DESIGN AND DEVELOPMENT OF A MODULE ABOUT OPTICAL PROPERTIES OF MATERIALS

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ABSTRACT
The University of Naples has created a Local Working Group as a partnership of university researchers and school teachers. This group has developed and implemented a research-based teaching/learning Module on the topic of Optical Properties of Materials. The broader aim of this effort was to propose an innovation in Science and Technology curricula in the interdisciplinary context of Materials Science. To achieve this, we adopted the Educational Reconstruction theoretical framework, according to a design – trial – redesign cycle: the Group first carried out a content structure analysis, including relevant results from Physics Education Research, then proceeded with a trial implementation of the initial design, in order to gather data to evaluate the module and further refine its design. Through this effort we explicitly aimed at promoting students' conceptual understanding through inquiry-oriented activities but also at enhancing their interest in further study of science and technology. The resulting activity sequence is structured in a few self-consistent Teaching-Learning Units, each proposing a problematic/motivating situation related to optical fibres as a chosen example of a technology-embedded scenario. The designed activities follow a Guided Inquiry Approach, focusing both on basic physics concepts and on the materials' properties relevant for modelling/interpreting the fibres' behaviours. The students are engaged in integrated lab-work and ICT activities to gain knowledge useful for managing with the driving questions of the "scenario". In this paper, we describe the initial design and development of the Module's construction and illustrate how these efforts have been informed by the results of the pilot implementations. The findings of this study support the crucial role, on one hand, played by the iterative design about key ideas related to science and technology aspects and, on the other hand, of the partnership between developers and teachers. Both these components have emerged as essential ingredients that affect the process of development and revision of effective research based curriculum materials.

KEYWORDS
Curriculum development, Inquiry-oriented teaching, University-School partnership, Optical properties of materials, Students' motivation

INTRODUCTION

An established strand in physics education research has, for the last twenty years, informed the development of innovative materials for classroom use (McDermott, 1991, 2004; McDermott & Redish, 1999; Ogborne, 2006). Such efforts have been proven to be an effective means to improve students' conceptual understanding in different content areas such as, for instance, mechanics (Thornton & Sokoloff, 1998) or electric circuits (Schaffer & McDermott, 1992). In recent years, however, there has emerged the additional need to develop innovative approaches that could enhance young people's interest in science in general and in physics in particular in order to address the decline in students pursuing science courses at undergraduate level, including at European level (Osborne, Simon & Collins, 2003; European Commission, 2007). One of the reasons of this decreased interest towards scientific careers is linked, by some authors (e.g. Gil-Pérez, Vilches & Ferreira-Gauchía, 2009) to the gap between students' every day life and school practice: for instance, progress in physics fundamental research is at the basis of many technological devices which the students are familiar with, but which rarely are addressed as part of school activities. As a consequence, the need to innovate with physics school curricula also emerges.

In the context of the EU-funded *Materials Science* Project, we have sought to respond to these needs by establishing a local partnership comprising researchers and teachers who were willing to devote their combined efforts to the design, development and gradual refinement of a teaching-learning module on the topic of *Optical Properties of Materials*. Through this approach, the University of Naples Physics Education Research group proposes a research-based teaching module featuring activities aimed at enhancing 14-16 years old students' learning interest and conceptual understanding about this topic with specific reference to refraction index and transparency. The applications addressed in this module relate to optical fibres and to their use in diverse domains, from medical care to communication, to architecture and design.

There are two reasons that guided our choice of optical fibres as a motivating context for promoting the above goals. The first is related to the fact that the optical fibres are a technological innovation used in a field, telecommunications, in which young students may be very interested in.. The second is linked to the fact that optical fibres represent a typical example of interplay between Science and Technology Knowledge, since they are the result of the integration of a technological design aimed at proposing a solution to a practical human need and of a scientific endeavour aimed at investigating the optical properties of materials

This paper is structured as follows: first we present the theoretical framework for the design and development of the Module, then we discuss the outline and content of the Module. Results from three pilot implementations of the Module, aimed at illustrating the Module's refinement process, are then described and finally some conclusions are inferred.

