The development and implementation of industry informed inquiry-based units for chemistry teachers (ESTABLISH project)

El desenvolupament i implementació d'unitats fonamentades en la indústria i basades en la indagació per a professors de química

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abstract

ESTABLISH (FP7 project) aims to increase the use of inquiry-based science education (IBSE) methodologies in classrooms across Europe. Through the provision of teaching and learning materials (ESTABLISH units), enhanced by authentic experiences provided by industry, and educational supports for both in-service and pre-service teachers (ESTABLISH Teacher Education Programmes), teachers have a range of suitable material to develop their own teaching. This paper discusses one of the ESTABLISH units and emphasises the development of the industrial links. A number of different approaches to industrial links are discussed, from providing context to actual design challenges.

keywords

Inquiry-based science education, teacher education, authentic learning experiences, industry informed education resources.

resum

El projecte ESTABLISH (7PM) té com a objectiu incrementar l'ús de metodologies d'ensenyament de les ciències basades en la indagació (ECBI) a les aules d'Europa. Mitjançant el subministrament de material didàctic (unitats ESTABLISH), reforçat per experiències reals proporcionades per la indústria, i el corresponent suport de formació educativa, tant per a professorat actiu com per a professorat en formació (Programes de Formació del Professorat ESTABLISH), els professors tenen a l'abast una àmplia gamma de recursos adequats per desenvolupar un ensenyament propi. En aquest treball s'analitza una de les unitats ESTABLISH i s'emfatitza el desenvolupament de vincles industrials. Es discuteix una sèrie d'enfocaments diferents dels vincles industrials per proporcionar un context als reptes actuals del disseny de materials didàctics.

paraules clau

Ensenyament de les ciències basat en la indagació, formació del professorat, experiències d'aprenentatge significatives, recursos educatius centrats en la indústria.

Introduction

Inquiry-based teaching methods have been suggested as a way to encourage and motivate students in science by increasing student interest (Fensham, 1986; Linn *et al.*, 2006). International reports (European Commission & High Level Group on Science Education, 2007; Osbourne & Dillon, 2008) have identified the need for «engaging curricula to tackle the issue of out-of date and irrelevant contexts and to enable teachers to develop their knowledge and pedagogical skills».

Linking these ideas suggests that inquiry methods and curricula must be engaging and include contexts that are relevant and familiar to be successful in encouraging and motivating students. Driving such a change in education requires many

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stakeholders from government agencies, industries, examination boards, but particularly participation from teachers and their students. As agents for change in the classroom, teachers must be both confident and competent in inquiry methodologies to successfully implement inquiry curricula. At present there are a number of national and pan-European projects active in facilitating the increased use of inquiry methodologies in classrooms with the overall aim of enhancing the teaching and learning of science across Europe; one such project is «European Science and Technology in Action: Building Links with Industry, Schools and Home» or ESTABLISH.

Overall ESTABLISH aims to provide teachers with both appropriate materials and supports to help them increase their use of inquiry-based teaching methods in their classrooms. In particular ESTABLISH aspires to create authentic learning environments for science education by providing industry informed contexts and problems that can be tackled in the classroom. This collaboration between industry and education has informed the development of the project's teaching and learning materials (ESTABLISH units) as well as educational supports for both in-service and pre-service teachers (ESTABLISH Teacher Education Programmes) designed to promote the use of inquiry-based teaching methodologies in classrooms across Europe.

Inquiry-based science education

Inquiry-based science education (IBSE) as a methodology is open to many interpretations. Although, many different types and levels of inquiry-based teaching and learning are discussed (Llewellyn, 2007), it is widely agreed that inquiry-based teaching is an organised and intentional effort on behalf of the teacher to engage students in inquiry-based learning. The goal of inquiry teaching is not to transfer scientific knowledge, facts, definitions and concepts, but rather to enhance students' ability to reason and to become independent learners who are capable of identifying questions and finding relevant answers through a gradual acquisition and expansion of a body of scientific knowledge and abilities. It is a student-centered approach to science learning.

Research has shown that when instruction is designed to engage students in the search of answers to questions that are relevant and interesting to them, their learning improves and they become more motivated (Donovan & Bransford, 2005). This is also the reason why inquiry lessons quite often are placed in the context of an everyday phenomenon with which students can link to or has personal experience of.

