to indicate a relationships between the students' learning outcomes and the combined influence of teacher's attitude/quality of the enactment of the Module. Actually, it seems plausible to infer, from the RTOP and TBI factor analysis, that the outcomes of the implementation of the Module can be heavily affected by teacher's attitudes, beliefs and convictions towards teaching. This result suggests to put more emphasis in the teachers' notes also to the general teaching-learning principles underlying the design of the Module (e.g., the value of science in society).

Beside teacher's attitude, other plausible factors may have influenced the G1 outcomes, in particular the fact that in this first study the activities have been implemented during after-school hours (three hours in the afternoon; the students had already attended 6 hours of classes) and at a very sharp pace (2 times in a week). Hence also the 'time' factor has to be taken into account when implementing the activities.

Overall, after this study, a further emphasis has been put on the role of the inquiry process on students' conceptual understanding; the role of the measurements made with Cabrì as a means to convey understanding of concepts and the difference between a phenomenon and its abstract model as, e.g., the model of 'ray' in geometric optics. As far as students are concerned, in particular, the main changes have been the more emphasis put on the measurements performed on digital images of experiments made with Cabrì. Lastly, the need to have a synthesis of the addressed contents was expressed by this teacher as well as other advisors in the local working group; this resulted in a first version of a "Conclusions" document given to students as a booklet.

PILOT STUDIES

First pilot study

Sample

18 students of the third class of a secondary school (15-16 years old). The students did not choose to participate to the activities on a personal basis. They were not particularly motivated in studying physics and scientific school subjects in general and their grades rather low. On the other hand, they were skilled and flexible in laboratory activities, and active in posing questions.

Context

Scientific Lyceum "G. Bruno", located in a small, highly populated town (about 10 kilometres from Naples' downtown) that shares many problems of other suburban northern areas, e.g. micro and organised criminality and a diffused social hassle due to unstable employment conditions. Also the students perceive such social inconveniences and on the average live in a depressed cultural and social context.

Duration

14 hours in five morning sessions over 20 days

Aims

- to quantitatively investigate students' learning outcomes about some of the contents addressed in the Module
- to investigate reliability of assessment tools for assessing students' learning outcomes
- to quantitatively investigate the feasibility and the enactment of the activities in a school context

Setting

The session were led by the students' teacher, a local working group advisor, who had participated spontaneously also to the design of some of the Module's activities. Three tutors were present during the activities to help in optimizing the experimental setting and in giving technical support, if needed: one was the major advisor of the local working group, the other was a University researcher, and the last tutor was one of the teachers-researchers involved in the design of the Modules' activities.

Tools

a) We designed a post-instruction questionnaire, called Vision, Optics and Optical Fibers Inventory (VOOFI) featuring questions, concerning some of the topics addressed during the Module. i.e., vision, index of refraction, total reflection (all concerning Scientific Knowledge), light guides, optical fibers functioning, optical fibers design (all concerning Technological Knowledge). In particular, the items of the questionnaire can be categorized as follows:

Scientific Knowledge scale. Items: 1, 3, 4, 10, 12, 14, 15, 17, 19, 20, 21, 24, 26, 28
Technological Knowledge scale. Items: 2, 5, 6, 7, 8, 9, 11, 13, 16, 18, 22, 23, 25, 27, 29
Maximum total score: 203
Minimum score: 29
Maximum Scientific knowledge scale range: 14-98
Maximum Technological knowledge scale range: 15 - 105

Scientific Knowledge Sub-Scales:
Vision. Items: 10, 12, 20, 24
Index of Refraction. Items: 1, 4, 14, 15, 17, 19, 28
Total Reflection. Items: 3, 21, 26

Technological Knowledge Subscales:
Light Guides. Items: 2, 7, 18, 29
Optical fibers functioning. Items: 9, 11, 23, 27
Optical fibers design. Items: 5, 6, 8, 13, 16, 22, 25

The questions have been scored on a scale of 7 according to the following levels:

1-3: not scientifically acceptable answer
3-5 partially scientifically acceptable answer
5-7: scientifically acceptable answer

A score of 4.5 was considered as a "sufficiency threshold". Due to the choice of the scale, high scores correspond to a good understanding of the concepts addressed during the Module's activities, whereas low scores reveal a low conceptual understanding of the topics addressed.

b) To analyze teacher's practice and attitude, we again used the RTOP, TBI and TSEBI tools.