THEORETICAL FRAMEWORK

The design of *the Optical Properties of Materials* Module started from a viewpoint in which *"the development of instructional materials and activities as well as research on various issues of teaching and learning science are intimately linked"* (Duit, Komorek & Muller, 2004). As a consequence, the model of Educational Reconstruction (ER) (Kattman et al., 1995), has been chosen as a theoretical framework for the design and implementation the Module's activities.

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". Firstly, key elementary ideas at the very basis of a given content are identified; then, relying, on such set of key ideas, the content structure for instruction is built.

Epistemologically, the ER model refers to the constructivist viewpoint (Duit & Treagust, 1998, 2003). The main facets of this epistemology are: - learning is a process in which students build their own 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 support the essence of the ER model: *"the science content structure has to be reconstructed from educational perspectives"* (Duit, 2006). The design of a teaching-learning sequence in this framework features an intrinsic iterative structure, similar to that of "Developmental

Research" by Lijnse (1995) and "Design-Based Research" (Design-Based Research Collective, 2003). This iterative aspect is exemplified in Figure 1.

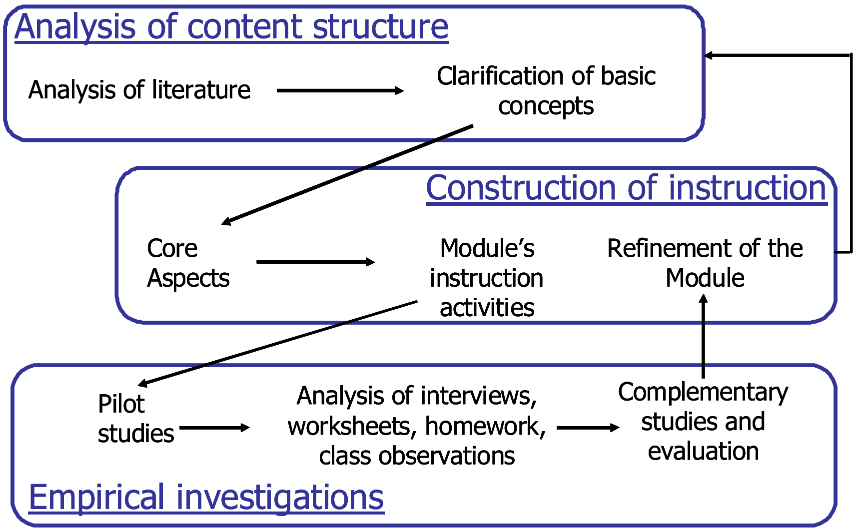

Figure 1. Structure of ER Model

In the case of our Module, the three main interconnected phases of the ER model have been implemented as follows.

The *"Analysis of content structure"* phase featured at first an overview of relevant literature about students' naive ideas and alternative conceptions about geometrical optics and vision (Galili & Hazan, 2000; Guesnè, Tiberghien & Delacôte, 1978; Heywood, 2005; Palacios, Cazorla & Madrid, 1989; Singh & Butler, 1990; Viennot & Chauvet, 1997). Previous didactical proposals about this content (Goldberg, Bendall & Galili, 1991; Rebmann & Chauvet, 2001) and textbook analysis guided the choice to address basic geometrical optics (reflection and refraction laws, refractive index, total internal reflection) as well as some non-conventional topics (distinction between light behaviour at an interface and in the material's bulk). Vision is addressed as a preliminary topic focusing on the role of the diffusing centres in the material and on its transparency.

The *clarification of basic contents* has led us to identify two *key ideas*, related to the optical properties of materials, on which to build the above contents:

- the path of light in the bulk and at an interface between two materials;
- the basic mechanisms for guiding light.

The mechanism of guiding the light along a curved path is addressed by focusing on the phenomenon of total internal reflection. This allows students to explain the basic functioning of an optical fibre referring to the optical properties of the materials of which it is constructed. Lastly, main characteristics of an optical fibre (e.g., numerical aperture) can be introduced.

