PATHWAY

The PATHWAY to Inquiry Based Science Education

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D3.3 The PATHWAY to Inquiry Based Science Education (UBT)

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Content

1. Executive Summary

«The PATHWAY to Inquiry Based Science Education», as an European education project has successfully set a structured set of guidelines and recommendations on

a) how inquiry based techniques can be introduced in the school practice,

b) how teachers can use the unique resources of science centres and museums in their lessons and

c) how effective forms of collaboration between researchers and the educational sector (formal and informal) could create valuable and meaningful learning experiences for all, fostering exploration, discovery, curiosity and collaboration.

PATHWAY emphasizes an innovative way of learning about science that reflects how science itself is done, on inquiry as a way of achieving knowledge and understanding about the world. It proposes new ways of interacting with scientific content and it will demonstrate the results from the extended validation effort in the participating institutions and beyond.

The potential benefits are discussed and recommendations for further application are given. The integration of the project results in training policies and practices is discussed as well.

This report is available in conventional form and in electronic format from the project web site: **http://www.PATHWAY-project.eu/** .

You can find it in eleven languages: English, French, German, Italian, Flemish, Finnish, Greek, Bulgarian, Romanian, Spanish and Russian.

2. Introduction

Teachers are key players in the renewal of science education. The effective widespread use of inquiry and problem based science teaching techniques in primary and secondary schools heavily depends on them. While there are many surveys that present a series of constraints in the adoption of inquiry based methods in science teaching, it is believed that for individual teachers to effectively implement inquiry in the classroom three conditions must be met:

1. Individual teachers need to become aware of specific weaknesses in their own practice. In most cases, this not only involves building an awareness of what they do but the mind-set underlying it.

2. Individual teachers need to be motivated to make necessary improvements. In general this requires a deeper change in motivation that cannot be achieved through changing material incentives.

3. Individual teachers need to gain understanding of specific best practices. In general, this can only be achieved through the demonstration of such practices in authentic settings.

The PATHWAY to Inquiry Based Science Teaching project added its contribution towards the improvement of the quality of science teaching through the development of an approach that:

a) proposed a standard-based approach to teaching science by inquiry that outlines instructional models that will help teachers to organize effectively their instruction,

b) deployed a series of methods to motivate teachers and provide them with the necessary skills to adopt inquiry based techniques and activities in their classrooms and

c) offered access to a unique collection of open educational resources and teaching practices (linked with the science curricula) that have proven their efficiency and efficacy in promoting inquiry based education and that are expanding the limitations of classroom instruction.

Such an approach enabling all stakeholders (teachers, teachers' trainers, curriculum developers, policy makers) to examine their own practices in the light of the best performing approaches that set the standards on what can be achieved and provides them with a unique tool to bring about improvements in their everyday practice.

In order to implement effectively the proposed standard-based approach, all training activities were expected to highlight and promote best practices in teaching science by inquiry. By building on the best of current practice, the PATHWAY approach aimed to take us beyond the constraints of present structures of schooling toward a shared vision of excellence. PATHWAY presents a series of exemplary teaching practices, resources and applications that provide teachers (and their students) with experiences that enable them to achieve scientific literacy. The aim was to offer to the teachers who were participating in the training activities a variety of resources. They are arranged so that they do not impose a fixed curriculum, but instead support customization to reflect location, culture and ideology. The PATHWAY repository of best practices was the window onto live scientific experiments and phenomena, on-going research, and the personalities and stories of working scientists across Europe.

To accomplish these goals, the coordinated activities were organised in three main categories:

- Effective educational activities based on inquiry based approaches (school based)
- Educational activities that promoted school – science centre and museum collaboration
- Educational activities that promoted school – research centre collaboration

All these materials were used for many years in numerous schools in Europe and they have proven their efficiency and efficacy as teaching resources that support inquiry. In the framework of the this project, PATHWAY had proposed value-added services to increase the utility of these resources through coordination, systematic dissemination and effective teachers' community building. The PATHWAY training resources were disseminated in different environments (teachers' preparation and professional development institutions and schools) across Europe during the life cycle of the project. The process of observing and reflecting on teachers' actions, and on students' learning and thinking, could lead to changes in the knowledge, beliefs, attitudes, and ultimately the practice of teachers.

OBJECTIVES

There is significant research evidence demonstrating that an inquiry approach to science teaching motivates and engages every type of student, helping students understand science's relevance to their lives as well as the nature of science itself. However, in order to facilitate the creation of modules that will allow educational resources to be incorporated into an inquiry based learning experience it is essential to implement the educational visions in teacher education and professional development programs, and most important, in the school classrooms.

PATHWAY modelled this effective approach to science teaching with a two-part structure: "Methods for teaching science by Inquiry" and "Activities for Teaching Science by Inquiry".

The "Methods for teaching Science by Inquiry" portion scaffold concepts and illustrated instructional models to help teachers to understand the inquiry approach to teaching.

The "Activities for teaching Science by Inquiry" implemented a specific inquiry educational approach, properly assembled to either implement existing Best Practice Educational Scenarios from international success stories or to create new Activities for Teaching science by Inquiry.

In general, the main project objectives linked to the implementation of the educational activities throughout the life of the project were the following:

- To implement a large number of training activities that facilitate the effective introduction of inquiry to science classrooms and professional development programmes. During the implementation phase teachers communities have been given access to a unique collection of open educational resources (linked with the science curricula) that have proven their efficiency and efficacy in promoting inquiry based education and that are expanding the limitations of classroom instruction.

- To further support the adoption of inquiry teaching by demonstrating ways to reduce the constraints presented by teachers and school management. PATHWAY deploys a series of methods of effectively involving teachers in the inquiry instruction. In order for them to fully realize the potential of inquiry based education, all potential fears and negative preconceptions related to the proposed approach needed to be addressed adequately. The task at hand was to manage this change in a uniform way, allowing teachers to realize the potential of the opportunity offered by the PATHWAY project, take ownership of their contribution and maximize the output for both the project and themselves.

- To systematic validate the proposed approaches and activities in order to identify their impact in terms of the effectiveness and efficiency. The key areas of interest of the proposed validation methodology was Science Pedagogy, Organization issues (e.g. impact on the national curriculum), Technology – tools, services and infrastructure, Economic – value for money, added value, Cultural and linguistic issues. The project was implemented in schools, science teachers training centres, science centres and museums and research centres in different countries that allowed for an ethnographic research and evaluation of different attitudes against the use of inquiry based techniques in different cultures providing thus ways for intercultural dialogue to improve these attitudes.

