

# The Impact Of Inquiry Based Learning In Pre-service Science Teacher Education - Experiences From ESTABLISH\*

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## Abstract

Inquiry-Based Science Education (IBSE) has been promoted in recent years as an innovative teaching and learning methodology that engages students in science and motivates them to pursue careers in this area. IBSE is a student-centred methodology which aims to both support students in developing a deep understanding of scientific knowledge, facts and concepts and to enhance students' abilities to reason and become independent learners. Through this approach students become capable of identifying main questions and finding relevant answers. Many recent national and international innovations in science education have focused on increasing the use of IBSE methodologies in primary and secondary level classrooms. The ESTABLISH project has contributed to this movement by adopting a pan-European approach for developing and implementing teacher education in IBSE and teaching and learning IBSE materials. The project consortium has engaged with national policy makers, teachers and educators, as well as scientific and industrial communities across the eleven participating countries in this endeavour. This paper will discuss the overall approach adopted by ESTABLISH and in particular, will present the experience of initial implementation with a cohort of Irish pre-service science teachers. The impact on this cohort's understanding of and attitudes to IBSE will be reported and will be used to inform the development of other pre-service and in-service teacher education programmes and their evaluation.

**Keywords:** Inquiry, science education, teacher education, pre-service

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## 1. Introduction.

The issues faced by the EU in terms of science uptake by young people is clearly articulated in the, so called, Rocard Report (European Commission High Level Group on Science Education 2007, pp. 2

*“In recent years, many studies have highlighted an alarming decline in young people’s interest for key science studies and mathematics. Despite the numerous projects and actions that are being implemented to reverse this trend, the signs of improvement are still modest. Unless more effective action is taken, Europe’s longer term capacity to innovate, and the quality of its research will also decline. Furthermore, 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”.*

Crucial to addressing this decline in interest and for the development of these key skills is student engagement and retention in science education. Recommendations from international reports identify 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” (Osbourne, Dillon 2008, European Commission High Level Group on Science Education 2007). Both of these high level reports call for reform of science education on a global scale by encouraging hands-on inquiry-based learning, especially in primary and secondary schools. IBSE is a student-centred methodology which aims to both support students in developing a deep understanding of scientific knowledge, facts and concepts and to enhance students’ abilities to reason and become independent learners. Through this approach students become capable of identifying main questions and finding relevant answers. The use of an inquiry based methodology in science has also been strongly encouraged by the global network of science academies (ALLEA Working Group Science Education 2012).

In recent years, the EU has advocated competence-based teaching and learning and a learning outcome approach (Commission of the European Communities (CEC) 2009), which has resulted in significant changes occurring in secondary level science curricula. These curricula are now being treated in more engaging cross-curricular ways, with greater emphasis being placed on

developing skills and positive attitudes towards science in tandem with the development and transfer of content knowledge, e.g. through increased use of “real-life” applications to provide appealing learning contexts.

In addition, the European Future Skills-Biotechnology project 2009-2011 (Europe Future Skills-Biotechnology (FS-Biotech) 2009) has reported on importance of development of skills in science and lists the “Top Transferable Skills sought by Biotech Employers in Europe”. This report, generated from a collation of responses from 206 European employers in the biopharmaceutical and biotechnology sector, identified the top transferable skills as: Oral Communication; Listening; Continuous Improvement and Excellence; Teamwork; Personal Strengths; Written Communication; Personal Organisation and Time Management. Many of today’s employers, however, have highlighted that young people or “...high school graduates were ‘deficient’ in skills such as problem solving and critical thinking” (Barth 2009, pp. 29), pointing to a mis-match between the skills that educational systems supply and the skills that employers desire.

Indeed, an Inquiry-Based Science Education (IBSE) has been proposed by academic leaders and policy makers as having the potential to increase student engagement and so provide opportunities for the development of the key skills desired by employers (Osbourne, Dillon 2008; Fensham 1986; Linn, et al. 2006; European Commission (EC), High Level Group on Science Education 2007). However, achieving the aim of Inquiry-Based Science Education (IBSE) to provide “experiences that enable students to develop an understanding about the scientific aspects of the world around through the development and use inquiry skills.” Harlen and Allende (2009, pp. 17) requires the provision of appropriate initial and continual support to teachers in adopting this approach in the classroom. The European Commission has made a significant contribution to this movement through the Seventh Framework Programme (FP7) by providing funding for ~20 large scale multinational projects to support and coordinate actions on innovative methods in science education through teacher education in IBSE.

