Learners as initiators through inquiry based science education – experiences from the european project ESTABLISH

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Abstract

Inquiry-Based Science Education (IBSE) has been the focus of many national and international programmes and projects in recent years as Inquiry based teaching methods have been suggested as a way to encourage and motivate students in science. The pan-European FP7-funded project ESTABLISH collaboration has led to the development of the project's teaching and learning materials as well as educational supports for both in-service and pre-service teachers designed to promote the use of Inquiry based approach at second level. In particular ESTABLISH aims to create authentic learning environments for science education through industry engagement to share contexts and problems that can be tackled in the classroom. This paper will share the approach adopted across 11 countries to engage second level students as initiators and innovators through inquiry based learning. In addition, this approach has been adopted with third level students (pre service teachers) by facilitating these teachers to gain experience in inquiry, and gain confidence in developing their own teaching practices and incorporating industrial engagement into their classroom practices.

Keywords

Inquiry, science education, teacher education, ICK, PCK

1. Introduction and Motivation

The recent trend across the EU towards competence-based teaching and learning and a learning outcome approach (Commission of the European Communities (CEC) 2009), has resulted in significant changes occurring at school curricula level in traditional subject areas such as science. 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.

The European Future Skills-Biotechnology project 2009-2011 (Europe Future Skills-Biotechnology, 2009) has reported on the “Top Transferable Skills sought by Biotech Employers in Europe” from a collation of responses from 206 European employers in the biopharmaceutical and biotechnology sector. The top transferable skills are identified as: Oral Communication; Listening; Continuous Improvement and Excellence; Teamwork; Personal Strengths; Written Communication; Personal Organisation and Time Management. However, many of today’s employers have identified that “high school graduates were ‘deficient’ in skills such as problem solving and critical thinking” (Barth 2009).

Crucial to the development of these key competencies in young people is their engagement in the education process. Methodologies such as inquiry-based science education (IBSE) have been highlighted as having the potential to increase student engagement in science at primary and second level and provide such development opportunities (Osbourne, Dillon 2008, Fensham 1986, Linn, Lee et al. 2006, European Commission (EC), High Level Group on Science Education 2007). Recommendations from these 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*”. This reform of science education on a global scale by encouraging hands-on inquiry-based learning (IBSE), especially in primary and secondary schools, is also encouraged by the global network of science academies (ALLEA Working Group Science Education 2012) where they define IBSE as comprising of "*experiences that enable students to develop an understanding about the scientific aspects of the world around through the development and use inquiry skills*." (Harlen, Allende 2006).

In recent years, the European Commission, having identified IBSE as a desirable methodology to implement in classrooms across Europe to engage young people in science and mathematics and develop skills and competencies to cope with the challenges for a changing world, has funded several large scale projects in science education through the Seventh Framework Programme (FP7) to support and coordinate actions on innovative methods in science education through teacher education in IBSE.

ESTABLISH is one such FP7-funded project which brings together a pan-European consortium from across 11 participating countries to increase the use and dissemination of IBSE across Europe. This paper presents the approach of the ESTABLISH consortium in adopting a common understanding of Inquiry Based Science Education (IBSE) which underpins the development of frameworks for the development of IBSE teaching and learning materials and the implementation of teacher education programmes, for both in-service and pre-service second level science teachers.

2. Background

The FP7 funded project ESTABLISH started in January 2010 and has brought together expertise from across 14 institutions in 11 European countries (Ireland, Germany, Sweden, Cyprus, Czech Republic, Poland, Slovakia, Malta, Netherlands, Estonia and Italy) to extend the use of inquiry-based science education (IBSE) in second level schools.

The specific aim of ESTABLISH is to promote innovation in classroom practice by bringing together and involving all the key communities in second level science education, including science teachers and educators, the scientific and industrial communities, the young people and their parents, the policy makers and the science education research community. It is important to recognise that these communities have a role to play in second level science education and some of these communities have a greater ‘voice’ whilst others have a more direct impact on either performance, policy or the ‘doing’ of science at second level. In fact the relationship between the stakeholders 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 (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 stakeholders 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.