> Inquiry-based teaching can be organized through an instructional learning model. The learning cycle is one of the most familiar and effective models for science instruction

For coherence within ESTABLISH, the project consortium have adopted an agreed understanding of inquiry as the «intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments» (Linn *et al.*, 2004). Scientific inquiry can be considered both as a learning goal (resulting in students able to carry out scientific inquiries) and as a teaching strategy (using instructional strategies in which students are physically active and mentally engaged).

Based on how scientists carry out their work and on constructivist theory, several models of the inquiry cycle have been published, of which that proposed by Llewelyn (2007) is the most comprehensive, offering many opportunities for students to search for and construct meaning from the real world and to reflect on their experiences. In this approach, students create their own mental models as they make sense of their experiences and can develop skills and competencies that are useful for life: the so-called 21st *century skills* (American Association of Colleges of Teachers Education, 2010).

Inquiry-based teaching can be organized through an instructional learning model. The learning cycle is one of the most familiar and effective models for science instruction. Initially the learning cycle was proposed (Atkin & Karplus, 1962) as a model of three phases, named *exploration*, *invention* and *discovery*, later renamed as *exploration*, *development* and *application*, respectively. Later, this model was extended to the 4E of *exploration*, *explanation*, *expansion* and *evaluation* (Martin *et al.*, 1998). With the emphasis on constructivism and assessing prior knowledge, the *engagement* phase has been added in a design study of BSCS (Bybee *et al.*, 2006), making the learning cycle a 5E model (fig. 1). Details and further explanation of each phase of the learning cycle can be found at *http://www.bscs.org*.

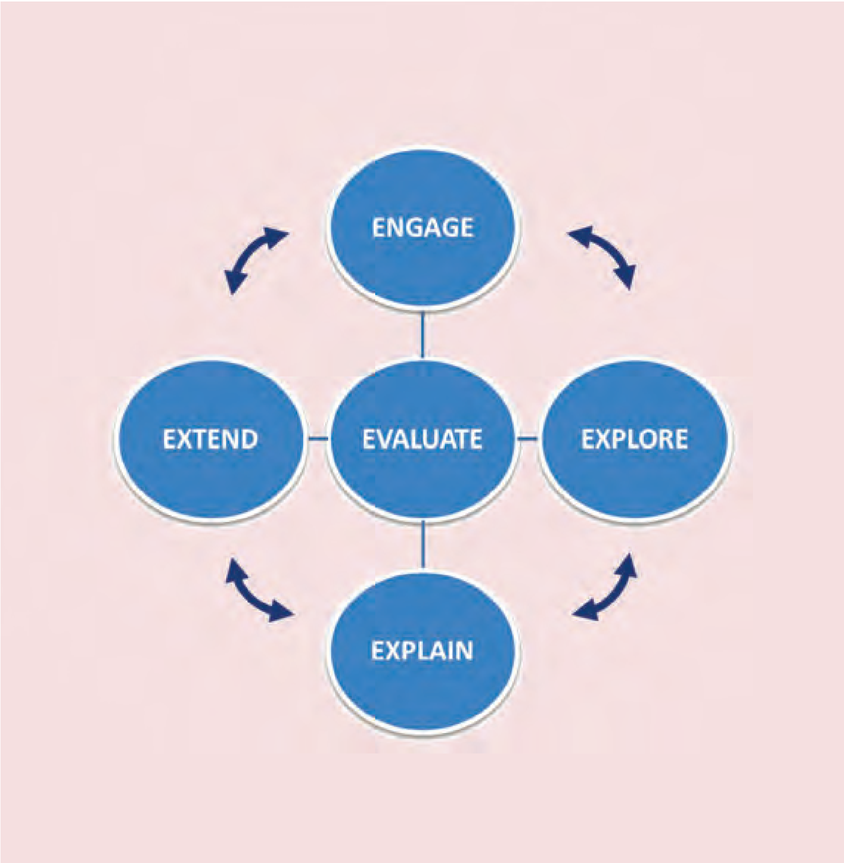

Figure 1. The 5E learning model (http://www.bscs.org).

Exemplary student learning activities included in ESTABLISH units offer activities with reference to these stages of the 5E model of learning cycle. Teachers as implementers and later as authors can structure their inquiry-based lessons by making their own selection of activities as useful for them in their particular teaching situations.