3. What is IBSE

a. Essentials of IBSE pedagogy: Strategies for developing inquiry as part of scientific literacy

Teaching science by inquiry is a multi-faceted, contingent practice. Some of the factors that, in any one context, combine to shape the way in which teachers approach design for IBSE include: the character of the national teaching and assessment policy regime; the character of the school or other institutional learning and teaching culture; the teachers' conceptions of teaching and learning; the pedagogic traditions of their specific science subjects; the availability of educational resources; the affordances of formal and informal learning spaces; and, of available technologies.

Design for IBSE involves exercising informed, creative professional judgments about, among other aspects: incorporating IBSE into frameworks of wider curriculum requirements; creating or selecting activities that will motivate and engage students; establishing appropriate learning outcomes and assessments; approaches to provision of guidance and support; using specialist equipment and digital technology; selecting learning resources including readings and links to useful websites; addressing classroom management issues and minimizing of any risks involved in hands-on activity. A science teacher may take notes on what went well and less well in order to strengthen certain inquiry aspects or to reflect on what should be kept into the inquiry process for the next year. While much of the design for learning work involved in IBSE entails planning and reflection, it also involves interacting with students and thinking fast during inquiry activity, and taking in-process decisions.

The focus of learning design is learning activity: what counts as most important in relation to learning outcomes is what the student does (Biggs 1996). Activity encompasses mental elements (e.g., a meta-cognitive reflection on the process of analysing scientific data), and physical elements (e.g., using laboratory equipment or a digital scientific tool) (Ellis &Goodyear 2010). However, while the ultimate focus of learning design is activity, activity is mediated in formal educational settings by tasks: students are set tasks and their activity ensues in response to the demands of these (Beetham 2007). Tasks designed by teachers thus can be seen as a key stimulus and resource for student activity. Within the PATHWAY framework of 'Seven Essential Features of IBSE' - questioning, evidencing, analysing, explaining, connecting, communicating, reflecting (adapted from Asay & Orgill 2010) – the design of tasks that will stimulate productive activity in each of these areas is the key challenge for science teachers.

Figure 1 illustrates the point that tasks are not the only influence on students' inquiry activity. Learning activity is contextually and socially situated: activity is influenced by a wide range of factors including among others the quality of interaction between students and between student peers and teachers. Thus, while teachers are responsible for setting in place many of the social and physical resources on which students draw, inquiry activity is strongly influenced by social and physical factors that teachers do not control (Ellis and Goodyear 2010).

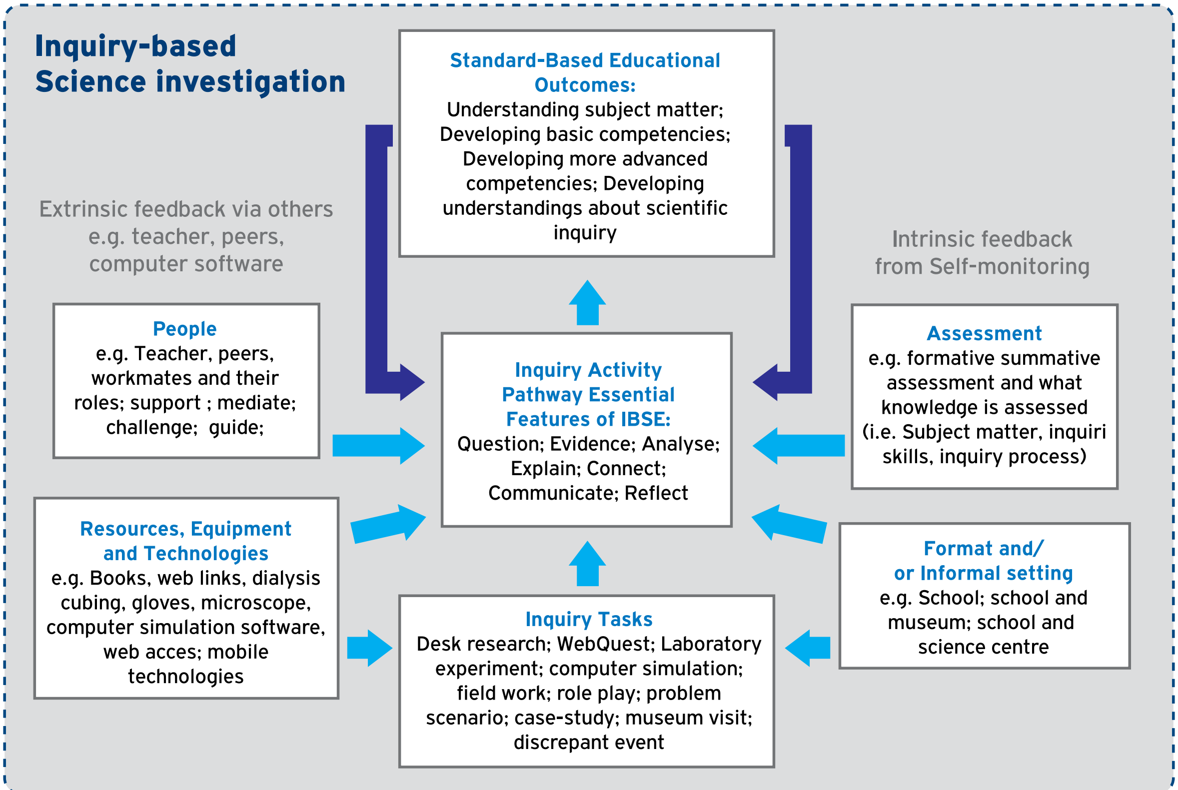


Figure 1: Influences on inquiry tasks, learning activities and learning outcomes in a scientific investigation (adapted from Ellis and Goodyear 2010)