Analysis of collected data

a) 11 questionnaires were collected. The distribution of the means of the students is reported in Figure E26. Overall mean is 4.83 ± 0.63 (st. dev.) which is a quite satisfactory result. 4 students out of 11

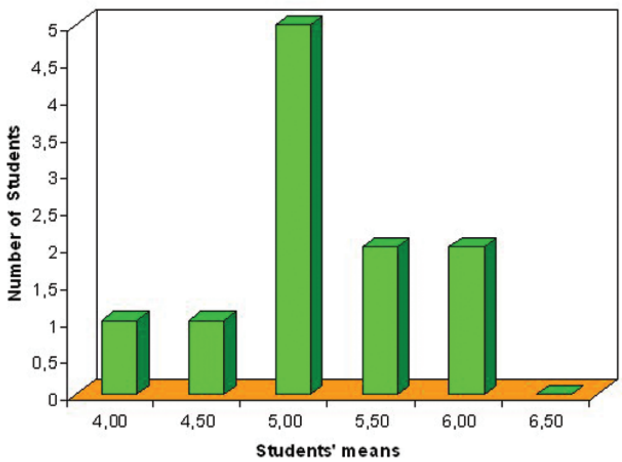

FIGURE E26: DISTRIBUTION OF MEANS IN THE FIRST PILOT STUDY scored more than 5. Two students scored significantly higher than the other students (means are respectively 5.97 and 5.72). 9 students obtained a score higher than 4.5. Such a result shows that the module has familiarized the majority of the students with concepts addressed.

Hereafter, for each of the concept addressed some more details are given.

- **Scientific Knowledge.** The index of refraction has been the content in which the students scored the highest (mean: 5.80, mode: 5.29), whereas both total reflection (mean: 4.76, mode: 4.67) and vision (mean: 4.95; mode: 3.75) have resulted slightly more difficult. It seems that these students have managed to grasp the importance of the index of refraction as a key property of materials. Such a result supports the relevance of the role of the Cabrì measurements in the whole module's activities. On the other hand, the difficulties with the concept of vision, addressed mainly through the experiments, suggest to deepen the discussion with the students about this topic throughout all the Module as well, not only at the beginning.
- **Technological knowledge.** Students found some difficulties mainly in familiarising with the design and the functioning of the optical fibers (respectively, mean: 3.07 and 4.54), whereas light guides' functioning principles have been more internalized (mean: 5.41). Such evidence may be plausible due to the time schedule of the Module that compressed the final activities which addressed mainly such topics.

b) We investigated the teacher practice during the implementation by means of the RTOP instrument. Four sessions, all led by the same teacher (T2), were observed and scored by the same trained Observer. The overall scores obtained by T2 indicate that she has internalized the Module and accepted the proposed innovative inquiry approach. Mean of the four sessions is 78.5 (st. dev. 2.1) which is compatible with 80, the threshold given by the designers of the RTOP instrument to consider the practice of the observed teacher as a 'reformed' one. The results are shown in the following table.

RTOP	SESSION 1	SESSION 2	SESSION 3	SESSION 4
Total score	79	81	76	78
Lesson Design and Implementation (total score)	19	18	17	15
Content (total score)	25	29	29	32
Propositional knowledge mean score (mean score)	2.8	2.8	3.4	3.8
Procedural knowledge mean score (mean score)	2.2	3.0	2.4	2.6
Classroom culture (total score)	35	34	30	31
Communicative Interactions (mean score)	3.6	3.4	2.6	2.8
Student/Teacher Relationships (mean score)	3.4	3.4	3.4	3.4

The main differences with T1 are:

- the content scale shows that T2 holds a sounder subject matter knowledge: mean score for propositional knowledge ranges from a minimum of 2.8 to a maximum of 3.8 (for T1 the minimum was 0.8, the maximum 1.2). This result is confirmed also by the score obtained in the procedural knowledge subscale (minimum is 2.2, maximum is 3.0). Both results are in accordance with the qualitative evidence that students achieved a highly coherent conceptual knowledge of the content addressed.
- a better score has been obtained by T2 also in items of the 'Classroom Culture' cluster:

communicative interactions with students (e.g. students were encouraged to contribute to the overall discourse and did most of the talking during the lesson) ranges from a minimum of 2.6 to a maximum of 3.6 of the first session in which, e.g., the students freely described what they had observed and raised some small debates to decide which interpretation was the better one; student/teacher interaction was also always very frequent, as testified by the scores obtained by the teacher during all the sessions: as an example, the agenda of the activities was often changed to follow the direction suggested by the students.

A somewhat different results have been obtained from the analysis of the TSEBI questionnaire for T2 (see following table)

T2 TSEBI RESULTS	TOTAL SCORE	MEAN SCORE
Overall	129	3.91
General Teaching Efficacy	14	2,33
Personal Teaching Efficacy	49	4,08
Innate Ability	23	5,75
Quick Learning	17	2,83
Simple Knowledge	26	5,20

The overall score obtained by T2 is lower than that of T1 (129 vs. 138). Both teachers scored almost the same as far as PTE factor is concerned; a significant difference is the score as far as GTE factor, plausible due to the suburban depressed context in which the T2 school is located. On the other hand we note that for T2 learning does not occur in a “quick or not-at-all” fashion (QL factor) and that in the teaching profession, it is important to transmit the basic simple facts at the basis of scientific knowledge (SK).