ESTABLISH units

To advance inquiry-based teaching use in classrooms, ESTABLISH has developed a range of inquiry teaching and learning materials (units) that can be used in different contexts, different curricula and at different educational levels at lower/upper second level. These units were developed primarily for use in teacher-education workshops, giving good examples of inquiry. They are representative of IBSE and were developed to show teachers the benefits of IBSE in classroom practice and to inspire them to generate their own IBSE materials. Each unit comprises of two sections: teacher information and classroom materials. The teacher information in each unit:

– Highlights the IBSE character and importance of the unit.

– Highlights pedagogical content knowledge.

– Links to real world/industrial applications, through industrial content knowledge.

– Includes a series of student learning activities which encourage and facilitate students to be active learners. These activities show different levels of IBSE.

– Offers suggestions of learning paths associated with these activities.

The classroom materials include a number of exemplar student activities that can be adapted by teachers for use in their own classrooms.

The industrial content knowledge highlights the relevance of the topic to industry and specifies the type of industry link(s) involved. It is recognised that different types of activities can link to industry in different ways and so the activities have been classified with regard to the degree of interaction with the industry. This range of depth of interaction is further explained as follows:

– *Lower level*. The context of the activity has a link, but the activity is rather traditional. In such an activity for example the application of science content in a certain product or process is demonstrated.

– In the activity, first an industry is studied (preferable by a site visit or other such introduction), and challenges faced in that industry are used to introduce science activities.

– Analysing the main product from industry or the product or process based on an industrial site visit and study of both the science content and the design process/choices that have been made. Students should experience different solutions for the same design task.

– A design task given by the teacher. Students will need to follow all steps in a design process. During the process they will need to learn science concepts and do experiments.

– *Higher level*. A design task with a customer. In this case contacts with industry leads to a design problem.

Within the ESTABLISH project, a number of units have been prepared addressing chemistry topics and these are listed in table 1 and are available at *http://www.establish-fp7.eu/index.php/dissemination-en/publish-material*.

Table 1. List of ESTABLISH units addressing chemistry topics

Exploring holes*	Chemistry
Chitosan – Fatmagnet?	Chemistry
Cosmetics	Chemistry
Photochemistry	Chemistry
Renewable energy	Physics/chemistry/biology
Chemical care	Chemistry
Photosynthesis	Chemistry
Polymers around us	Chemistry
Forensic science	Physics/chemistry/biology
Medical imaging	Physics/chemistry/biology

* One particular unit will be discussed in this paper: «Exploring holes».

«Exploring holes»

A central concept that underlies all chemistry understanding is that of the particulate nature of matter (Onwu, 2006; Johnstone, 1982; Johnstone, 1991). Many difficulties with student ideas have been identified in this area (Gilbert & Watts, 1983; Gilbert, 1994; Treagust, 1988). These difficulties may be associated with the different levels of representation of matter, as identified by Johnstone (1982) and the conceptual complications and confusion that can arise. These representational levels are: 1) the macroscopic level, which is associated with tangible objects or visible material; 2) the (sub)-microscopic level, which explains the particulate state of matter and is at the level of atoms, molecules, electrons etc., and 3) the symbolic level, the symbolism that we use to represent particularly the sub-microscopic levels and this can take several forms from pictorial representations, to symbols, etc. A further level has also been suggested which is 4) the human, societal dimension (Mahaffy, 2006). Thus, in the development of material for use in chemistry teaching, it is crucial that these conceptual challenges are considered. Many approaches have been taken to addressing these issues, such as focusing on identifying misconceptions (Kelly *et al.*, 2009), modelling ability (Chittleborough & Treagust, 2007) or representations (Onwu, 2006), among others.

The «Exploring holes» unit was developed around these ideas and to address the teaching of the particulate nature of matter through inquiry. Throughout the unit, the macro-, sub-micro- and symbolic representations are linked and opportunities are provided for teachers to further adapt and develop these for their own classroom. There is an emphasis throughout the unit on developing an understanding of molecular size, shape and particularly on linking molecular properties to structure to macro properties (the three levels advocated by Johnstone).

The unit divided into three subunits aimed at different educational levels. Each subunit can take multiple directions and emphasis depending on the curriculum and particular learning aims of the teacher. The subunits can also be used in a spiral type curriculum with subunit 1 focused at an introductory chemistry level, subunit 2 at an intermediate level and subunit 3 at the higher stages of second-level school.