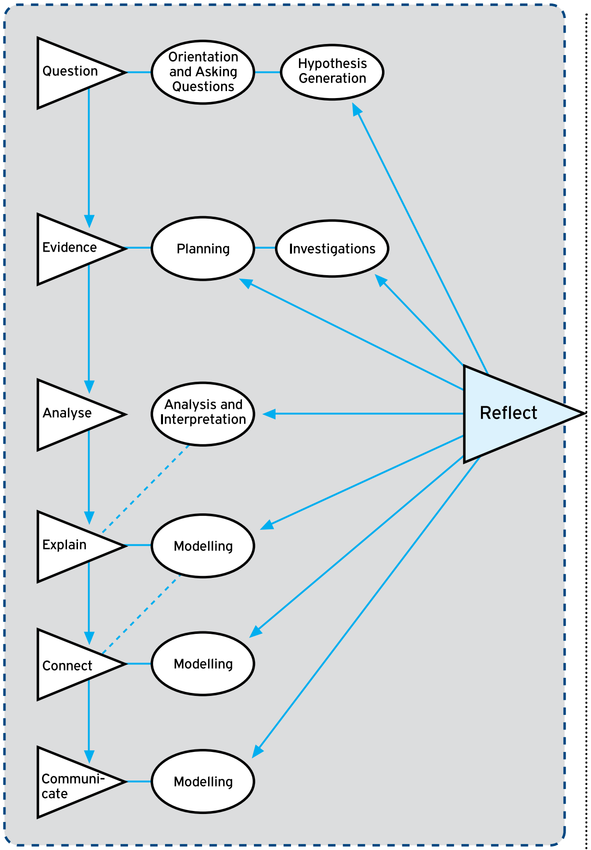


Figure 2: Mapping of inquiry tools identified in Bell et al.'s paper (2010) to PATHWAY's proposed essential features for IBSE

b. Effective learning environments for inquiry learning and teaching

How collaborative inquiry processes can be supported by computer-based tools and learning environments:

Bell et al (2010) determined a set of nine categories of inquiry processes that capture a wide range of ideas about inquiry held by researchers in the field and presented examples of computer-based collaborative tools and environments that support these processes, describing their effects on students' learning processes.

These nine categories are: orienting and asking questions; generating hypotheses; planning; investigating; analysing and interpreting; exploring and creating models; evaluating and concluding; communicating; predicting.

Figure 2 shows how these categories correspond to the seven essential features of IBSE proposed by the PATHWAY framework.

Emphasizing that it is "a good balance of challenge and support" (Bell et al, 2010: p372) that leads to enhanced learning outcomes, the authors highlight the following challenges for the field:

- the need to balance opportunity for open-ended exploration with guidance to support the needs of individual learners, for example by using computer-based diagnostics or by strongly emphasizing peer collaboration and support;
- the need to structure environments in such a way that learners can use the full potential of embedded tools;
- the need to allow for more flexible learning, for example by enabling different modes of data-collection (quantitative and qualitative) and modeling, and by allowing for students to take different PATHWAYs towards solutions;
- and the need to facilitate integration of different learning environments that have complementary tools.

4. Guidelines and Best Practices of IBSE:

The PATHWAY repository of Best Practices is the window onto live scientific experiments and phenomena, on-going research, and the personalities and stories of working scientists across Europe. The PATHWAY book of "Best Practices" describes a series of methodologies for initial teacher preparation and professional development (PD) programmes, along with a series of Best Practices for implementation in formal and informal learning settings.

a. IBSE for school practice, science centers and museums, and IBSE in collaboration between research and the educational sector

Following the recommendations of the "Science Education Now: A renewed Pedagogy for the Future of Europe" report (Rocard, 2007), PATHWAY was bringing together experts in the field of science education research and teachers' communities, scientists and researchers involved in pioneering scientific research, policy makers and curriculum developers to promote the effective widespread use of inquiry and problem based science teaching techniques in primary and secondary schools in Europe and beyond. The project aimed to set the PATHWAY toward a standard-based approach to teaching science by inquiry, to support the adoption of inquiry teaching by demonstrating ways to reduce the constrains presented by teachers and school organization, to demonstrate and disseminate methods and exemplary cases of both effective introduction of inquiry to science classrooms and professional development programmes, and finally to deliver a set of guidelines for the educational community to further explore and exploit the unique benefits of the proposed approach in science teaching.

PATHWAY has developed a series of basic principles that the Best Practices have to meet.

The determination of the underlying principles govern the presented standardization approach based on the concepts and the theoretical approaches deriving from recent educational research on the field. It imparts a deep understanding of content, teaches prospective teachers many ways to motivate young minds, especially with the appropriate use of technology, and to guide them in active and extended scientific inquiry, and instills a knowledge of — and basic skills in using — effective teaching methods in the discipline.

These principles are:

1. Best Practices are supposed to sustain learners' curiosity about the world, enjoyment of scientific activity and understanding of how natural phenomena can be explained

2. Best Practices have to focus on all learners, both those who may later become scientists or technologists or take up occupations requiring some scientific knowledge and those who may not do so.

3. Best Practices must have multiple goals. They need:

a. to develop an understanding of a set of big ideas in science which include ideas of science and ideas about science and its role in society

b. to improve scientific capabilities concerned with gathering and using evidence

c. to promote scientific attitudes.

4. The implementation of the Best Practice should be a clear progression towards the goals of science education, indicating the ideas that need to be achieved at various points, based on careful analysis of concepts and on current research and understanding of how learning takes place.

5. The themes of the Best Practices should refer to students' relevance in their lives.

6. Best Practices should reflect a view of scientific knowledge and scientific inquiry that is explicit and in line with current scientific and educational thinking.

7. Best Practices should deepen understanding of scientific ideas as well as having other possible aims, such as fostering attitudes and capabilities.

8. Programmes of learning for students, and the initial training and professional development of teachers, should be consistent with the teaching and learning methods required to achieve the goals set out in Principle 3.

9. Assessment should be an integral part of the Best Practices. The formative assessment of students' learning and the summative assessment of their progress must apply to all goals.

10. Best Practices should promote cooperation among teachers and engagement of the community including the involvement of scientists.

Moreover, certain additional criteria were defined to support the implementation of the Best Practice in real settings:

1. must apply universally

2. can be developed through a variety of content, chosen to be relevant, interesting and motivating

3. can be applied to new content and enable learners to understand situations and events, as yet unknown, that may be encountered in their lives.