As for the case of T1, much more useful has revealed the TBI tool, whose results for T2 are synthetically reported in the following table:

TRADITIONAL	INSTRUCTIVE	TRANSITIONAL	RESPONSIVE	REFORM-BASED
	*	*	*	****

As before, the 7 stars represent the seven questions of the interview. If we score each of the answers according to the previously reported scale (Traditional: 1; Instructive: 2; Transitional: 3; Responsive: 4; Reform-based: 5) we obtain an overall score of 29 which is rather high and points to a remarkable student-centered attitude in the teaching practice, as shown by the following excerpts from some of the answers:

I. How do you maximize student learning in your classroom?

T1: …let’s say that I try to start from their ideas… then I try to motivate them with activities related to their everyday life…

I. How do you describe your role as a teacher?

T1: …I am a kind of team-leader… but a counsellor as well…

I. How do you know when your students understand?

T1: … when they apply the acquired knowledge in different contexts

I. In the school setting, how do you decide what to teach and what not to teach?

T1: …there are things that I have to teach, but in general I feel free to choose

I. How do your students learn science best?

T1: … starting from the their interests… promoting their creativity

From such excerpts it emerges a clear tendency of T2 to value students' perspectives as their own naïve ideas and interests. Also in the case of T2, the TBI results confirm those obtained with the RTOP tool, which indicated a strong direction of this teacher towards a reform- or inquiry-based teaching.

Main conclusions

The observations of the classroom sessions carried out in this first pilot study have confirmed once again the influence of teachers' epistemological and methodological approach on the Module's efficacy, this time with a very positive impact on the implementation of the proposed activities.

From this result we inferred that, in order to evaluate the Module in a reliable way and to promote a sound conceptual knowledge of the contents addressed, activities had to be led by teacher who was a designer or eager to implement a student-centered approach. For this reason, in the following pilot study the young teacher who implemented the Module was in the LWG and very enthusiastic in adopting student-centered approach.

As far as the students' learning outcomes, a rather satisfactory conceptual understanding of the mechanism of vision, of the geometric optics laws and the basic functioning of the optical fibers seems to emerge. On the other hand, some problems with the functioning and design of optical fibers still emerged.

As a consequence the following changes were made: 1) the sequence of activities has been made more flexible according to the needs of the teachers; 2) more emphasis has been put on the formalization of the experimental and simulation results resulting in the drafting of a small booklet to distribute to students about the main concepts addressed during the activities; 3) more emphasis has been put on the initial scenario and on related problematic that the students are asked to address during the activities.

SECOND PILOT STUDY

Sample

17 students of the third class of a secondary school (15-16 years old). The students did not choose to participate to the activities. Students' attitude towards scientific school subjects varied a lot: four students were particularly motivated with very good grades in mathematics and in scientific school subjects. All the remaining students showed very little interest in studying scientific school subjects and in particular physics.

Context

The Scientific Lyceum "G. Siani" is located in an urban area between the northern suburbs of Naples and a residential district where, since last century, the most important hospital area of southern Italy is present. The students were from urban areas with a multivariate family background determined by different socio-economic cultures characterized by different professional and educational needs.

Duration

The activities were carried out during curricular hours in six morning sessions, for an overall duration of about 15 hours over 15 days.

Aims

- to quantitatively investigate students' learning outcomes about some of the contents addressed in the Module
- to investigate reliability of assessment tools for assessing students' learning outcomes

Setting

The sessions were led by their teacher who had very little experience in teaching but was very willing to implement the Module and particularly eager to enact student-centered inquiry approaches. At least two tutors were present during the activities to help in optimizing the experimental setting and in giving technical support. Two sessions have been observed by three external experts of the MS Project.

Tools

To investigate students' learning outcomes we again used the VOOFI questionnaire as post-test. As for the first pilot study, the questions have been scored according to predefined rubrics on a scale of 7. The "sufficiency threshold" was put at 4.5

Analysis of collected data

13 students completed the post-instruction questionnaire. The preliminary analysis shows that overall mean is 5.33 ± 0.52 (st. dev.) a result which indicates that the changes made to the Module's activities have been on average effective on students' understanding of the concepts addressed. The distribution of students' means is reported in Figure E27.

In this implementation, 5 out of 13 students scored more than 5. One student scored significantly higher than the other students (mean: 6.31). 12 out of 13 students scored more than 4.5. Also these evidences point to the effectiveness of the refinements made to the Module's activities.