This unit is built around the theme of «holes», from those that are visible to the naked eye (subunit 1: «Visible holes») to those that are invisible (subunit 2: «Invisible holes») to those that can be made within molecules (subunit 3: «Interesting holes»). Excerpts of each subunit will now be discussed, with highlights of industrial links noted.

Subunit 1: «Visible holes»

This subunit is set at an introductory chemistry level targeted at upper primary or lower second level. It focuses on holes and separation techniques in daily life and industry (fig. 10). Presenting the group with a mixture of seeds of different sizes and asking them to separate the seeds into their different kinds, without touching them, allows students to develop the ideas of a sieve with suitable sized holes. Separations using for example a coffee filter allow for building mental models of the separation

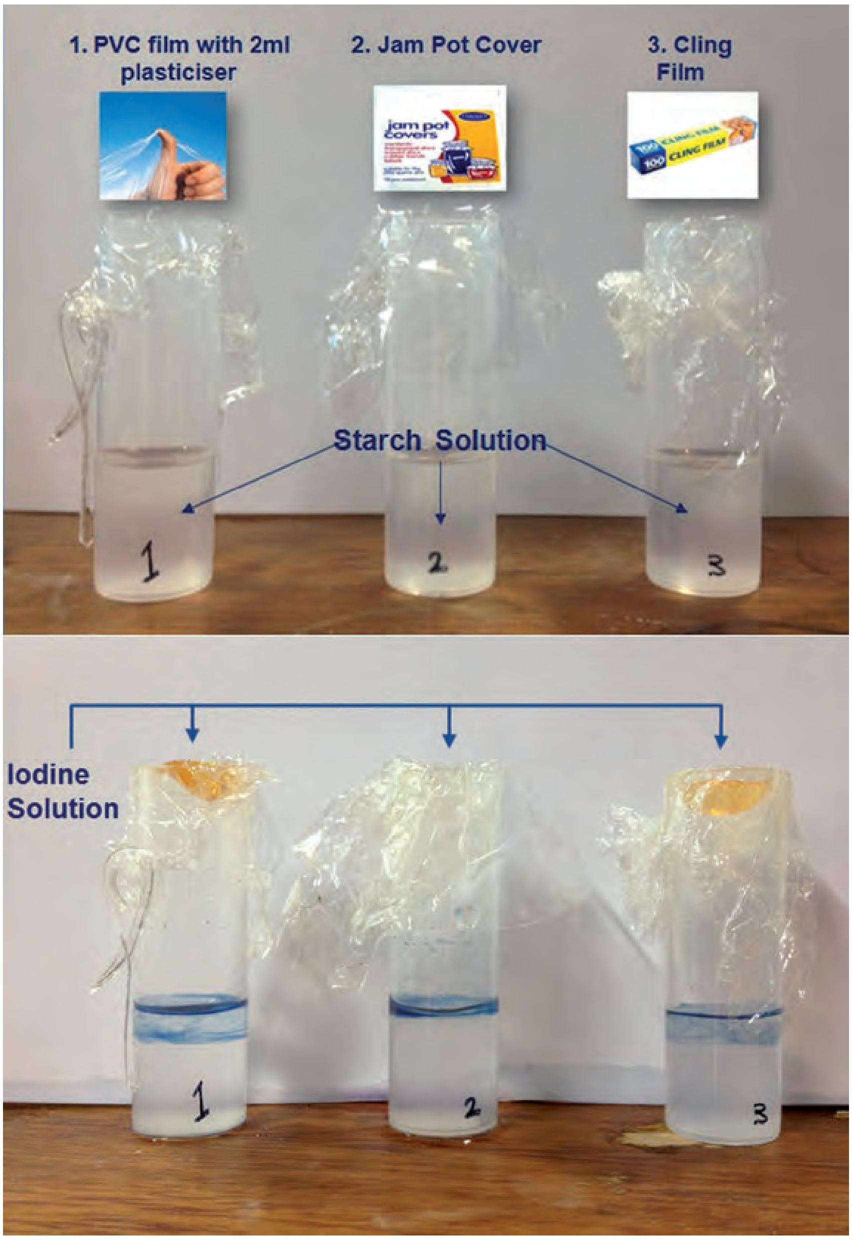

Figure 2. Selection of equipment for carrying out separations in daily life.

process, addressing questions such as: «Why do you think the coffee granules do not pass through the filter paper but the water can? Why has the water in the cup now turned brown? Could the separation device used for the seed activity be used in the coffee filter?».