In the *"Construction of Instruction"* phase, on the basis of the results of the "*Analysis of content structure*", a first draft of the Module's activities was developed, based on the following pedagogical choices:
1) to implement a descriptive modelling approach (Lijnse, 2008) inspired from the "from Real to Ideal" rationale, which we have explored for many years (Sassi, 2001). In the proposed approach, *direct evidence* of the light path in certain conditions is first given to students by performing light propagation experiments with a laser and a water tank in order to give students the possibility to observe light trajectories, often used in geometrical optics; then, a picture of the experiment is imported in a

dynamical geometry software environment [1] in order to identify regularities through measurements on the picture; then, regularities inferred from the measurements are generalised into rules by use of a simulation; finally, the students go back to the original experiment and interpret it. The aim of the approach is to gather a set of clues about how materials' optical properties come into play when light interacts with diverse media. Experiments are performed with everyday materials so students can rely also on their own common-sense experience to interpret the regularities observed. Simulations are designed using the same dynamical geometry software to improve students' abstraction capabilities and modelling competences, here in geometrical optics area.

2) to produce research-based materials inspired by basic principles of *inquiry-based teaching-learning* (see, e.g., McDermott, 1996). In particular, a guided inquiry approach has been chosen in a way such that the teacher: suggests a scientific question to be addressed; encourages the students to express their ideas, justify their reasoning and possibly formulate hypotheses; suggests to perform a semi-guided experiment; fosters students to test hypotheses and reflect on the initial scientific question/problem. On such basis, the activities operatively guide the students through a balanced series of experiments and simulations.

In the "*Empirical investigations"* phase the preliminary version of the instruction materials has been implemented in real contexts (pilot studies). In the school year 2007-08, three pilot studies have been carried out in order to refine the activity sequence and the assessment tools. Some account of the results of the pilot studies are given in the following sections. During the implementation of the instructional materials, various kinds of raw data (e.g., interviews, worksheets, homework) have been collected in order to address the evaluation of the materials by analysing students' learning outcomes and/or reasoning strategies about the key ideas.

In the school year 2008-09 two further implementations, as complementary studies aimed at validating the Module, will allow to optimise the instructional materials. Such an operation, drawn on both reflection on the factors that promoted students' conceptual change or hindered students' conceptual understanding and on logistic factors (context/curriculum limitations and local constraints), will be documented in order to facilitate the optimization of the Module materials in promoting student learning. The last stage will feature the modification of the content structure (if needed) and the systematization of results and implications from all the previous stages of the empirical investigations carried out. The global aim is a possible contribution to the body of knowledge of science education literature with emphasis on iterative curriculum design.

MODULE DESIGN AND STRUCTURE

Within the project, each group substantiates the local partnerships in the form of a Local Working Group (LWG), i.e. a panel composed of sinergetically interacting university researchers and school teachers. Our LWG is composed by three University researchers and seven school teachers, who have different roles: two are *teachers-researchers* actively participating in the design of the students' activities; two play the role of *major advisor* (providing feedback on the research design and the proposed activities), other three teachers are *advisors* (giving feedback during the Modules implementation).

[1] In the activities presented in this paper, we propose a measurement procedure that allows students to make quantitative and accurate measurements on digital pictures of phenomena in which a visible trajectory can be approximated by a geometrical entity or figure. With this procedure, for instance, accurate measurements (about ±0.05%) of the wavelength of straight and circular water waves in a ripple tank and of the electron charge to mass ratio can be obtained (more details are presented in Monroy, Lombardi & Testa, 2008). The software used is Cabrì Gèometré®, available at www.cabri.com. Costs vary according to the type of software and license purchased. For the purpose of this study *Cabrì II Plus* has been used. For this product, a school site license costs about € 700.