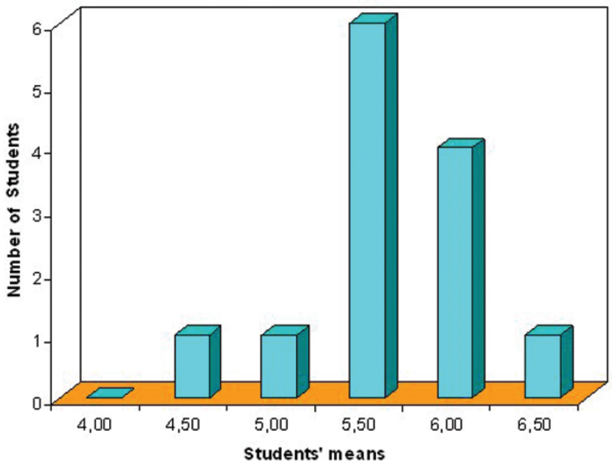

FIGURE E27: DISTRIBUTION OF MEANS IN THE SECOND PILOT STUDY

Hereafter, for each of the concept addressed some more details are given.

- Scientific Knowledge. The overall mean is 5.77, a result that shows that the concepts addressed have been well grasped by the students. Of the three concepts in this area, vision seems the concept better understood by the students (mean: 6.10) as well as total reflection (mean: 5.85). Index of reflection seems to be less internalized (mean: 5.55) with respect to the other two concepts.

- Technological knowledge. The main difficulties that this group of students have shown concern this area (mean: 4.93). Difficulties have been found especially as far as the functioning of the optical fibers is concerned (mean: 3.52). Better results have been obtained for light guides' functioning principles (mean: 5.52) and optical fiber design (mean: 5.40). Also for this sample, such an evidence may be plausible due to the time schedule of the Module that compressed the final activities dealing with the functioning of Optical fibers in detail.

To estimate the effectiveness of the process of refinement of the Module's activities we have compared the overall means in the scales of the concepts addressed for the implementation in the two above Pilot Studies (Figure E28). Overall gain between the two implementations for the Scientific knowledge is 26% whereas for Technological knowledge is 22%. Such a result implies that the changes made have been effective specially as far as the Unit 1 is concerned. In particular, the gain for the

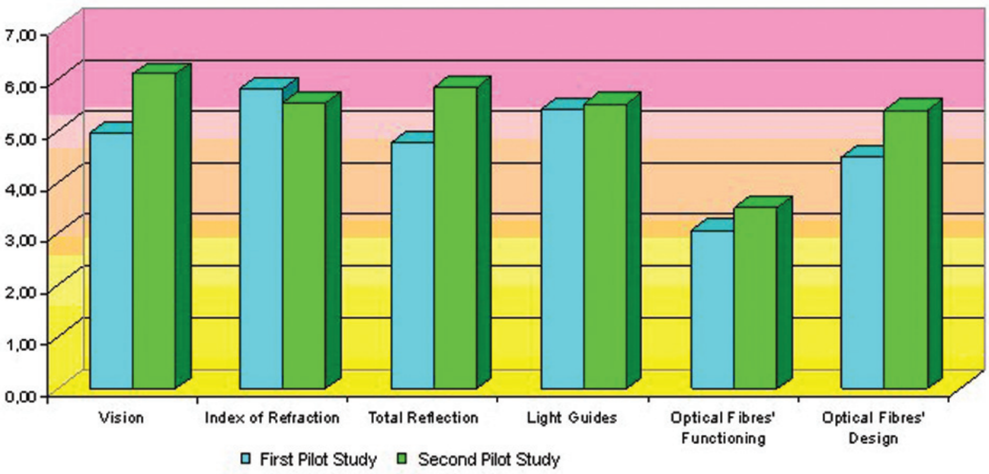

FIGURE E28: COMPARISON OF MEANS IN THE FIRST AND SECOND PILOT STUDY vision concept has been about 55% whereas for total reflection 49%: hence, we can plausibly infer that a major emphasis on the activities about these concepts have been placed during the implementation in the second pilot study with respect to the first one. On the other hand, activities about optical fibers functioning and design need to be further improved (gain is respectively 11% and 36%). The results about the light guides have been almost the same due to the great emphasis placed in both implementations on the introductory experiments.

Main conclusions

In this study, only the average score on the content “Optical fibers functioning” was lower than the sufficiency threshold. Since this result emerged also in all the previous studies, we decided to put much more emphasis on activities about optical fibers’ design and functioning by introducing a motivating scenario, in which the students are introduced to current applications and uses of optical fibers and on related problematic.

In order to further improve students’ understanding of conceptual aspects of geometric optics: 1) refraction and reflection phenomena have been treated not independently (as traditional teaching usually does) but as two linked aspects of the deviation of light from rectilinear path; 2) refraction has been introduced first and linked to the relative index of refraction of two materials; 3) reflection has been addressed via total reflection experiments as a way to bound the light to propagate within a material in a not rectilinear way; 4) reflection and refraction laws have been used to interpret the basic functioning of optical fibers addressed in the initial scenario.