4. must have explanatory power in relation to a large number of objects, events and phenomena

b. Professional development of IBSE-teachers: Considerations and strategies

Understanding scientific inquiry must be learned. Although the process starts with the teacher deciding to change his behaviour and 'use inquiry', the essential part for the teacher is to learn how to accomplish that. Developing an understanding of scientific inquiry by students is a long-term process. There are many aspects that may seem to hinder the use of inquiry in science lessons, such as time constriction, high levels of energy for preparation, reading difficulties by the students, risks of experiments not working well, or physical risks for the students, costs for equipment and the already heavy burden of the subject as exists before using inquiry to teach it.

Teaching by inquiry supports abilities of students that are consistent with other stated goals for science teaching like problem solving, working in teams, critical thinking and argumentation.

Science-related projects involve experimental work and have an investigative character for the student. Students can work individually or in small groups. It can extend from single hours to several project weeks. It provides opportunity for students to engage in a science-related study with a particular focus. It may involve collaboration with people in other institutions, and outcomes are manifested in a kind of report at the end of the study (Eurydice 2006).

The essential features of inquiry

There are certain essential features that we need to keep in mind when going further in the direction of inquiry in the classrooms of Europe and beyond. The project adapted five of these features and formed the seven essential features of IBSE as listed in the following table.

c. Teacher guidelines and supporting materials

To this end, PATHWAY aimed to support the adoption of Inquiry-Based Science Education (IBSE) by demonstrating and disseminating best teaching practices. In this way the project team encouraged development of communities of practitioners of inquiry that enable teachers to learn from each other.

In this context and in order to support communities of practitioners of inquiry to share, use and re-use best teaching practices through web-based repositories, PATHWAY provided:

a) a set of guidelines for the implementation of IBSE in practice (in parallel with a large number of educational practices that are presented in "The PATHAY Best Practices"-book along with their supporting materials for classroom implementation).

b) a stand-alone tool (namely "PATHWAY ASK-LDT"), which enables community members to design and express IBSE Scenarios based on best teaching practices following consistent and commonly recognized terms among the educational practitioners of a given community.

Essential Features of IBSE	**Variations** 1 (Open)	2 (Guided)	3 (Structured)
QUESTION: students investigate scientifically oriented question	Student poses a scientifically oriented question	Student selects from a range of, or refines, a scientifically oriented question provided by the teacher, materials or other source.	Student is given a scientifically oriented question by the teacher, materials or other source
EVIDENCE: students give priority to evidence	Student determines what constitutes evidence/data and collects it	Student selects from data/evidence provided by the teacher, materials or other source	Student is given evidence/data by the teacher, materials or other source
ANALYSE: students analyse evidence	Student decides how to analyse evidence	Student selects from ways of analysing evidence provided by the teacher, materials or other source	Student is told how to analyse evidence provided by the teacher, materials or other source
EXPLAIN: students formulate explanation based on evidence	Student decides how to formulate evidence based on evidence	Student selects from possible ways to formulate explanation given by the teacher, materials or other source	Student is given a way to formulate explanation based on evidence
CONNECT: students connect explanations to scientific knowledge	Student independently finds and examines other resources and forms links to scientific knowledge	Student is directed to other resources and shown how to form links to scientific knowledge	Student is given other resources and shown the links with scientific knowledge
COMMUNICATE: students communicate and justify explanation	Student chooses how to communicate and justify explanations	Student is given broad guidelines on how to justify and communicate explanations	Student is given all the steps to justify and communicate explanations by the teacher, materials or other source.
REFLECT: students reflect on the inquiry process and their learning	Student decides independently how to structure reflection on the inquiry process and his/her learning	Student is given broad guidelines to structure reflection on the inquiry process and his/her learning by the teacher, materials or other source	Student is given a structured framework for reflection by the teacher, materials or other source

More--------------------Amount of Student Self-Direction----------------Less

Table 1: Seven essential features of IBSE (Levy et al, in preparation), adapted from Asay and Orgill 2010)

The following key messages can be drawn from the literature review on Key Features for involving Teachers, Developing Communities of Best Practice, Assisting Behavioural Change and Adaptation of a New Culture and Philosophy by Teachers.
Key Features: Methods For Involving Teachers
1. Giving teachers guidelines for teaching and assessment that support inquiry oriented outcomes helps them to implement the new teaching style in their classroom. Teachers gain insights in how to structure their lesson and lesson contents when having a guide at hand about what to aim for, what to include and how to secure success in obtaining the goals with students. 2. The PATHWAY project offered seven essential features of inquiry that serve as reference points for constructing interactive hands on inquiry based science classes. These seven essential features of inquiry are: question, evidence, analyse, explain, connect, communicate and reflect – They can be applied in open, guided or structured forms of classroom performance. Each feature has its own essential contribution for teaching through inquiry.
Developing Communities of Practice
3. Spreading the information of successful IBSE in the classrooms of Europe and beyond is the main thought behind the PATHWAY project. For this to succeed the project build up communities of practitioners, mainly teachers, and enabled them to act as change agents in their school or educational environment. These change agents were supported by PATHWAY with effective training methods on inquiry teaching and learning and there was on-going support when new members are introduced to the community of practitioners. 4. A vivid network of science teachers and other stakeholders of the educational sector was an important feature of the PATHWAY approach. Communication with experts and other members of the community helped to overcome individual problems in understanding and implementing successful IBSE in the classroom of our community of practitioners. The network had access to resources, experts, and peers via the community's server, which was provided by the PATHWAY project.
Assisting Behavioural Change
• When teachers adapted their teaching style to the successful use of inquiry, they needed to change their behaviour and culture of teaching in the first place. There were three key points that made it more likely that such a behavioural change occurred. Teachers saw that their changes and the program they listen to was meaningful for them and their students. • They were reinforced so that the time spent on learning the new methods and behaviours were recognized and rewarded. That
Adapt a New Culture and Vision
• Last but not least, to successfully implement IBSE long-term, teachers adapted a new culture and philosophy of teaching and learning with their students. Hands-on experiences and experiments were well planned by the involved teachers in advance. The spirit of inquiry needed to be understood beforehand, to use these experiences and experiments in a meaningful way where students can learn from investigating themselves, not by merely following a cooking receipt of experiment with little or no thinking about what stands behind all the steps, and the theory behind the experiment. Teachers learned to let students investigate and no longer be the merely centre of the lesson that provides information.

The teacher guidelines and supporting materials are available in 11 languages for local distribution at schools and workshops in the participating countries in the PATHWAY Project to facilitate the teacher community and spreading of the IBSE-theory and practice.