Throughout various face to face sessions, the LWG has developed a set of activities clustered in separate Units. As a consequence, one may flexibly adapt the implementation to a particular teaching context, choosing whether or not to propose all the Units, that are substantiated in Students' Worksheets and Teachers' Notes. The Students' Worksheets, feature questions to inform group reflection and discussion about scientific aspects and technological aspects; indications for performing the suggested experiments; guidance for the proposed modelling activities; some clues for the conclusions to be drawn at the end of the activities.

The Teachers' Notes aim at giving guidance to the teachers for performing the proposed activities as well as for clarifying and elaborating the main ideas addressed.

Figure 2 schematises the structure of the Module's first two Units.

	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 the above materials / objects also trap and do not attenuate light	Light propagation in the fiber Light diffusion at surface and bulk	A light guide with specific core and cladding and few / controlled impurities is an optical fiber

Figure 2. Sequence of the first two Units of the UoN Module

Unit 1 activities aim at guiding the students to understand that a light guide is *any* object made of two transparent materials: one with a refraction index n_1 surrounded by another whose refraction index n_2 is smaller than n_1, provided that light is sent within the inner medium. Firstly, an introductory problematic situation related to the use of optical fibres in telecommunications is presented (the "Scenario" of the Module). Then, the students are told that they will investigate about the basic principles of simple light guides. The behaviour of fibre glass lamps, plastic rods, glass rods etc. with respect to light is initially observed in order to find similarities and differences between optical fibres and other transparent objects that can guide the light.

An intriguing experiment with an illuminated water jet triggers the discussion among students about how to build a light guide (Figure 3).

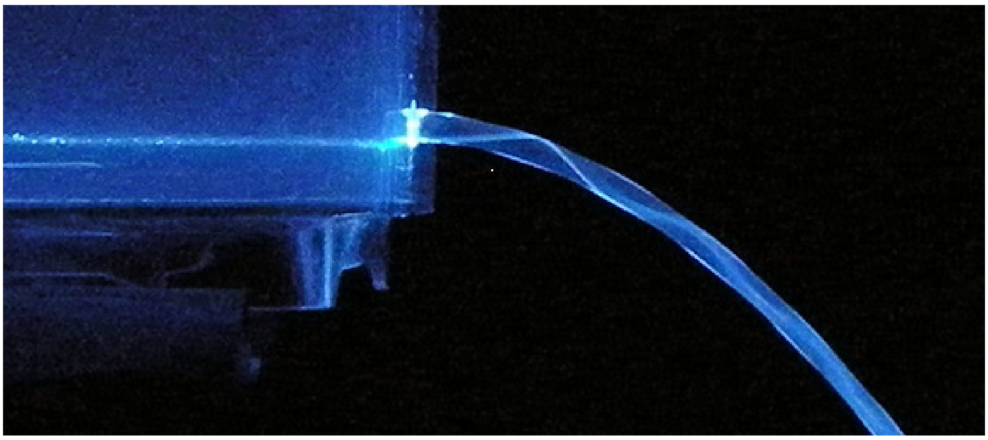

Figure 3. A light guide realized with a water jet

Analysis of this experiment allows students to address the law of rectilinear propagation in an homogeneous medium, and the behaviour of light when it encounters interfaces between two materials with different refraction index.

In the second experiment, students are guided to observe *in the same experiment* the reflection and refraction phenomena. By means of the Cabrì environment, refraction is formalised first; then, the reflection law is introduced to quantitatively describe what happens when total reflection conditions are met. Reflected and refracted beams might have different visibility due to both surface and bulk effects (diffusing centres in the bulk and the nature of the surface) (Figure 4). The index of refraction of one medium with respect to another is introduced as the optical property which allows the prediction of the light path deviation when hitting the interface between the two.