The ESTABLISH project (2010-2014) was one such FP7-funded project which brought together a pan-European consortium from across 11 participating countries to increase the use and dissemination of IBSE across Europe. This paper will share the approach of this project and describe the process adopted for developing teacher education materials and programmes given

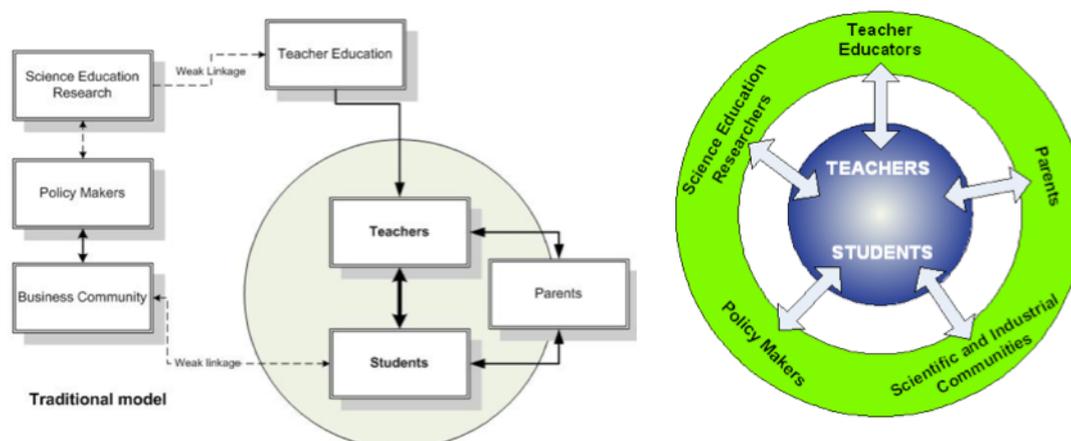
the local educational and cultural factors that had to be considered. In particular, this paper will focus on the implementation of a teacher education programme and its impact on a cohort of pre-service second level science teachers in Ireland.

### **1.1 Background.**

The FP7 funded ESTABLISH project (2010-2014) has enabled experts from science education research, teacher education, scientific companies, across 11 European countries (Ireland, Germany, Sweden, Cyprus, Czech Republic, Poland, Slovakia, Malta, Netherlands, Estonia and Italy) to come together to develop materials and supports to extend the use of inquiry-based science education (IBSE) in second level schools.

The specific aim of ESTABLISH was to bring together and involve key communities in second level science education to inform in the development of inquiry based science education materials and supports. These key communities, the stakeholders of science education, include science teachers and educators, the scientific and industrial communities, young people and their parents, the policy makers and the science education research community. Each of these have a role to play in second level science education, with some having a more direct impact on performance, other on policy, and others on the 'doing' of science at second level. The relationship between these communities is quite complex given the unequal strength of each relationship. There are many societal demands placed on science education which may or may not be complementary. Fensham (1991) characterises science education as offering the realisation of the potential to meet the demands of its learners for individual growth and satisfaction. Teachers want their students to do 'well', while industry needs employees with an ability to innovate, and policymakers want the economy to grow. Thus we see a shift in emphasis from the micro level (the student) to the macro level (the economy) and it is often assumed that there is a direct thread running between these levels. However, many other communities need to actively share and understand the common goals and methodologies used to attain them. The interactions of these communities have been considered as integral in the education strategy adopted by ESTABLISH as shown in Figure 1 and can be contrasted with the traditional modes of interaction as also shown.

**Figure 1: Traditional modes of interaction between science education communities versus the ESTABLISH model.**



ESTABLISH has provided the opportunity for these communities in second level science education to work together to achieve the specific aim of creating authentic learning environments for science education. This collaboration 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 Science Education (IBSE) in classrooms across Europe.

## 2. Methods.

This project adopted a research and development process for the promotion of inquiry based learning in science classrooms across Europe and has been informed by policy and governance as well as education and practice. The core tasks of the project have been to determine the extent of the use of IBSE in national curricula and assessment statements of each participant country, and to establish a framework and models for teacher education in IBSE.

## 2.1 Defining IBSE

There is much international variation in descriptions of IBSE and how it manifests in the classroom. For the purposes of the ESTABLISH project, the following definition of inquiry with nine identified elements, was adopted:

*“inquiry is 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, Davis & Bell 2004, pp. p. xvi).

## 2.2 Analysis of national curricula and assessment strategies.

The identification of the individual elements of inquiry allowed for the development of a questionnaire to analyse the extent to which IBSE was implemented in national science curricula and assessment practices at secondary level. This questionnaire was distributed to all partners at the beginning of the project to determine existing policies and practices in the participating countries across Europe.