5. Main outcomes of PATHWAY

a. Teacher communities

The PATHWAY project is available for the public community through its web portal at: **http://www.PATHWAY-project.eu/**

The homepage provides the Best Practice book, informs about current events of PATHWAY, and general the background about IBSE.

Furthermore the consortium created a platform where upcoming events are posted by each partner: http://fit-bscw.fit.fraunhofer.de/pub/bscw.cgi/39089761

Through these public information sources, teachers can get informed about IBSE as a standard based approach, available workshops near their town, download guidelines and lesson materials.

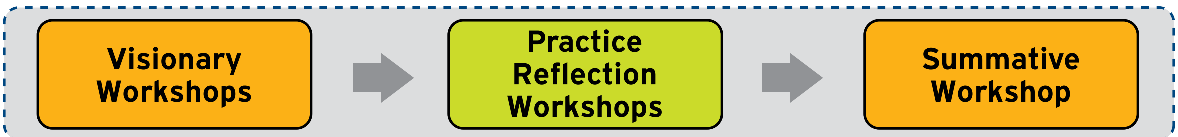
b. Workshops

In order for teachers to fully realize the potential of inquiry-based education, we needed to address all potential fears and negative preconceptions related to the proposed approach adequately and assist them in every step of the process.

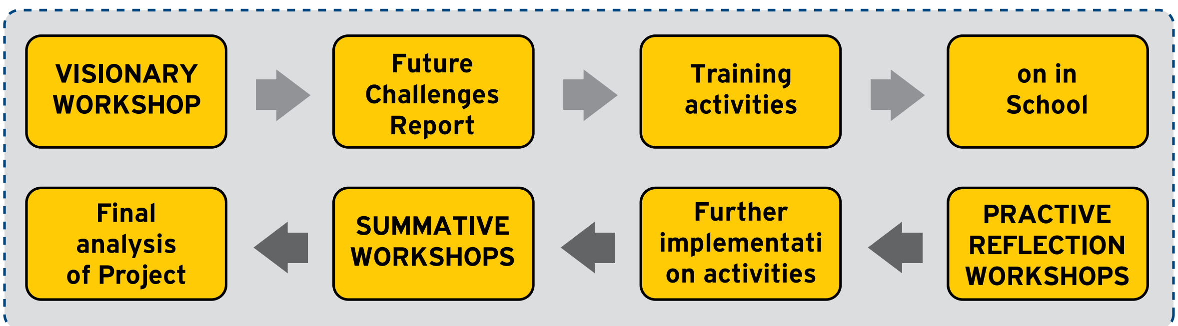
The workshops respond to the PATHWAY objective of building a group of practitioners of inquiry who shared leading practices and influence policy development, teachers with specific change management competences required to operate successfully as change agents in their schools facilitating the implementation of inquiry based methods.

As a whole the workshops initiated the process of the gradual development of the community of teacher leaders (first locally, and then gradually nationally and at the cross-European level). The ultimate goal was to empower the teachers by giving them the opportunity to work and exchange

together, by treating teachers as equal partners in decision making. In order to achieve maximum impact from our initial interaction and consultations with the teachers, teacher trainers, and the other stakeholders, PATHWAY proposes the following three-step workshop process:



These three sets of workshops feed into and from other work packages (WP) as follows:



Description of workshops:

Visionary workshops (first phase): In these workshops teachers' current teaching needs were explored and their specific grade level curricular objectives in order to introduce IBSE methods were adressed. Teachers and teacher trainers, school administrators, curriculum developers, policy makers were given an introduction to PATHWAY.

The first cycle of workshops was a series of Visionary Workshops organised locally in the participating countries during the first 6 months of the project. The Visionary Workshops provided direct input from the stakeholders.

Practice Reflection Workshops (second phase): These workshops further informed the processes for the design of the proposed approach with input from experience and knowledge gained through the large scale implementation at the local and national level.

Practice Reflection Workshops took place during the large scale implementation period, consisting mainly of training activities, which took place at local, national and international level. They were an opportunity to reflect on a national level on the results of the training on a national level, helping to build the PATHWAY IBSE model from the workshop outcomes.

Participants in these Workshops were selected among those involved in the training activities, but also included other stakeholders such as representatives of museums and science centers, teacher trainers, etc. In general we focused on the change actors that can influence the adoption of IBSE in the educational system.

Summative Workshops (third phase): These workshops were organized in the last phase of the project. After the completion of the last implementation cycle in the pilot sites, the last Practice Reflection Workshops took place, in the form of Summative Workshops in which the Communities of Practice recapitulated on the experiences and lessons obtained from implementation of the training activities.

During the Summative Workshops information was gathered to help the validation process of the PATHWAY IBSE model by summarizing discussions on the following themes:

- Essential Features of PATHWAY Enquiry Learning Approach: Building on the experiences of the previous workshops, these Workshops helped in the construction of the PATHWAY model for IBSE by comparing the proposed model with the views of the PATHWAY stakeholders.

- The Profile of the effective PATHWAY science teacher: We considered aligning the models for teaching and training with the needs and structure of the different educational systems of the different partner countries.

- Designing effective teacher training IBSE modules: The information gathered helped in the design of a PATHWAY module in IBSE. As before the training programme comprised essential modules adapted to the national specificities of the different partner countries.

c. Spreading IBSE among Europe and beyond

The implementation activities were organized in three main categories depending on their scale: local educational activities, national educational activities and international (large scale) educational activities (Figure 3).

LOCAL LEVEL IMPLEMENTATION ACTIVITIES:

a) demonstrations and training activities in schools

b) demonstrations and training activities in Teachers Training Centres. During the training workshops teachers had the opportunity to get familiarized with the proposed approach and exchange ideas and experiences with experts and teachers trainers.

c) inquiry workshops. The inquiry workshops were crafted to provide powerful and transformative experiences by immersing participants in the process of science inquiry.

These experiences introduced participants to the special character of science—that it is at once a body of knowledge and a dynamic questioning activity. A primary focus of the facilitator's work was to use hands-on investigation, reflection, and group discussion to foster an understanding of the essential features and structure of inquiry, which participants were asked to take back and share with colleagues in their schools and projects. These experiences served as a framework for designing strategies that can support the creation of classroom environments for students' inquiry.