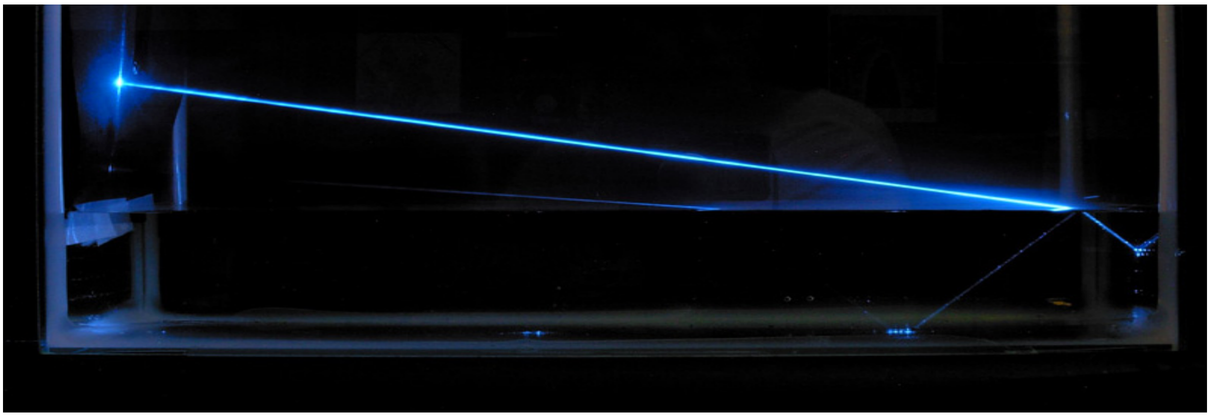

Figure 4. Refraction and reflection observed when a laser beam hits an air - water surface.

At the end of Unit 1, students can explore light propagation in diverse media, e.g. from more refractive to less refractive ones, and investigate the conditions under which total internal reflection occurs. The relationships between the critical angle and the two media relative to refractive indices is eventually proposed and "experimented" (virtually) in the Cabrì environment. An example of measurement carried out is reported in Figure 5.

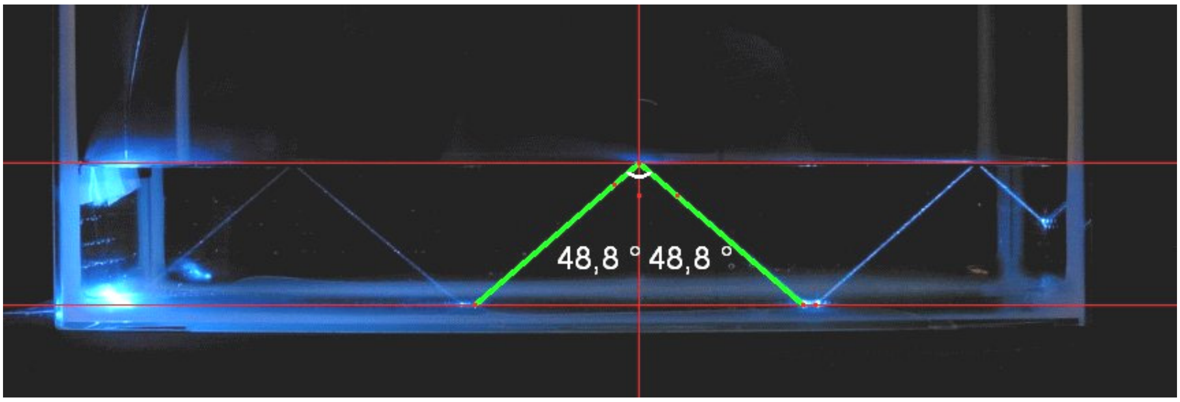

Figure 5: Air-Water critical angle measured in Cabrì environment

The above combination of experimental and modelling activities aims also at addressing the following common difficulties: reflection and refraction are not mutually exclusive properties of light (except in the case of total internal reflection); the difference between the characteristics of the laser beam and its "ray" model with Cabrì (which uses only geometrical optics). Lastly, the main conditions for designing a light guide are established.

In Unit 2, the students become aware that an optical fibre is a light guide with a controlled core and cladding; this realization functions as a basis for studying the main characteristics of an optical fibre.

Further qualitative experiments are proposed to collect evidence on how an optical fibre is made. Some preliminary "clues" can be offered such as the fact that a cladding is necessary, and that it influences light propagation in the fibre and the acceptance angle of the fibre.