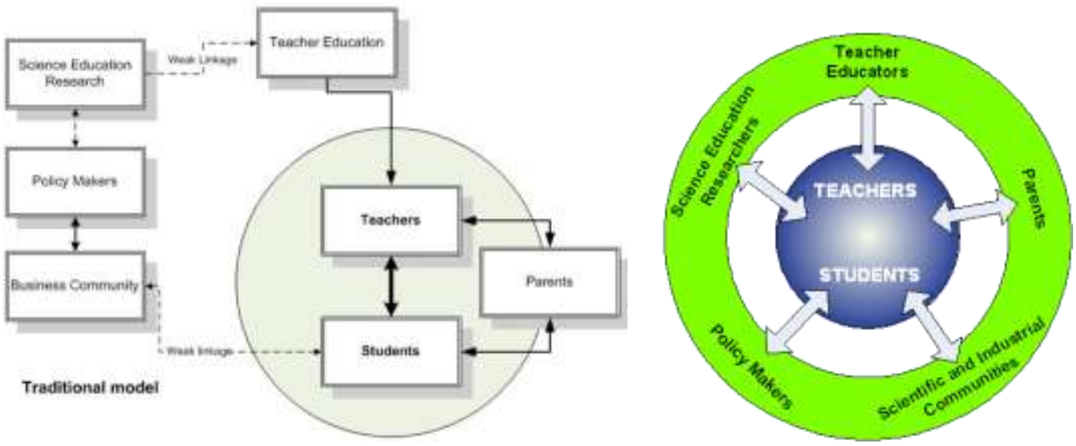

Figure 1: Traditional modes of interaction between stakeholders in science education versus the ESTABLISH model.

3. Methods

To achieve its goals, the ESTABLISH project consortium have adopted a common 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, Davis E.A. et al. 2004). Using this definition and arising from extended group discussions, the individual elements of inquiry were identified and operationalized to represent the role of the student in an IBSE classroom. A questionnaire was then developed and completed by each country partner to determine the extent of implementation of inquiry in national science curricula and assessment practices for science at second level.

A key aspect of this project was to develop teaching and learning materials, IBSE units, which collate activities that facilitate students to be active learners, are appropriate for IBSE and can be used in teacher education – both pre-service and in-service. An agreed framework for the development of these IBSE units has been developed by the consortium, and each unit describes: (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 of the unit describes the IBSE nature of the unit along with the element(s) and type(s) of inquiry involved. The Industrial Content Knowledge highlights the relevance of/to industry and links the science concept to an industrial process/product. Using this framework, central IBSE units have been developed and piloted in several countries by the consortium members working with local science teachers. The central unit is then adapted for implementation in each country, taking into account cultural and curriculum differences.

To complement and facilitate the adoption of inquiry as a teaching methodology across Europe, the ESTABLISH consortium examined the challenges and obstacles to implementing inquiry. Through this reflection, a framework for Teacher Education Programmes (TEPs), informed by existing good practice in in-service and pre-service teacher education, has been adopted by the project.

4. Results

A review of the second level curriculum for each of the eleven countries participating in the ESTABLISH project was carried out through the use of written questionnaires and one to one interviews. Each of the eleven countries nominated a teacher or educator as the contributor and therefore the findings are informed by the opinion of the contributors and may not necessarily reflect national policy. The contributors were asked to indicate which of these nine elements of inquiry are included in respective national curriculum and assessment documentation. Responses indicated that, in every country, at least some elements of inquiry are explicitly or implicitly stated in curriculum and over half of these countries' curricula include all of the elements (Table 1).

Table 1: Extent to elements of inquiry are explicitly stated or implied in National Curricula across ESTABLISH beneficiary countries.