Finally, as far as the assessment tools used are concerned, they have been analysed in depth with the External Experts during the Study Visit and it was recognized the need to introduce significant changes in them. Accordingly, the assessment tools have been totally redesigned. In particular, some tasks to test students’ ability to shift from the observed phenomena to abstract representations in the Cabrì environment have been introduced.

DESCRIPTION OF FINAL MODULE VALIDATION

Sample

23 students (15-16 years), 11 females and 12 males, of a suburban school district in the south of Italy have been involved in the study. They had average school grades (mean=6.5/10) and were sufficiently motivated; moreover, they had no experience in hands-on experiments. These data suggest that the chosen sample was a reliable one for assessing the teaching module in a typical Italian secondary school context.

Context

The Scientific Lyceum “Brunelleschi” is located in a small populated town about 12 kilometres from Naples’ downtown. The background of the students varies a lot according to the financial situation of the family. There are some problems of unemployment and criminality but, overall, the presence of many big stores and commercial centres close to the town helps a lot the local economy.

Duration

The class activities occurred in normal school time, for a total of about 16 hours over a long period of time (about 3 months, 2 hs/week) due to logistic constraints (frequent strikes, low computer room availability, …).

Aims

To quantitatively investigate students’ learning outcomes about some of the contents addressed in the Module

Setting

The activities were jointly held by two school teachers who also participated actively in the module design. In this context, one tutor was present during the activities to help in optimizing the experimental setting and in giving technical support.

Tools

For this final validation of the module the assessment tasks described in Document D (pre-test, Interim Task 1, 2, 3, post-test) were used. The tasks were scored according to the reported rubrics. The three interim tasks were submitted respectively after 4, 8, and 12 hours of teaching. The post-test was submitted one week after the end of the activities.

Analysis of collected data[15]

- Pre-Test (Part A)
  21 Students completed the questionnaire. Average score was 5.66 ± 0.07 (s.e.). The overall distribution is reported in Figure E29.

15. *For the specific learning objectives of the tasks refer to Document D*

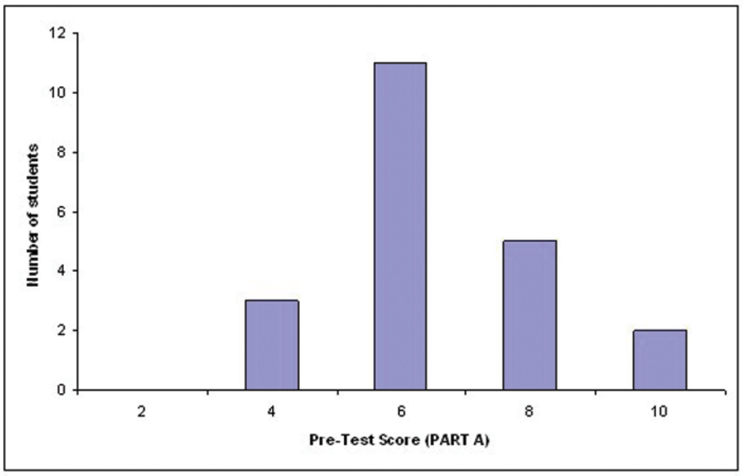

FIGURE E29: SCORES DISTRIBUTION OF PRE-TEST (PART A) IN THE FINAL MODULE VALIDATION

The average score was only slightly greater than the sufficiency threshold (5). Hence, the sample only partly had the adequate knowledge of Euclidean Geometry needed for addressing the Module contents. For this reason, the teacher addressed again some basic geometry concepts before the beginning of the activities.

- Pre-Test (Part B)
  Average score was 1.74 ± 0.02 (s.e.). This implies that most of the student did not answered correctly to at least two questions. Hence, the first activities of the Module were devoted to the concept of vision.

- Interim Task 1
  The average score was 3.13 ± 0.05 (s.e.), slightly above the sufficiency threshold for an interim task. The distribution of scores is reported in Figure E30. Such result indicates that the activities were not completely successful in helping students achieve the intended learning objectives.