According to the "from Real to Ideal" rationale, the observed regularities are transformed into some rules by means of the modelling activities with Cabrì. The latter allow students to: become familiar with both acceptance angle and numerical aperture of a fibre; investigate the relation between refractive indices of core and cladding and critical angle at which total internal reflection within the core occurs; relate the numerical aperture and the refractive indices of core and cladding in a step-index optical fibre. A quasi perfect, pure, non-attenuating core material is thus addressed.

MODULE DEVELOPMENT

After outlining an initial activity sequence, the Module development has been driven mainly by the pilot studies aimed at refining the activities' sequence, the assessment tools and the research instruments to be used later for evaluation, by assessing students' learning outcomes about the key ideas.

The pilot studies featured three secondary School Contexts (Scientific Lyceum) implementations (Table 1). Overall, 44 students (15-16 years old) have been involved.

Table 1. School contexts for the module implementation

School Context Code	Brief description
SC1	In a residential district of Naples. The students are, on average, motivated and interested in studying scientific school subjects
SC2	In a small, highly populated town. The students are usually interested, skilled and flexible in laboratory activities, as well as active in posing questions.
SC3	In an urban area of Naples. The students have, on average, different professional and educational needs.

Indications about students' learning outcomes have been gathered by means of the following data: analysis of the students' worksheets completed during the implementation; analysis of the observers' notes and in some cases of some audio taped parts of the classroom intervention. Homework tasks and interviews have been used in the SC1, SC2 and SC3 contexts; in addition, a questionnaire was administered in the SC2 and SC3 contexts.

SC1 context
Nine students were involved in four afternoon sessions held at the school's laboratory of physics, for an overall duration of about ten hours. The students' choice to participate to these extra-curricular activities was based on personal motivation; overall, they had very high grades in physics and other scientific subjects. The teacher was one of the advisors of the LWG. Three tutors were present during the activities, to help optimising the experimental setting, take detailed notes and audio tape parts of the interventions; one was another advisor of the LWG, two were the teachers-researchers. During the activities the students filled the worksheets in groups (three students per group), that have been later analysed. As homework, after each session, the students were asked to answer a set of questions involving the addressed concepts. Four of these students have been interviewed about some answers they gave to the homework questions.

The answers indicated that the students have encountered some difficulties in understanding basic concepts, such as the refraction index. Two students stated that, *"the more the quantity of substance, the more the refraction"*. This naive idea led us to improve the experimental activities about the index of refraction of a medium, placing more emphasis on the "test hypothesis" and "reflect" phases. In some cases, an excessive attention on the visibility of the laser beam in air and water led some students to overlook the deviation in the propagation of the beam when crossing the interface of the two media. This led us to re-design the experiments in order to better distinguish when to focus on beam visibility and when on beam deviation. In other cases, the focus on a qualitative mechanism at the basis of the functioning of the fibre has shadowed a correct understanding of quantitative relationships (refraction law and conditions for total reflection at the core-cladding interface). This suggested that our Module should have focused more on the regularities and formalization of the geometrical optics laws inferred during the Cabrì activities. Finally it emerged that the understanding of the mechanism at the basis of the fibres' functioning remained only qualitative.

An interview with the teacher, using the TBI (Luft & Roehrig, 2007) protocol and analysis of her practice using the RTOP (McIsaac & Falconer, 2002)[2] instrument has indicated also the need to give better guidance to those teachers not fully acquainted with inquiry-based approaches and modelling strategies. The Teachers' Notes have been therefore improved and enriched with, e.g., indications of how to implement a guided inquiry approach and perform measurements with Cabrì and on the modelling activities. Finally, the need to have a synthesis of the addressed contents was expressed by the teacher as well as other advisors in the LWG; this resulted in a first version of a "Conclusions" booklet given to the students.