Elements of Inquiry	CY	CZ	DE	EE	**IE***	IT	MT	NL	PL	SK	SE
Diagnosing problems		√	√	√		√	√	√	√	√	√
Critiquing exp**e**riments	√	√	√	√	√		√	√	√	√	√
Distinguishing alternatives		√	√	√		√		√	√	√	√
Planning investigations	√	√	√	√	√	√	√	√	√	√	√
Researching conjectures		√	√	√		√		√	√	√	√
Searching for information	√	√	√	√	√	√		√	√	√	√
Constructing models		√	√	√		√		√		√	√
Debating with peers	√	√	√	√	√			√	√	√	√
Forming coherent arguments		√	√	√	√			√	√	√	√

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.

Table 2: Extent to which IBSE is explicitly stated or implied in National Assessment criteria across ESTABLISH beneficiary countries.

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

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.
('0' indicates that while this element is included in the curriculum, it is not assessed directly.
**For Ireland the information provided represents the junior cycle science subject (12-15 years).*

However, a strong mismatch was observed between the inclusion of these elements in the curricula (Table 1) and the assessment (Table 2) of them. All of the countries have implemented initiatives for increasing the uptake of IBSE but the scope of these are very varied, as well as the provider of these initiatives, e.g. from local/regional/national level to European funded programmes. Thus the development of resources and supports for IBSE must be cognisant of these contexts and be designed appropriately.

The objective of this project is, through the education of teachers, to increase the use of IBSE in classrooms across Europe. This process has required the ESTABLISH consortium members to collaborate with the local key communities, especially with teachers, resulting in 18 substantial IBSE teaching and learning units that encompass an extensive range of science activities that are suitable for using in inquiry teaching and learning across the participating countries. Table 3 presents a listing of these 18

Unit titles which encompass Physics, Chemistry, Biology and Integrated Science topics.

Table 3: List of ESTABLISH Teaching and Learning Units

Chemistry	**Biology**
Exploring Holes Chitosan – Fatmagnet? Cosmetics Chemical Care Polymers around us	Disability Blood donation Ecology Water in the Life of man Photosynthesis
Physics	**Integrated Science**
Designing a low energy home Direct current electricity Sound Light	Forensic science Medical imaging Photochemistry Renewable energy

The framework for ESTABLISH Teacher Education Programme is founded on the integral use of the ESTBALISH 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. The framework identifies four core elements for teacher education in IBSE and four supporting elements identified as supportive aspects of implementing IBSE (Figure 2, Table 4). This framework provides a flexible and comparable description of ESTABLISH Teacher Education Programmes (TEPs) which cater for in-service and pre-service teacher education delivered by both face-to-face and online strategies across a range of cultural, educational and disciplinary contexts.

Table 4: Elements of ESTABLISH Teacher Education Programmes

Core TEP Elements	**Supporting TEP Elements**
I. ESTABLISH view of IBSE	V. ICT
II. Industrial Content Knowledge	VI. Argumentation
III. Science Teacher as Implementer	VII. Research & Design Projects
IV. Science Teacher as Developer	VIII. Assessment of IBSE

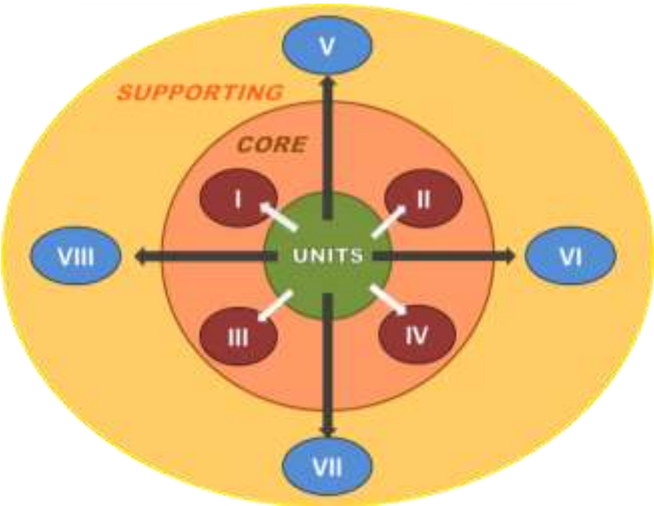

Figure 2: Schematic representation of ESTABLISH TEP elements supported by activities from the units