Industry can provide many examples of the use of filters, particularly the food industry, e. g. gauze or muslin in cheese making to separate the liquid whey from the solid curd or in wine making to remove sediments. Further examples include water treatment and air filters. The first ideas of investigating the invisible can be made, linking ideas of particles in solution versus large clumps of particles.

Subunit 2: «Invisible holes»

In this subunit, the students can link their macroscopic knowledge onto the sub-micro to invisible level of atoms and molecules. These activities aim to help develop a deeper understanding of the particulate nature of matter and can be used to show both the existence of molecules and that they have different sizes. Several suggestions are presented within this subunit on how the activities can be implemented with the class.

One suggestion is to allow students to observe a «strange event»; in this case to observe a reaction between two solutions that seem to be separated by a barrier. In this activity an iodine solution is separated from a starch solution by a layer of «plastic film» (e. g. cling film, cellophane as jam pot covers or even plastic bags), as shown in the top of fig. 2 and observe that the starch solution turns blue (bottom of fig. 2). This can occur when the plastic film is in contact with both solutions but it can also occur when the plastic film is not directly in contact with the starch solution.

Linking the ideas back to previous activities can lead to the development of model-based explanations, in relation to the

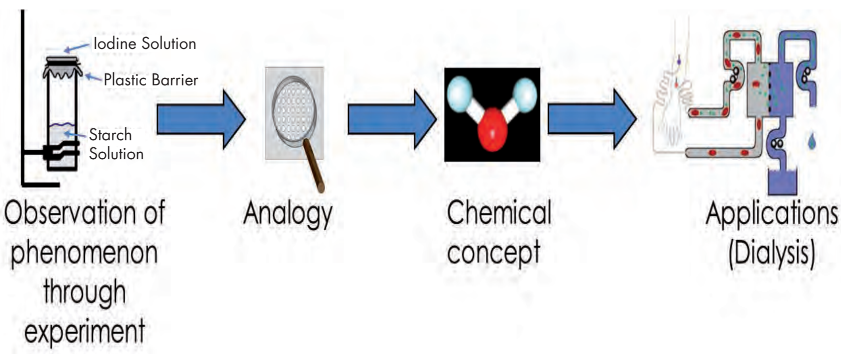

Figure 3. Experimental setup for observing interaction between starch solution and iodine solution separated by different plastic films.

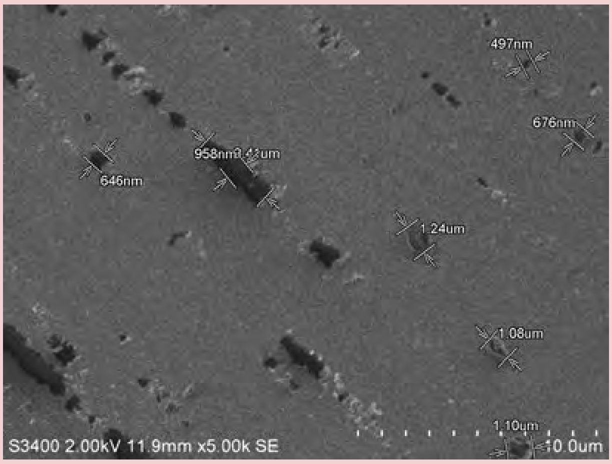

Figure 4. SEM image of PVC film with plasticizer (2 mL) × 5.00 keV.

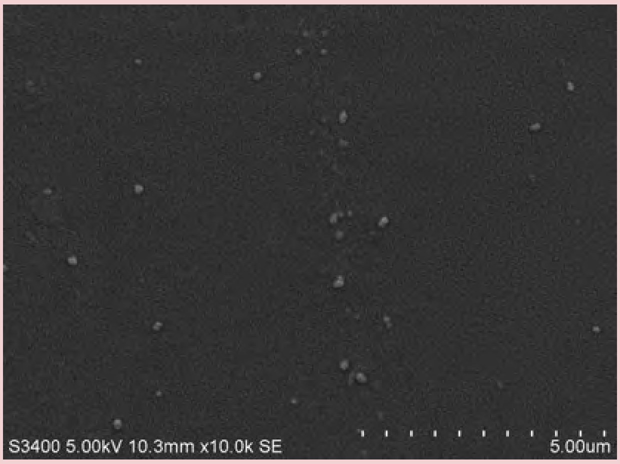

Figure 5. SEM image of PVC with no plasticizer × 10.00 keV.