## 2.3 Development of IBSE Teacher Education Programmes and supporting IBSE Units.

The main focus of this project was the development of IBSE teacher programmes for both in-service and pre-service teachers. A key aspect of this provision was the development of appropriate teaching and learning materials which provide teachers with opportunities to experience inquiry and support them in adopting inquiry in the classroom. In this project, an agreed framework for the development of IBSE materials was developed and presented as IBSE Units which described: (1) Unit/science topic, (2) IBSE character, (3) Pedagogical Content Knowledge, (4) Industrial Content Knowledge, (5) Learning Path(s) and (6) Student Learning Activities and Classroom Materials. The IBSE character (2) of the unit described the inquiry nature of the unit along with the element(s) and type(s) of inquiry involved. The Industrial Content Knowledge highlighted the relevance of/to industry and links the science concept to an industrial process/product. Using this framework, a number of IBSE units (as outlined in Table 3) were

proposed centrally by the consortium partners and piloted in several countries in collaboration with local science teachers. These central units were then reviewed and adapted so as to be suitable for implementation in each country taking into account cultural and curriculum variations.

To complement and facilitate the development of appropriate IBSE teacher education programmes an examination of the challenges and obstacles to implementing inquiry in the classroom was conducted. In this way, ESTABLISH developed a framework and models for Teacher Education Programmes (TEPs) that was informed by existing policy and practice in in-service and pre-service teacher education.

## **2.4 Impact of IBSE Teacher Education programmes.**

To determine impact of Teacher Education programmes and supporting IBSE teaching and learning Units, an evaluation instrument was developed, informed by literature, for use with participating teachers. Teachers completed this questionnaire both prior to and after completion of the teacher education programme.

## **3. Results.**

### **3.1 Analysis of national curricula and assessment strategies.**

The review of the second level curriculum for each of the eleven countries participating in the ESTABLISH project showed a large variation in the implementation of IBSE. It was observed that all countries having implemented at least three of the inquiry elements in their curricula and over half of the countries' curricula include all of the elements (Table 1). However, upon analysis of the extent of IBSE in the national assessment strategies a mismatch is observed, as indicated by the '0' symbol in Table 1.

All of the eleven countries have introduced initiatives for increasing the uptake of IBSE at secondary level but the scope of these actions are very varied, as are the providers of these initiatives (e.g. from local, regional, national or European funding sources). The ESTABLISH approach for the development of resources and supports for IBSE took cognisance of these efforts in its design and development.

**Table 1: Extent to elements of inquiry are included in National Curricula and assessment statements across ESTABLISH beneficiary countries. ✓ indicated that this element is included in both curriculum and assessment and 0 indicates that it is included in the curriculum only.**

Elements of inquiry	CY	CZ	DE	EE	IE	IT	MT	NL	PL	SK	SE
Diagnosing problems.		ü	ü	ü	ü	ü	ü	ü	ü	0	0
Critiquing experiments.		ü		ü	0		ü	ü	0	0	ü
Distinguishing alternatives.		ü	ü	ü		ü		ü	ü	ü	
Planning investigations.	ü	ü	ü	ü	ü	ü	ü	ü	ü	0	ü
Researching conjectures.		ü	0	ü		ü		ü	ü	0	0
Searching for information.	ü	ü	0	ü	0	ü		ü	ü	ü	0
Constructing models.		ü	0	ü		ü		ü		ü	0
Debating with peers.	0	ü	0	ü	0			ü	0	0	0
Forming coherent arguments.		ü	0	ü	ü			ü	ü	ü	ü

*Identification of each country is: CY- Cyprus, CZ-Czech Republic, DE-Germany, EE-Estonia, IE- Ireland, IT- Italy, MT- Malta, NL-Netherlands, PL- Poland, SK-Slovakia and SE-Sweden.*

### **3.2 Development of Teacher Education programmes and IBSE materials.**

The framework for ESTABLISH Teacher Education Programme was founded on the integral use of the ESTABLISH IBSE units and activities to engage the learner so that they may experience inquiry as well as be exposed to examples of how to teach by inquiry. Table 2 shows the variety of scientific topics that were developed into IBSE teaching and learning materials during the ESTABLISH project. Each of these units was developed to embed industrial products and processes so as to provide direct links from science in the classroom to science in scientific and industrial contexts.

**Table 2: List of ESTABLISH teaching and learning units.**

<b>Physics</b>	<b>Chemistry</b>	<b>Biology</b>	
Sound.	Exploring holes.	Disability.	Forensic science Medical imaging
Heating & Cooling- Designing a low-energy home.	Chitosan– Fatmagnet?  Cosmetics.	Blood donation.	Renewable energy
Direct current electricity.	Chemical care.	Ecology.	Photochemistry.
Light.	Plastics and plastic waste.	Water in the life of man.	Photosynthesis.

The framework for ESTABLISH teacher education, as illustrated in Table 3, identified and described four core elements together with four supporting elements for teacher education in IBSE. This framework provided a flexible and comparable description for all ESTABLISH Teacher Education Programmes (TEPs) in the participating countries and required a minimum of 10 hours of face to face participation. The subsequent TEPs implemented catered for in-service and pre-service teachers and were delivered by face-to-face and online strategies across a range of cultural, educational and disciplinary contexts.