SC2 context

Eighteen students have been engaged in five curricular compulsory morning sessions held at the school's laboratory of chemistry (equipped with PCs), for an overall duration of about 14 hours. On average, the students were not particularly motivated in studying physics or other scientific subjects and their grades were rather low. Their teacher, one LWG advisor, had participated also in the design of some of the Module's activities. As in SC1, three tutors were present to help in optimizing the experimental setting and in providing technical support, if needed: one was one of the major advisors of the LWG, one was a University researcher, one a teacher-researcher.

Among these students in the preliminary activities about vision some issues have been raised: e.g. referring to the experiment in which a laser beam is made visible by means of chalk dust, one student claimed that *"we see the laser beam because the chalk particles hold the light"*. Another student, when addressing substances' transparency proposed an experiment in which a coin was placed in a glass filled with Coca Cola to see the difference with respect to the case in which the glass was filled with water.

To assess students' understanding of some of the proposed concepts, a post instruction questionnaire (max score = 7), constructed on the basis of the SC1 students' answers to the homework, has been administered to the students, to be answered within 1 hour. The topics addressed were Vision, Index of Refraction, Total Reflection (Scientific Knowledge), Light Guides, Optical Fibres Functioning, Optical Fibres Design (Technological Knowledge). 11 students completed the questionnaire. The mean performance was 4.83 ± 0.63 (st. dev.), a satisfactory result since we considered 4.5 as a "sufficiency threshold". Four students out of 11 scored more than 5. Two students scored significantly higher than the others (means 5.97 and 5.72). Nine students scored higher than the sufficiency threshold. This overall result shows that the Module has familiarised the majority of the students with the addressed contents.

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[2] The Reformed Teaching Observation Protocol (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. To use the protocol in the observation of the Module some of the items have been adapted.

The students were later interviewed about the items of the questionnaire that proved to be the most difficult. The highest score was obtained for the index of refraction questions; on the contrary, students scored lower in questions concerning vision, total reflection and understanding of optical fibres design and functioning.

Drawing from these results more emphasis has been placed on both conceptual aspects (role of diffusing particles, transparency) and experimental features in the preliminary activities about vision.

SC3 context

Seventeen students have been engaged in six morning curricular compulsory sessions, for an overall duration of about 15 hours. Students' attitudes towards scientific school subjects varied; four students were particularly motivated with very good grades in mathematics and other scientific subjects. The others showed very little interest in studying science, particularly physics. At least two tutors were present during the activities. Two sessions have been observed by two "External visiting Experts"[3] according to the protocol of the Materials Science Project.

The same post-instruction questionnaire used in SC2 was also administered here. 13 students completed the questionnaire. The overall mean was 5.33 ± 0.52 (st. dev.). Five out of 13 students scored more than 5. One student scored significantly higher than the others (mean: 6.31). 12 out of 13 students scored more than 4.5. A couple of weeks after the implementation, the students were interviewed about some of the concepts addressed in the questionnaire.

From the questionnaire's and interviews' answers it emerged that the concepts addressed had been well grasped, specially Vision, Light guides' functioning principles and optical fibre design, whereas index of refraction and the functioning of the optical fibres seemed to have been less internalized.

Very interesting questions regarding the role of modelling activities and the "measuring" process proposed with the Cabrì environment were raised by the students during the intervention. A long discussion about the meaning of the different results obtained for the refraction index by the groups raised the issue of the meaning of measurement in physics. As regards the Cabrì applets one student remarked in a very insightful way: *"how do I know that someone is not interfering with my research if I am only using the applet (not having the possibility to access the underlying algorithm)..?*

The latter comment made us aware of the fact that, when using a Cabrì simulation, the students need to be able to access and manipulate also the underlying rules and functions.

After this implementation, further changes to the students' worksheets have been made, specially in the link between the experimental evidence and simulation results and in the formalization of the addressed concepts. Moreover, we decided to emphasize the initial scenario and the related problematic the students are asked to address.

DISCUSSION AND CONCLUSIONS

This paper has described the main features of a teaching sequence about Optical Properties of Materials developed within the EU funded "Material Science" Project. Some insights on the process of design and refinement of the proposed activity sequence have also been reported.