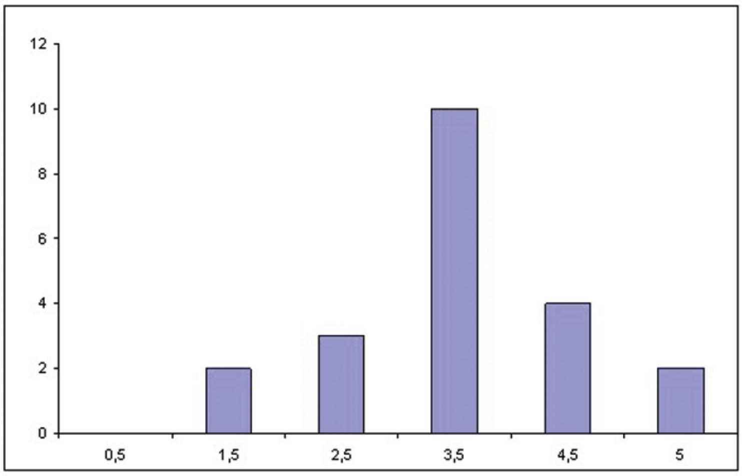

FIGURE E30: SCORES DISTRIBUTION OF INTERIM TASK 1 IN THE FINAL MODULE VALIDATION

- Interim Task 2
  Average score in this task was 3.01 ± 0.03 (s.e.). The distribution of scores is reported in Figure E31. Also in this case, the average score is above sufficiency but not too much: therefore also for from this second task, it emerges that not all the intended learning objectives were successfully addressed.

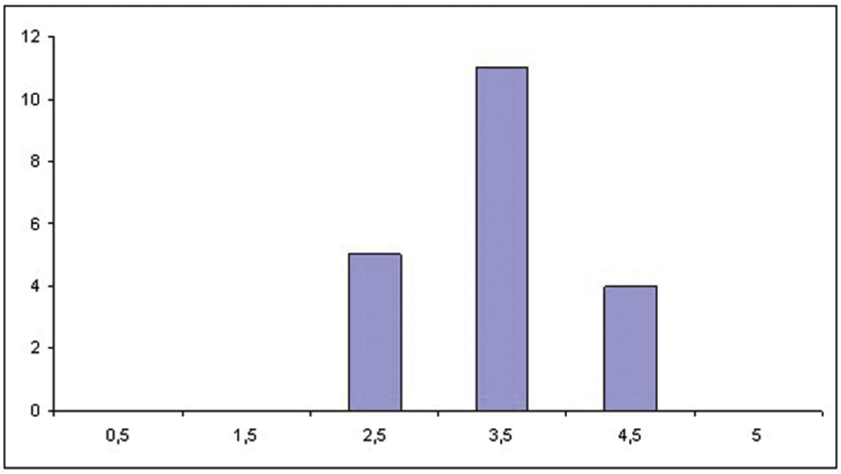

FIGURE E31: SCORES DISTRIBUTION OF INTERIM TASK 2 IN THE FINAL MODULE VALIDATION

- Interim Task 3
  In this task the average score was slightly lower than the sufficiency threshold: 2.97± 0.04 (s.e.). The distribution of scores is reported in Figure E32.

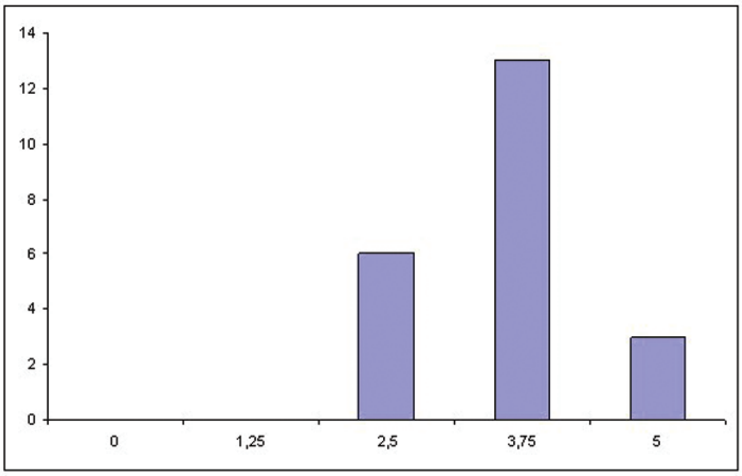

FIGURE E32: SCORES DISTRIBUTION OF INTERIM TASK 3 IN THE FINAL MODULE VALIDATION

The result may be due to the fact that the last activities were carried out in a small amount of time due to the ending of the second trimester in which the students had to give exams also in other subjects.

- Post-Test
  The average score was 9.10 ± 0.03 (s.e.) which is well above from the sufficiency threshold for the post-test of 7. The distribution is reported in Figure E33.