NATIONAL LEVEL IMPLEMENTATION ACTIVITIES:

a) National Conferences and Workshops

b) National Contests for students and teachers that promoted the use of inquiry based approaches in the classroom (hands-on activities, laboratory experiments with everyday materials, collaborative projects, field trips to science museums and centres, virtual visits).

In order to ensure the large participation of teachers and students preliminary planning steps had been taken so that the structure of each of the National Workshops and Contests could be developed and fully formulated through vital collaborations with other interested organizations such as for example the National Physical or Chemical Societies, Ministries of Education and Science Centers & Museums.

Such networking and clustering activities were considered by the PATHWAY partnership as major factors of the viability and the effectiveness of the results of PATHWAY. Promoting the national implementation activities through dissemination channels of various educational organizations interested in raising the quality of educational performances at school could maximize the impact of the planned activities both on teachers and students.

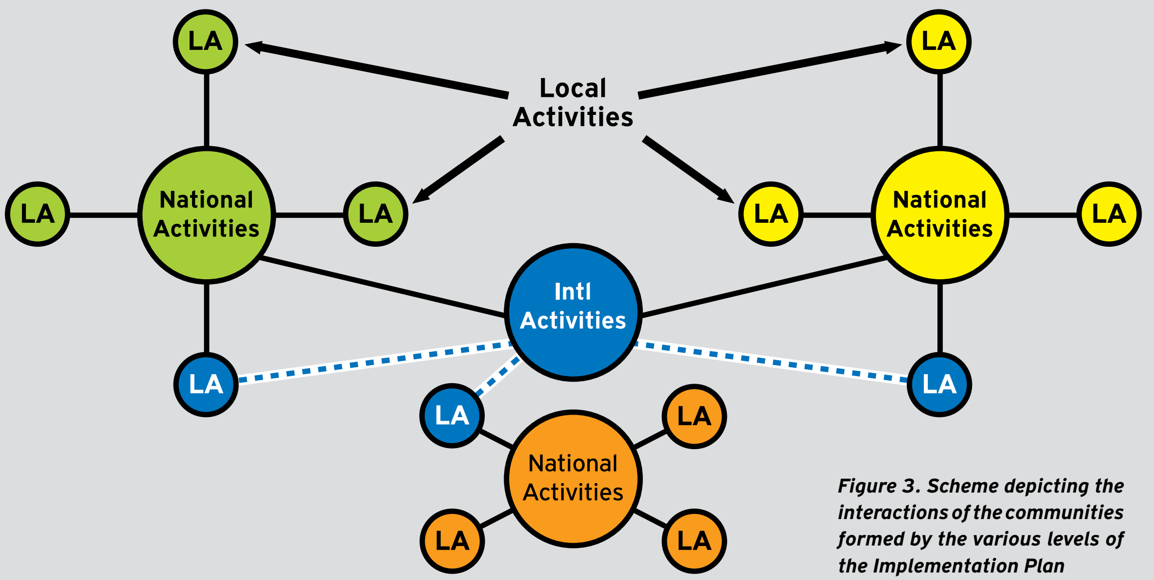


Figure 3. Scheme depicting the interactions of the communities formed by the various levels of the Implementation Plan

National Impementation Activities			
	Indicative Number of Schools	Training Avtivities (Indicative Number of Events) Estimated Number of Participants per event: 20-30	Indicative Number of Students and Teachers Contest
Germany	200	**40** Training Workshops and Seminars	3
Greece	200	**40** Training Workshops and Seminars	3
UK	100	**20** Training Workshops and Seminars	2
Ireland	100	**20** Training Workshops and Seminars	2
Spain	100	**20** Training Workshops and Seminars	2
Bulgaria	100	**20** Training Workshops and Seminars	2
Italy	100	**20** Training Workshops and Seminars	2
Switzerland	100	**20** Training Workshops and Seminars	2
Austria	200	**40** Training Workshops and Seminars	3
Finland	100	**20** Training Workshops and Seminars	2
Belgium	200	**30** Training Workshops and Seminars	4
Romania	100	**20** Training Workshops and Seminars	2
Russia	200	**20** Training Workshops and Seminars	3

Table 2. National Implementation Activities

INTERNATIONAL LEVEL IMPLEMENTATION ACTIVITIES:

The international level educational activities that were planned by the PATHWAY consortium to take place over the life of the project can be classified into five major types:

- **I.** International Conferences (annual and biannual)
- **II.** International Summer & Winter COMENIUS-GRUNDTVIG schools
- **III.** International CERN Teacher Programmes
- **IV.** International Hands-on Particle Physics Master Classes
- **V.** Pan-European Contests for Students and Teachers.

6. Recommendations for further practice

PATHWAY modelled an effective approach to science teaching with a two-part structure: Methods for Teaching Science by Inquiry and Activities for Teaching Science by Inquiry. The methods scaffold concepts and illustrate instructional models to help teachers understand the inquiry approach to teaching. Additionally the project presents a number of Activities for Teaching Science by Inquiry that follow the selected instructional models. Integrating an inquiry approach, science content, teaching methods, standards, and a bank of inquiry activities, PATHWAY aimed to demonstrate and disseminate these manageable ways for new and experienced teachers to bring inquiry into the science classroom. The European Science Education Academy, building on the unique outcomes of PATHWAY aimed to adopt this approach and to expand it to all European countries.

PATHWAY proposed to move towards a standard-based approach that brought coordination, consistency and coherence to the improvement of science education. Such a process allowed all stakeholders to move in the same direction, with the assurance that the risk they take in the name of improving science education is supported by policies and practices throughout the Member States educational systems. By building on the best of current practice, PATHWAY aimed to take us beyond the constraints of present structures of schooling toward a shared vision of excellence.