**Table 3: Schematic representation of ESTABLISH framework for teacher education programmes.**

<b>Core TEP elements</b>	<b>Supporting TEP elements.</b>
I. ESTABLISH view of IBSE	V. ICT
II. Industrial content of knowledge.	VI. Argumentation.
III. Science teacher as implementer.	VII. Research and design.
IV. Science teacher as developer.	VIII. Assessment of IBSE.

### 3.3 Impact of pre-service teacher education programme in IBSE.

This paper presents the initial experiences of the Irish partners in implementing IBSE in pre-service science teacher education. The Irish national curriculum for lower secondary science emphasises teaching strategies that encourage investigative work as well as experimental prescribed work. The syllabus promotes the development of logical thinking and reasoning, and skills of observation, measurement, interpretation, numeracy, problem solving and decision making. With respect to the IBSE elements there are opportunities for students to investigate their own problems by searching for information and planning investigations. Mostly students take investigation titles assigned by the national examination authority and these students' investigation plans are assessed using a summative exam/review at the end of the lower secondary level ~15years. However, depending on teachers' capabilities to manage inquiry and such open teaching, they may wish to set the investigation so as to limit the openness of the problem, and may present the required information and experiments for the students, again limiting their opportunity to search for information, and plan their investigation. So while the national curriculum includes IBSE elements, in general, teachers are not educated at either pre-service or in-service level and there is a lack of appropriate instructional materials available to support the teaching of national syllabi. In this national context, 37 pre-service physics teachers participated in introductory lectures plus 9 hours of hands-on Inquiry Based Labs using materials from the ESTABLISH Sound Unit. 39% of these students considered themselves IBSE beginners while 61% of them expressed that they had some experience with inquiry-based teaching. The InquiryBased Labs were focusing on developing inquiry questioning skills. Before the labs sessions started, students answered a pre-questionnaire on their views of inquiry. After completing the sessions they answered a concept based assessment as well as a post-questionnaire on their views of inquiry teaching and approaches.

Overall, these pre-service teachers were very positive about the values and benefits of inquiry as a methodology. Importantly, 67% believed the use of inquiry is appropriate to achieving the aims of the curriculum and 70% expressed confidence in their understanding of inquiry based science education. However, this cohort of pre-service teachers appeared unconfident and uncomfortable with delving outside the limits of their own knowledge in the classroom. 61% of teachers felt

uncomfortable with teaching areas of science they had limited knowledge of and 64% admitted to being uncomfortable with asking questions where they are unsure of the answer themselves. They were very divided in their responses as to their role as the teacher in the classroom and 54% disagreed with the statement “my goal is to transfer factual knowledge to the students” while 55% felt that teaching was more effective when all students are doing the same activity at the same time”. It is evident, that these conflicts arise from their lack of experience in the classroom and their understanding of the national examinations in science.

A set of ten open questions were presented to the students to obtain feedback on their understanding of IBSE after completing these sessions. 87% expressed that they felt they now understood inquiry better and commented on the benefits of inquiry teaching. 97% of them identified the role of the teacher to guide/ask questions in the inquiry classroom where the students are active and self-directed. When asked what was the most important inquiry skill that they gained from these labs, the students recognized that they had developed questioning skills (48%), experience in planning and doing investigations (27%) and learning from mistakes (22%). 77% of the students were very positive about the materials from the ESTABLISH units and felt they gave them good ideas and developed understanding and skills.

#### **4. Conclusions And Future Work.**

ESTABLISH has provided the opportunity for the development of a framework for teacher education programmes in IBSE that supports teachers in the use of IBSE in the second level science classroom. In particular, this project has involved working with local teachers, industries and ministries to develop science activities that engage learners as initiators in science education. This pan-European collaboration has informed the development of the project’s 18 teaching and learning materials (ESTABLISH Units) as well as educational supports for both in-service and pre-service teachers (ESTABLISH Teacher Education Programmes) that are culturally adapted for each country and promote the use of IBSE in classrooms across Europe.

The results of an initial implementation of a IBSE teacher education programme and its impact on a cohort of Irish pre-service cohort have been presented in this paper. The majority of these teachers expressed an increased understanding of inquiry and the benefits of inquiry in this

teaching. These preliminary results will inform the development of further teacher education programmes and the instruments to collect evidence of this impact of this approach on pre-service teachers, in-service teachers and their second level students, from across Europe. Through initial and on-going engagement with teachers and students, a range of specific instruments will be developed to determine the impact of the ESTABLISH approach on their understanding, attitudes and skills in inquiry based science education.

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