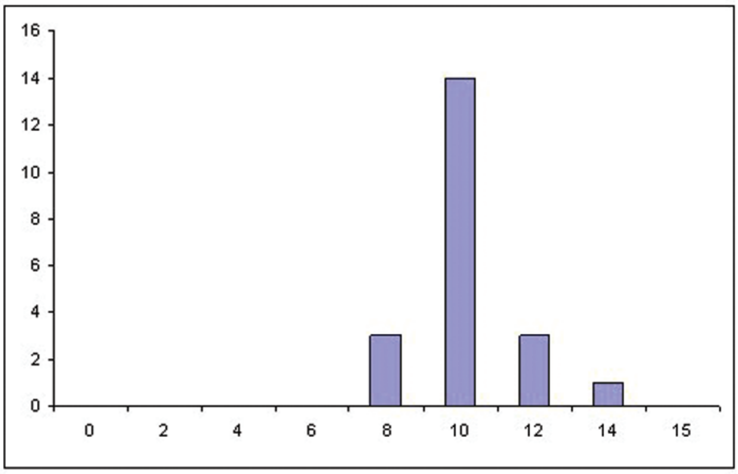

FIGURE E33: SCORES DISTRIBUTION OF POST-TEST IN THE FINAL MODULE VALIDATION

- Overall evaluation

  Taking into account the three interim tasks and the Post-Test, the average score of the students was 8.66 ± 0.06 (s.e.), which corresponds to a medium-high level of achievement. Overall, 4 students obtained a medium-low level, 15 a medium –high level, whereas 4 students a high level of achievement.

  The results from the final implementation of the module suggest that the proposed activities were only partially effective. Amongst the factors there are:

- the students were not completely at ease with the geometry concepts involved in the addressed physical content (e.g. reflection, refraction, etc…). According to their teacher, they had also some difficulty in algebra which impaired the understanding of the optical fibers functioning and design.
- the implementation was carried out for a very extensive school period (3 months) and this has lead to a loss of attention and motivation in the students towards the addressed content. This aspect has to be carefully taken into account if further implementations will be on the agenda.

Further results from this implementation will be reported in two forthcoming research papers.

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8. APPENDIX

REFORMED TEACHING OBSERVATION PROTOCOL (RTOP) (5 POINTS LIKERT-SCALE)

1) The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.
2) The lesson was designed to engage students as members of a learning community.
3) In this lesson, student exploration preceded formal presentation.
4) This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.
5) The focus and direction of the lesson was often determined by ideas originating with students.
6) The lesson involved fundamental concepts of the subject.
7) The lesson promoted strongly coherent conceptual understanding.
8) The teacher had a solid grasp of the subject matter content inherent in the lesson.
9) Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.
10) Connections with other content disciplines and/or real world phenomena were explored and valued.
11) Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.
12) Students made predictions, estimations and/or hypotheses and devised means for testing them.
13) Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.
14) Students were reflective about their learning.
15) Intellectual rigor, constructive criticism, and the challenging of ideas were valued.
16) Students were involved in the communication of their ideas to others using a variety of means and media.
17) The teacher's questions triggered divergent modes of thinking.
18) There was a high proportion of student talk and a significant amount of it occurred between and among students.
19) Student questions and comments often determined the focus and direction of classroom discourse.
20) There was a climate of respect for what others had to say.
21) Active participation of students was encouraged and valued.
22) Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.
23) In general the teacher was patient with students.
24) The teacher acted as a resource person, working to support and enhance student investigations.
25) The metaphor "teacher as listener" was very characteristic of this classroom.

TEACHER BELIEFS INTERVIEW (TBI)

1. How do you maximize student learning in your classroom?
2. How do you describe your role as a teacher?
3. How do you know when your students understand?
4. In the school setting, how do you decide what to teach and what not to teach?
5. How do you decide when to move on to a new topic in your classroom?
6. How do your students learn science best?
7. How do you know when learning is occurring in your classroom?

TEACHER'S SELF-EFFICACY AND EPISTEMIC BELIEFS INVENTORY (TSEBI) (7 POINTS LIKERT-SCALE)

1) When a student does better than usually, many times it is because I exert a little extra effort.
2) The hours in my class have little influence on students compared to the influence of their home environment.
3) The amount a student can learn is primarily related to family background.
4) I have enough training to deal with almost any learning problem.
5) When a student is having difficulty with an assignment, I am usually able to adjust it to his/her level.

6) When a student gets a better grade than he/she usually gets, it is usually because I found better ways of teaching that student.
7) If a student in my class becomes disruptive and noisy, I feel assured that I know some techniques to redirect him/her quickly.
8) Even a teacher with good teaching abilities may not reach many students.
9) If one of my students couldn't do a class assignment, I would be able to accurately assess whether the assignment was at the correct level of difficulty.
10) If I really try hard, I can get through to even the most difficult or unmotivated students.
11) When it comes right down to it, a teacher really can't do much because most of a student's motivation and performance depends on his/her home environment.
12) My teacher training program and/or experience has given me the necessary skills to be an effective teacher.
13) Most things worth knowing are not very complicated.
14) Really smart students learn things with less effort.
15) Working on a problem with no quick solution is a waste of time.
16) Really smart students don't have to work as hard to do well.
17) Solutions to problems usually come quickly or not at all.
18) Most important ideas are pretty simple when you get down to it.
19) Some people are born with more ability than others.
20) Teachers should focus on facts instead of abstract ideas.
21) If a student masters a new concept quickly, this might be because I knew the necessary steps in teaching that concept.
22) How well you do in school depends on how smart you are.
23) Too many theories just complicate things.
24) Things are simpler than most experts would have you believe.
25) If you don't learn something quickly, you won't ever learn it.
26) If you don't understand a problem right away, going back over it won't help.
27) Smart people are born that way.
28) Most of what you learn, you learn during the first try.
29) If a student did not remember information I gave in a previous lesson, I would know how to increase his/her retention in the next lesson.
30) When I really try, I can get through to most difficult students.
31) A teacher is very limited in what he/she can achieve because a student's home environment is a large influence on his/her achievement.
32) Teachers are not a very powerful influence on student achievement when all factors are considered.
33) When the grades of my students improve, it is usually because I found more effective teaching approaches