Change occurred locally, and differences in individuals, schools and communities produced different PATHWAYs of reform, different rates of progress and different emphases. Nevertheless, with the common vision of a standard-based approach, we expected deliberate movement over time, leading to reform that is pervasive and permanent. No group could implement such a process by itself. The challenge extended to everyone within the education system, including teachers, administrators, science teachers' educators, curriculum developers, assessment experts, local and national educational authorities and educational policy makers. It also extended to all those outside the system who had an influence on science education, including parents, scientists, engineers. All individuals have unique and complementary roles to play in improving the science education for the future of Europe. PATHWAY's impact was performed the first step on a journey of educational reform that might take many further years.

a. Toward a Standard-Based Approach to Teaching Science by Inquiry

Most discussions of teaching science by inquiry begin with the assumption that inquiry is a teaching strategy. Science teachers ask, «Should I use full or partial inquiries? Should the approach be guided by the teacher or left to the student?» The PATHWAY project was introducing a Standard-Based approach which views the situation differently. Such a perspective began with the educational outcomes—Set clear and high expectations for the performance of the students — and then identifies the best strategies to achieve these outcomes. Table 3 provides examples of the PATHWAY perspective. Reading from left to right, the table asks these questions: What content do I wish students to learn? Which teaching techniques provide the best opportunities to accomplish that? What assessment strategies are most aligned with the students' opportunities to learn, and provide the best evidence of the degree to which they have done so?

In developing the examples in this table, a clear understanding of the realities of standards, schools, science teachers, and students is needed. Science teachers must teach the basics of subjects. The science curriculum for physical, life, earth and space sciences provides teachers with a set of fundamental understandings to base their educational outcomes. After identifying these, teachers must consider the effective teaching strategies and recognize that we have a considerable research base for the concepts that students hold about basic science. We also have some comprehension of the processes and strategies required to bring about conceptual change (Bybee et al, 2008; Loucks-Horsley et al., 2003; Berkheimer & Anderson, 1989; Gazzetti, Snyder, Glass, & Gamas, 1993; King, 1994; Lott, 1983).

The teaching strategies include a series of laboratory experiences that help students to confront current concepts and reconstruct them so they align with basic scientific concepts and principles of the educational curricula. For teaching science by inquiry, a variety of educators have described methods compatible with such a standard-based approach to teaching science by inquiry (Novak, 1963; Bybee 2000). Learning science through an investigatory approach also helps students develop the competences necessary to do scientific inquiry.

The use of laboratory activities for the teaching of science will encourage the use by students of technology and mathematics to formulate and revise scientific explanations and models by use of logic and evidence, and to communicate and defend of scientific arguments. Another example is the use of the idea that reading authentic scientific texts is considered as inquiry by itself

Standards-Based Educational Outcomes. What should students learn?	**Teaching Strategies.** What are the techniques that will provide opportunities for students to learn?	**Assessment Strategies.** What assessments align with the educational outcomes and teaching strategies?
Understanding Subject Matter (e.g., Motions and Forces; Matter, Energy, and Organization in Living Systems; Energy in the Earth System)	Students engage in a series of guided or structured laboratory activities that include developing some abilities to do scientific inquiry but emphasize subject matter (e.g., laws of motion, F = ma, etc.).	Students are given measures that assess their understanding of subject matter. These may include performance assessment in the form of a laboratory investigation, open response questions, interviews, and traditional multiple choice.
Developing Competencies Necessary to Do Scientific Inquiry (e.g., students formulate and revise scientific explanations and models using logic and evidence)	Students engage in guided or structured laboratory activities and form an explanation based on data. They present and defend their explanations using (1) scientific knowledge and (2) logic and evidence. The teacher emphasises some inquiry abilities in the laboratory activities used for subject-matter outcomes.	Students perform a task in which they gather data and use that data as the basis for an explanation.
Developing Competencies Necessary to Do Scientific Inquiry (e.g., students have opportunities to develop all the fundamental abilities of the standard)	Students carry out a full inquiry that originates with their questions about the natural world and culminates with a scientific explanation based on evidence. The teacher assists, guides, and coaches students.	Students do an inquiry about a question of personal interest without direction or coaching. The assessment rubric includes the complete list of fundamental abilities.
Developing Understandings about Scientific Inquiry (e.g., scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide the rules of evidence; it must be open to question and possible modification; and it must be based on historical and current scientific knowledge)	The teacher could direct students to reflect on activities from several laboratory activities. Students also could read historical case studies of scientific inquiry (e.g., Darwin, Copernicus, Galileo, Lavoisier, Einstein). Discussion groups pursue questions about logic, evidence, skepticism, modification, and communication.	Students are given a brief account of a scientific discovery and asked to describe the place of logic, evidence, criticism, and modification.

Table 3: Examples of Teaching and Assessment that Support Inquiry-Oriented Outcomes

(Norris and Phillips, 2008], and especially those that are adapted to the students' cognitive abilities (Falk et al., 2008. As already mentioned, laboratories provide many opportunities to strengthen the competencies necessary to do scientific inquiry (Hofstein and Lunetta, 2004), as well as computer-based learning environments that simulate authentic scientific research (i.e., Gelbart, et al., 2008). Science teachers could indeed base the learning activities on content, such as motions and forces, energy in the Earth's system, or the molecular basis of heredity, but they could make several of the fundamental inquiry competencies the explicit outcomes of instruction. Over time, students would have ample opportunities to develop all of them. This approach to teaching science by inquiry overlaps and complements the science teachers efforts to promote an understanding of science concepts. The teacher structures the series of inquiry activities and provides varying levels of direct guidance. A further result also sharpens student's competencies for scientific inquiry, since students have opportunities to conduct a full inquiry, which they plan, design, complete, and report. In other words, they experience all of the fundamental abilities of a scientific inquiry appropriate to their stage of sophistication and current understanding of science. The science teacher's role is to guide and coach (Zion and Slezak, 2005). The classic examples of this range from the organization of a science fair or a science contest to guiding of a whole inquiry project performed by the students.

Finally, we come to the aspect of teaching science by inquiry that is most frequently overlooked, namely, developing understandings about scientific inquiry. On the face of it, this seems like an educational outcome that would be easy to accomplish once the science teacher has decided to instruct by means of an activity or laboratory and has gained an understanding of inquiry. Numerous ways are available of having students identify, compare, synthesize, and reflect on their various experiences founded in inquiry. Case studies from the history of science provide insights about the processes of scientific inquiry. Developing students' understanding of scientific inquiry is a long-term process. Questions of time, energy, reading difficulties, risks, expenses, and the burden of the subject should not be rationalizations for avoiding teaching science by inquiry. Nurturing the abilities of inquiry is consistent with other stated goals for science teaching, for example, critical thinking; and it complements other school subjects, among them problem solving in mathematics and design in technology. Understanding science as inquiry is a basic component of the history and nature of science itself.

b. Defining Best Practices in Teachers Preparation Programmes

There were two key points where we needed to focus our full attention to:

• Effective training on inquiry based methods: Albeit very effective, inquiry-based methods in science education constitute a major paradigm shift for teachers: they needed to acquire new skills, abandon long standing practices and move away from their professional —comfort zone, therefore exposing themselves to perceived, or real, risks.

