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2012 Phys. Educ. 47 69
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Teaching optics with an intra-curricular kit designed for inquiry-based learning

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Abstract
In order to increase scientific literacy and the knowledge of science and technology of Europe’s citizens, the European Commission suggests a more student-centred implementation of natural sciences in education systems. Inquiry-based learning (IBL) is not only an accepted method to promote students’ interest and motivation, it also helps students learn the scientific method and fosters their research skills. However, IBL is rarely used in European classrooms. The main reason is that due to the strict curricula teachers do not have the time for preparation and they do not feel well equipped and trained in the use of IBL methods in class. The Photonics Explorer programme addresses these problems on the European level. Within the programme, a pan-European collaboration of professors, teachers and photonics experts have developed the Photonics Explorer kit for the teaching of optics and light-related topics in physics across various European secondary school curricula. It is designed for intra-curricular use and contains specially designed, hands-on experimental components, worksheets based on guided IBL and multimedia material. Additionally, the kit provides a teacher guide with a suggested lesson outline and sufficient background information for each topic.

According to the Rocard report, the EU needs a stronger emphasis on the use of inquiry-based learning (IBL) in its classrooms to achieve the goals of a knowledge based society and increase the scientific literacy of its citizens (Csermely et al 2007). It is said that based on the complexity of social, political and technological environment many people have increasing troubles in understanding their surrounding world (Dubs 2002) and ‘… among the population in general, the acquisition of skills that are becoming essential in all walks of life, in a society increasingly dependent on the use of knowledge, is also under increasing threat’ (Csermely et al 2007). There are similar calls all over the world, since the main stakeholders realize that the future competitiveness of their countries strongly depends on the quality of education, especially in science and technology.

Even though IBL methods are seen as a more effective way of teaching compared to the teacher-centred approach, they are rarely implemented within the classroom (Csermely et al 2007). Research has shown that the use of IBL helps students learn the scientific method and fosters research skills such as ‘working in groups, written and verbal expression, experience of open-ended problem solving and other cross-disciplinary abilities’ (Csermely et al 2007). However, teachers still seem to emphasize science concepts and facts rather than problem solving and critical thinking (Rennie 2007).
According to teachers, the difficulty of implementing IBL is based on the fact that it requires more time, which they simply do not have due to a set curriculum. They therefore conclude that a teacher-centred style is more effective in preparing students for centralized exams that focus mainly on factual knowledge rather than on skills. Furthermore, teachers often feel inadequately equipped and trained in the use of IBL to guide students in designing and conducting their own hands-on experiments. Most of the commercially available equipment for science teaching is not designed for use in IBL but only for experiments where students follow step-by-step instructions to a predefined result.

Various international initiatives are promoting IBL in schools by addressing these issues at different levels. They supply teachers with a variety of educational activities, materials, programmes and events. However, not all of them are equally accepted by the teachers. Interaction with teachers from various European countries has shown that the acceptance of IBL based materials is directly linked to the following two criteria:

- whether the material helps to achieve educational targets set in curricula within the given time budget;
- the effort required to prepare and give the lesson.

These requirements motivated the authors to develop the concept of an intra-curricular educational kit. Such a kit is specifically designed to cover the topics that are in the curriculum in order to help the teacher and students to achieve educational targets—yet with the use of hands-on experiments in an IBL context. An intra-curricular kit has the advantage of being integrated into regular teaching and does not need the additional time and effort required by extra-curricular demonstrations. Most outreach activities fall into the latter category and they do not fulfil the goal of guiding students through the curriculum.

Commercially available experimental materials for secondary schools are usually designed to illustrate a specific physical effect by following a fixed recipe, rather than to let students discover the effect with their own experiments. For the use of IBL in class, however, teachers need safe, robust and, especially, versatile components, which ignite the inquiry and ingenuity of their students. Often, these are simple and generic objects, rather than expensive tools. The worksheets are intended to guide students with questions, to make the best use of such materials, and then to enquiries that lead to the understanding of physical concepts and show the relation to their personal life or society in general, e.g. modern applications they use everyday.

The Photonics Explorer kit also includes a class-set of experimental materials such that a class of about 25–30 students can work together in small groups of 2–3. The components have been selected or even specifically developed to support the IBL approach in the didactic framework of the kit. The material is packed up in a box and includes a class-set of easy-to-use experimental equipment, worksheets, background information and additional resources such as, for example, videos, which will be handed out in conjunction with a teacher training programme.