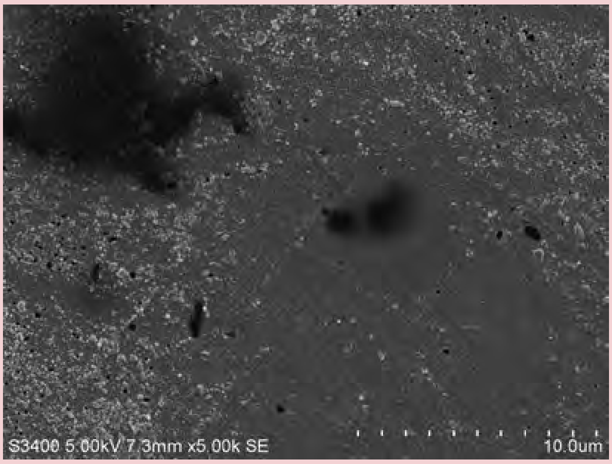

Figure 6. SEM image of cellophane (jam-jar cover) × 5.00 keV.

Figure 7. SEM image of cling film × 5.00 keV.

particles in solution and also the holes in the film. Based on the explanations developed by the students, further experimentation can be conducted to test their hypotheses, or use of SEM imaging as shown in fig. 6 and fig. 7.

Industry provides many examples for these activities in terms of contexts and applications as well as products themselves. For example, dialysis is similarly based on using membranes with suitable sized holes for passage of small particles while larger particles cannot get through.

Other suggested activities include the making of plastic films to mimic the industrial process. Films such as polyvinyl chloride (PVC) can be prepared easily by dissolving PVC powder in a suitable solvent, such as warm THF, adding small quantities of PVC powder at a time, to prevent lumps. The solution can then be caste, by pouring over a clock glass in a fume hood and the allowing the solvent to evaporate over a short period (10 min). A thin layer of PVC film can then be peeled away from the clock-glass. Often in industry it is necessary to adjust the properties of products such as to make a plastic more flexible. This can be done by adding a small amount of plasticiser to the PVC solution such as a drop of liquid detergent containing sodium lauryl sulphate. The addition of plasticiser to the solution creates a more flexible film, but it will also increase the number of holes (as shown in fig. 4 and fig. 5). Through the preparation and testing of these PVC films with varying amounts of plasticiser, students can feel the differences in the flexibility of the film and relate the macro level properties to changes at a sub-micro- level.

Subunit 3: «Interesting holes»

Subunit 3 is directed towards upper second level and the activities aim to develop the students' understanding of particles through a systematic look at molecular structures, forces and interactions. As examples, functional polymers such as superabsorbers, cyclo-dextrines or hydrogels, can be used. In all of these products, the «holes» within the molecular structure account for the properties of the material.

In this case, industry provides products for analyses, thus allowing the build up models to explain properties. Investigations can enhance testing of these models-based hypotheses and help to advance the development of the conceptual relationship between structure and property of molecules/materials.

One example is included here of super absorbing polymers (SAP), used in nappies and other hygiene products (fig. 8).

The development of the SAP and the industry itself could be investigated. Taking some SAP, either extracted from a nappy or a sample of pure polymer, some simple questions can lead to interesting investigations, such as: «How much water will SAP absorb? How can I measure this?». Allowing students time to «play» with the SAP and water, they will quickly identify that it is difficult to determine the saturation point of the SAP and that time is a factor in determining the amount absorbed. Criteria for saturation can then be developed to allow further investigation. The structure of the SAP (fig. 9) is then discussed to develop simple models to explain the absoption of water and its retention.

Further questions then arise as to whether absorption of urine is the same as water? This can be investigated by using solutions with different concentrations of NaCl and the models further developed by testing using $CaCl_2$ solution. In the latter case, the structure of the molecule will be altered and the change in property of the SAP is readily observed.

The industrial input to these activities is through the provision of the materials for testing. Within the context of SAPs, design processes can also be considered in terms of designing further products with SAPs or optimising their use.

Other examples that are included within this subunit are important industrially such as in drug release (as in hydrogels) and in environmental protection (as antimicrobial coatings). More details on these activities can be found on ESTABLISH website (*http://www.establish-fp7.eu*).