• Assisting behavioural change: In addition to their training, in order for teachers to introduce inquiry based methods and activities into their everyday routine, they had to perform a change in behaviour and to adapt a new culture and philosophy.

There was no single correct way to plan and implement training and professional development that is intended to improve teaching and student learning. The planning and implementation of successful professional development efforts always occur within a particular setting that presents unique goals, strengths, resources and barriers. Effective planning and implementation of the training process require the blending of research, practitioner wisdom, passionate beliefs and a repertoire of strategies from which to choose with an emphasis always on the process of thoughtful, conscious decision-making. Seeking maximum efficiency in training teachers, these training programmes resorted to a blended learning delivery model. This was arguably the optimal model for professional development since it allowed for flexibility without sacrificing efficiency. According to Hofstein, Shore and Kipnis (2004), accomplished teachers who are involved in an inquiry based training programme should be able:

- To encourage students to interact professionally, including sharing knowledge with their peers, community members, or experts.
- To help students solve problems, ask high-level questions, and hypothesize regarding certain unsolved inquiry problems.
- To assess students continuously using a variety of alternative assessment methods.
- To customize the new activities according to their needs, and make decisions regarding the level of inquiry suitable for their students.
- To align the inquiry with the concepts taught or discussed in the classroom.

The Professional Development (PD) programmes that were implemented in the framework of the PATHWAY project provided an opportunity for teachers to familiarize themselves with the new inquiry ideas and also understand the implications for themselves as teachers and for their learners in the classroom before they adopt and adapt them. As the new approach differed greatly from their previous practice, this involved them reshaping their own beliefs regarding science teaching and learning.

Methods for Improving Teacher Effectiveness in Schools

To implement inquiry in the classroom effectively there were three crucial ingredients: (1) teachers must understand precisely what scientific inquiry is; (2) they must have sufficient understanding of the structure and content of science itself; and (3) they must become skilled in inquiry teaching techniques. Science teachers should know the differences between these three concepts. First was inquiry as a description of methods and processes that scientists use; next was inquiry as a set of cognitive abilities that students might develop; and last was inquiry as a constellation of teaching strategies that can facilitate learning about scientific inquiry, developing the abilities of inquiry, and understanding scientific concepts and principles. At the level of individual teachers this implied getting three things to happen:

- Individual teachers needed to become aware of specific weaknesses in their own practice. In most cases, this not only involves building an awareness of what they do but the mindset underlying it.
- Individual teachers needed to be motivated to make necessary improvements. In general this requires a deeper change in motivation that cannot be achieved through changing material incentives. Such changes come about when teachers have high expectations, a shared sense of purpose, and above all, a collective belief in their common ability to make a difference to the education of the children they serve.
- Individual teachers needed to gain understanding of specific best practices. In general, this can only be achieved through the demonstration of such practices in authentic settings.

c. Best Practices in Implementing Inquiry Based Science Education in Schools

The aim of PATHWAY was to offer to the teachers who were involved in the training activities a variety of resources that were arranged so that it did not impose a fixed curriculum, but instead supported the development of a model that can be customized to reflect location, culture and ideology. The PATHWAY Repository of Best Practices served as the window onto live scientific experiments and phenomena, on-going research, and the personalities and stories of working scientists across Europe. In the framework of the project these inquiry based science education activities were organized in three main categories:

- Educational activities based at school
- Educational activities that promote school – science center and museum collaboration
- Educational activities that promote school – research center collaboration

These materials have been used for many years in numerous schools in Europe and they have proven their efficiency and efficacy as teaching resources that support inquiry. In the framework of the PATHWAY project as well as in the framework of the proposed future actions we were proposing a series of value-added services to increase the utility of these resources through coordination, systematic dissemination and effective teachers' community building. The PATHWAY training resources were treated as case studies and were disseminated in different environments (teachers' preparation and professional development institutions, schools) across Europe during the life cycle of the project. The process of observing and reflecting on teachers' actions, and on students' learning and thinking, lead to changes in the knowledge, beliefs, attitudes, and ultimately the practice of teachers.

7. Conclusions

The PATHWAY project:

Due to the successful implementation, the consortium reached a diverse set of people, working in the educational sector, in Europe an beyond. Beside museums, research centers and higher educational institutions, PATHWAY reached schools, teachers, stakeholders and students with its standard based approach of teaching science in a new way.

Content:

PATHWAY had set several key goals:

- Distribution a standard based approach of Inquiry Based Science Education
- Creating guidelines for science teachers or similar in the educational sector
- Providing teachers all over Europe and beyond with Best Practice examples, for direct use in school, for museums and science centers, as well with examples of professional development programs.
- Enhancing students to learn by inquiry, mimicking the way of how scientists gain new knowledge through experiments and research.

Organization:

PATHWAY gained a lot new information first hand, mainly from teachers and educators in schools, museums and science centers that participated in our extended workshops on Inquiry Based Science Education. We like to thank everybody who gave feedback and first hand impressions, as well as expression needs and problematic circumstances they are confronted with. PATHWAY always took these reports into account and tried to solve problems and overcome fears and barriers connected to the new way of teaching science by Inquiry.

PATHWAY always focused on science subjects in school and museums and science centers. We would like to enhance the use of IBSE as a frequently used tool in science classes over and above the lifetime of the PATHWAY project itself. Therefore, we invite everybody to get informed about THE PATHWAY TO INQURIY BASED SCIENCE TEACHING, its guidelines and recommendations, that make teaching science by inquiry more easy, as they give a structured outline of how to create a meaningful Inquiry lesson; its rich collection of Best Practices, that give any science teacher the possibility to repeat them in class, or visit an science museum or science center where inquiry learning is a main key; its workshops and demonstrations, and invite everybody to start a chance in teaching science in their class and their school. Start on your own, or get together with teachers that already visited our workshops, who already started to teach science by inquiry, giving their students the possibility to use and follow their curiosity about science and phenomena in the world around them.

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