The sequence presents an innovative way to address some concepts of geometrical optics in an effort to enhance 14-16 years old students' learning interest in science and in physics in particular. The innovative character of the proposed materials relies on the choice of two key ideas (the path of light and the guiding of light in materials) which act as organizers of the activity sequence. In particular, first the distinction between the behaviour of light when it travels within a medium and when it encounters

[3] In our case prof. Martine Meheut and prof. Dimitri Psillos

the separation surface of two media is addressed. Such behaviour is related with the materials' optical properties (such as transparency and index of refraction) and is explained, in the geometrical optics model, by means of the rectilinear propagation of light, and of the laws of refraction and reflection.

Then, the behaviour of light at the interface between two materials is analysed, the focus being on refraction and reflection. Refraction, introduced first, is related to the two materials' optical properties, whereas reflection is interpreted as a way of constraining the light to propagate within a material in a non rectilinear way, by internal reflections. This leads the students to identify the conditions for guiding the light. The reflection and refraction laws previously introduced are then used to interpret the basic functioning of an optical fibre.

The overall process described in this study contributes to and extends recent research efforts (e.g., Anderson & Bach, 2005) towards a new paradigm for framing the design and development of teaching-learning sequences. In particular, this study plausibly suggests that the application of the iterative design process in developing curriculum materials about topics strongly related to students' every day life may be effective for addressing important physics concepts.

Overall, the analysis of data collected so far (through students' interviews and worksheets; observers' notes; teacher's ideas, beliefs and attitudes) in three pilot implementations have allowed the gathering of information about major changes to be inserted in the activity sequence and organisation in order to be more effective in promoting students' learning outcomes and motivation.

However, the analysis shows also that the teaching-learning sequence still does not completely fulfil the intended objectives. Some of the problems that had been encountered in the preliminary version have been partially solved: the results in the written assessment tasks on understanding of the physics concepts and on the design of optical fibres were on average rather satisfactory for SC2 and SC3 with respect to SC1. However, despite this, during the post-instruction interview, some other problems emerged either about conceptual understanding or about the proposed activities. Moreover, the scientific and technological content were not yet harmonically integrated in the sequence: much more attention was given to the physics concepts and laws whereas optical fibres still merely appeared as a technological application of the geometrical optics theory. Such limitation will be addressed in a forthcoming revised version where the science and technology content will be more integrated.

The next step will consist in setting up two complementary research studies: one focused on the effectiveness of the design – trial - redesign cycle under the specific viewpoint of the science and technology integration, the other on the relative effectiveness of the proposed ICT activities and hands-on experiments in school practice implementations.

A further insight to curriculum design research can be learnt from the role played by the Local Working Group established between university researchers and school teachers. With respect to previous similar efforts, e.g, the PLON project (Eijkelhof & Lijnse, 1988) or the "Logical Reasoning in Science & Technology" textbook (Aikenhead, 1994), the partnership contributed, since the beginning, to the whole process of design, development and pilot implementation of the activity sequence and thus has taken full advantage of the fruitful merging of different strands of expertise. For instance, while the University researchers and the teachers-researchers contributed more from the methodological viewpoint, the analysis of current literature about the chosen subject, and the design of the students' activities, all teachers participated actively as expert practitioners in order to give feedback about the feasibility of the proposed activities, each of them with his/her background knowledge, specificity and competence; this resulted in a sound contribution to e.g. the Teachers' Notes and the structure of Students' Worksheets. This study has shown also that the presence of such a diverse group of people in the design, development and evaluation of a didactical proposal adds a great value and that it gives all the participants involved in the partnership a possibility to enlarge their perspectives.

ACKNOWLEDGEMENT

Work presented in this paper has been supported by the European Union Commission of the European Communities Research Directorate General in the project «Materials Science –Univesrity School-partnership for the design and implementation of research based ICT enhanced modules on Materials Properties», " Science and Society, FP6 ". SAS6-CT -2006-042942)

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