Overview of «Exploring holes» unit

The activities within each of the subunits focus on different types of inquiry ranging from guided to open with linkages to different parts of the 5E learning cycle, outlined previously. Table 2 summarises the range of inquiry and the E-emphasis of each activity.

Use of unit activities for ESTABLISH Teacher Education Programmes

The units has been shared and adapted in a number of countries for use in pre-service and in-service teacher education related to professional development associated with inquiry. As the curricula differ, the resources differ and the educational levels also differ in each of these countries, the units have been adapted to suit each national environment. At all times however, the integrity of the unit as an inquiry unit is maintained.

By using the units for the teacher education programme, participating teachers can gain experience of inquiry, and gain confidence in developing their own teaching practices. ESTABLISH consortium members have collaborated with local teachers during the development and piloting of these IBSE teaching and learning materials and will continue to support and inspire the further development of IBSE activities and units to facilitate the sharing and dissemination of these materials.

Profile data from teachers experienced in inquiry teaching have indicated that teaching through inquiry does not take up too much time overall or much more time in comparison to more traditional approaches; more time needs to be allocated at the early stages but once the practice is established, time is saved later on as students become more familiar with the methodology and their skills in inquiry have increased. These teachers also point out that not

Figure 8. Selection of everyday items which use SAP.

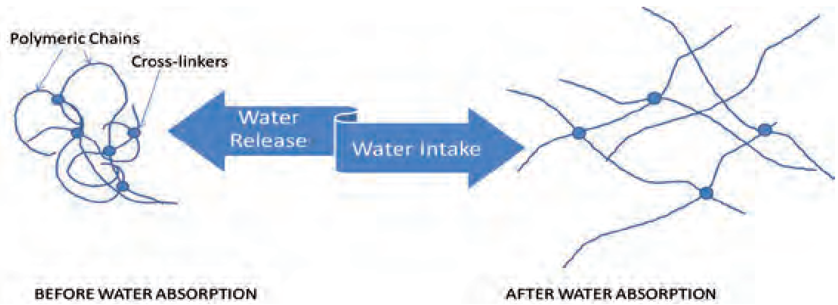

Figure 9. Graphical representations of SAP before and after absorption of water.

Table 2. Subunits within «Exploring holes»

1	**Visible holes**	Early second level (11-13 years)	1.1. Making sieves	Open inquiry	Exploration
			1.2. Observation and explanation of filters	Guided inquiry	Elaboration
			1.3. Use of filters in industry	Bounded inquiry	Evaluation
			1.4. Separation challenge	Open inquiry	Extend
			1.5. Assessment activity	Open inquiry	E-assessment
			1.6. Transfer: air filters	Guided inquiry	Extend
2	**Invisible holes**	Mid second level (13-15 years)	2.1. Membranes with invisible holes	Guided inquiry	Exploration
			2.2. Set of activities on diffusion, particles and holes	Guided inquiry/ open	Elaboration
			2.3. Transfer and extension/ assessment: dialysis	Bounded inquiry	E-assessment
			2.4 What is the best wrapping material?	Open inquiry	Exploration
3	**Interesting holes**	Upper second level (15-17 years)	3.1. Investigating the development of particular polymer products	Open inquiry	Exploration
			3.2. Investigations of properties and factors affecting SAP	Guided/open inquiry	Elaboration/ exploration
			3.3. Properties and applications of cyclo-dextrines	Bounded inquiry	Elaboration
			3.1. Investigating the development of particular polymer products	Open inquiry	Exploration

every lesson needs to be an inquiry lesson, but that inquiry can enhance the teaching and learning and inquiry classes are more engaging and challenging for both teacher and student.

Figure 10. Process of linking science teaching and learning to authentic experiences of science.

Conclusion

ESTABLISH aims to increase the use of IBSE methodologies, enhanced by authentic experiences provided by industry (fig. 3, 9), by teachers in classrooms across Europe. The resulting expectation is to impact positively on student's intrinsic motivation in science and technology, improve scientific literacy, promote student involvement in experiential learning and inform science career choices by students. Through on-going engagement with ESTABLISH, teachers will gain in confidence and competence in implementing inquiry methodologies with their students. At all times, the ESTABLISH project seeks to foster a mutually beneficial relationship between industries/research, teaching communities and local educational systems, for the on-going advancement of science and technology.

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