For the development of the experimental equipment certain aspects had to be taken into account. The preparation time for the experiment by the students should be a minimum time so that by the time the teacher hands out the components the students can start working. The material itself should support and encourage the students to design their own experiments and follow their own ideas, so that they can not only build it but also test their hypotheses with their own hands-on experiments.

The modular structure of the kit allows a flexible integration of the material into various educational systems and cultures all over Europe. In order to ensure that the material fits into each curriculum and school system in the various European countries, the development was done together with more than 30 teachers and science education professors from 11 countries. In an extensive survey of physics teachers throughout Europe, the various curricula have been analyzed concerning the timing of basic and light-related topics and what other physical concepts the students already know and at what age. Furthermore, the teachers were asked to specify the different teaching methods that were used in class. The outcome of the survey showed a similarity in the timing of the topics and therefore suggested a list of topics that could be treated within the project of an intra-curricular kit.
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The selection of the components in the Photonics Explorer kit had an additional cost constraint: since the kit will be handed out free-of-charge to teachers, it is essential to keep the material costs at a minimum. Many components, e.g. a polymer optical fibre or polarizers, were sponsored by manufacturers. However, some components were specifically developed for safe, hands-on use in the classroom. For instance, it is very beneficial for a kit on light, optics and photonics to include a laser, e.g. for diffraction experiments. The student’s safety has been of foremost concern in the design of a laser that is not only robust, cheap and offers the required beam quality for the experiments but is also eye-safe (meaning that the output power is limited to less than 1 mW) and stays stable on the table while a warning LED indicates that the laser is operating (see figure 1). The laser focus lies about 20 cm from the source to suit experiments that fit on a student’s desk. Students follow an obligatory laser safety instruction before working with the laser, which intends to also raise the students’ awareness on laser safety outside the classroom—the laser is an important element in increasingly many technical devices. Classroom tests have shown that such a simple and flexible laser module inspires students to implement very different experimental setups. Many students find creative solutions to improve the quality of their measurements that would not be possible with regular laser pointers, while most commercially available experimental material for schools is even designed to prevent students from building setups that differ from the one suggested by the producer. Since the laser module is manufactured as a single circuit board that can be directly attached to a battery, the manufacturing, packaging and transportation costs should be kept at a minimum.

Another example of a very simple yet versatile component in the kit is the LED module that includes a red, green and blue LED (see figure 2). Each LED can be switched on independently by pressing a button. This very robust component was specifically designed for use by younger students (aged 10 and up) and serves as a light source in various experiments to generate coloured light signals and let students experiment with colour mixing, as well as to illustrate LEDs and to compare them with other light sources. The electric circuit is printed on the back, so that students can understand what ‘happens’ in the device, and calculate, for example, the electric power that the LEDs use. Once this module is in the hands of students, the list of possible experiments soon exceeds the imagination of most adults. This module has been used in class as well as at science fairs and other events and has proven to be very successful in raising the curiosity and interest of both students and teachers alike.

This new approach to encourage and support teachers to use IBL has shown very positive results. In a pilot study in six school classes...
in Germany and five school classes in Belgium, this approach has been very well received by both teachers and students, and it has demonstrated the potential of having a lasting positive impact on teaching styles. Many students have said that they appreciate the additional freedom due to the ‘simplicity’ of the components to develop their own experimental setups far away from the regular step-by-step programme. They often come up with ideas and suggestions for their own experiments that were not planned or imagined by the designers of the educational material (see figure 3).

The Photonics Explorer project offers well prepared material that can be easily integrated into the existing European curricula. It will not take away teaching time but rather help the teacher to make the best out of the time already designated for light and optics in their curriculum to ensure that educational targets can be easily achieved. The teacher can use guided IBL methods at a little more cost regarding the time budget and let the students use the material in the kit to create their own experiments in small groups. The Photonics Explorer kit contains not only the components, worksheets and factsheets for conducting hands-on experiments but also a guide for the teacher with a suggested outline for the use of each module. These save the teacher valuable preparation time. The experimental equipment in the kit has been specifically designed to support IBL teaching.

Although the concept of an intra-curricular kit shows very positive results in encouraging teachers to use IBL in their classes for specific topics, the general implementation of such student-centred teaching methods remains a challenge. However, teachers should not have to face this challenge on their own. They deserve support from society by receiving adequate materials and training, and sufficient time reserved in the curriculum to teach with student-centred methods.

The Photonics Explorer kit can be obtained from VUB Brussels, Belgium.

Received 22 July 2011, in final form 21 September 2011
doi:10.1088/0031-9120/47/1/69

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