VOOFI QUESTIONNAIRE

Briefly indicate, for each statement, if it is true or false and justify your answer

1. The index of refraction of a substance depends on the amount of substance that is considered
2. We can not use a tube of transparent material filled with air to guide the light because there is not a material with lower refractive index than air
3. The light travelling from water to air can undergo total reflection
4. To measure the refractive index of water one has to measure the brightness of a light beam when it propagates in water
5. In the situation of the Figure, where n2> 1.40, there is refraction between core and cladding
6. In an optical fiber, the cladding refractive index must be less than that of the core to avoid the phenomenon of refraction
7. We can not use a tube of transparent cord full of air to guide the light because the air is not a transparent material
8. To decrease the number of reflections on the surface of separation between core and cladding light has to be sent into a fiber parallel to its axes

9. In the situation of the Figure, the beam deflects towards the top of the fiber
10. We see objects because the particles retain the light
11. In the situation of the Figure, the beam deflects toward the bottom of the fiber
12. We see only the objects that refract light
13. The total reflection is the phenomenon that allows light to travel along the curved path because if there is refraction the light loses intensity
14. A laser beam is brighter in a substance with higher refractive index
15. To measure the refractive index of a substance one must know its density
16. In the situation of the Figure, it is sufficient if n2 <1.40 to have total reflection between the core and having cladding
17. If you increase the amount of substance that is considered, its refractive index increases
18. Any filled tube is a light guide
19. The brightness of a laser beam depends on the refractive index of the substance in which propagates
20. In a dark room you do not see objects that are contained because there is not a light source
21. The light travelling from air to water can undergo total reflection
22. To avoid than in a curve a light beam exits from a fiber, it is needed that it propagates parallel to the fiber axis
23. In the situation of the Figure, the beam deflects toward the axis of the fiber
24. We do not see the trajectory of a laser beam in the air because it is absorbed by the air particles
25. In an optical fiber, the core must have a refractive index greater than that of the cladding for the phenomenon of total reflection to happen
26. The total reflection occurs when light travels from a less refractive material to a more refractive
27. In the situation of the Figure, to know how the beam deflects, one needs to know n_2
28. The index of refraction of a substance does not depend on the amount of substance that is considered because it is a property of substance
29. The tank filled with water is a light guide because the light can be totally reflected on the surface of separation between water and air

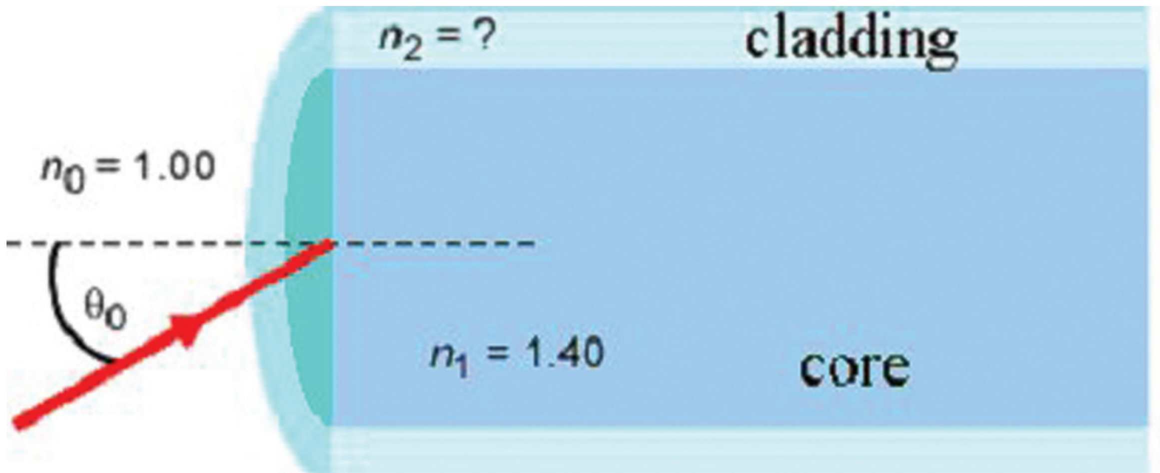

FIGURE E34: SCHEMA OF OPTICAL FIBER. Θ_0 IS 45°

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