A significant focus of the ESTABLISH project is to determine the impact of its Teacher Education Programmes on the participating teachers, both pre-service and in-service and also on the students in the second level classroom. A complete report on this will be published in due course. However, this paper presents preliminary results from a particular example of one country's experiences in implementing IBSE. In this country, the national curriculum for lower secondary science emphasizes teaching strategies that encourages 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 problem 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 pre-service teachers considered themselves beginners while 61% of them expressed that they had some experience with inquiry-based teaching. The Inquiry Based Labs were focusing on developing inquiry questioning skills. Before the labs sessions started, pre-service teachers answered a questionnaire on their attitudes and 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.

As regards responses to questions, these pre-service teachers were 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, these pre-service teachers appeared unconfident and uncomfortable with delving outside the limits of their own knowledge in the classroom. 61% of these pre-service 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 also presented to these pre-service teachers to obtain detailed 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 selfdirected. When asked what was the most important inquiry skill that they gained from these workshops, the pre-service teachers recognized that they had developed questioning skills (48%), experience in planning and doing investigations (27%) and learning from mistakes (22%). 77% of the pre-service teachers were very positive about the materials from the ESTABLISH units and felt they gave them good ideas and developed their understanding and skills.

5. Conclusions and Future Work

The members of the ESTABLISH project consortium have worked with local teachers, industries and ministries to develop science activities that engage learners as initiators in science education at second level. 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 implementation with one pre-service cohort have been presented here and further data collection and analysis will be collated from pre-service teachers, in-service teachers and their second level students, across Europe. Through initial and on-going engagement with teachers and students, the skills and competencies gained in IBSE are expected to be improved and a range of specific instruments to determine the extent of this impact will be utilised on a pan-European scale by the consortium members.

6. References

ALLEA WORKING GROUP SCIENCE EDUCATION, 2012. *Summary: A renewal of science education in Europe - Views and Actions of National Academies.* Berlin, Germany: ALLEA ALL European Academies.

BARTH, P., 2009. *What do we mean by 21st century skills?* .

COMMISSION OF THE EUROPEAN COMMUNITIES (CEC), 2009. *Key competences for a changing world: Progress towards the Lisbon objectives in Education and Training.* SEC(2009) 1598 FIN. Brussels: Commission of the European Communities.

COMMISSION OF THE EUROPEAN COMMUNITIES (CEC), 2008. *A European Economic Recovery Plan.* COM (2008) 800 FIN. Brussels: Commission of the European Communities.

EUROPEAN COMMISSION (EC) and HIGH LEVEL GROUP ON SCIENCE EDUCATION, 2007. *Science Education NOW: A Renewed Pedagogy for the Future of Europe.* EUR 22845. Brussels: DG Research.

FENSHAM, P.J., 1991. Familiar but different: some dilemmas and new directions in science education. In: P.J. FENSHAM, ed, *Development and dilemmas in science education.* London: Falmer Press, .

FENSHAM, P.J., 1986. Science for all. *Educational Leadership,* **44**(4), pp. 18-23.

HARLEN, W. and ALLENDE, J., 2006. *IAP Report of the Working Group on the International Collaboration in the Evaluation of IBSE programs.*

LINN, M.C., DAVIS E.A. and BELL, P., 2004. *Internet Environments for Science Education.* Mahwah, NJ.: Lawrence Erlbaum Associates.

LINN, M.C., LEE, H.S., TINKER, R., HUSIC, F. and CHIU, J.L., 2006. Inquiry Learning: Teaching and Assessing Knowledge Integration in Science. *Science,* **313**(5790), pp. 1049-1050.

OSBOURNE, J. and DILLON, J., 2008. *Science Education in Europe: Critical Reflections.* 32. London: King's College, London.