

## A Pathway to Inquiry-Based Teaching: Digital Knowledge Transfer from Natural History Museums to School Classrooms

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**Abstract**— The objective of the three-year European project (acronym: PATHWAY) with its 25 partner organizations is to set the pathway toward a standard-based approach to teaching science by inquiry. The project focuses on (i) supporting the adoption of inquiry teaching by demonstrating ways to reduce the constraints presented by teachers and school organizations, (ii) demonstrating and disseminating methods and exemplary cases of both effective introduction of inquiry to science classrooms and professional development programs, as well as (iii) delivering a guideline set for the educational community to further explore and exploit the unique benefits of the proposed approach in science teaching. In this way, the project team aims to facilitate the development of communities of practitioners of inquiry that will enable teachers to learn from each other. Out of about 50 selected Best Practice examples within the Pathway project, one specific approach labeled Natural Europe is linking museums and school classrooms, and thus harvesting the potential of digital libraries in natural history museums as a very attractive option. An impressive abundance of high quality digital contents still remains largely unexploited due to a number of barriers, such as: the lack of interconnection and interoperability, the lack of centralized access as well as the inefficiency of current content organization and the metadata used. First empirical evidence supports this pathway to bridge the gap between formal and informal education by specifically using the proposed digital bridge.

**Keywords**-*E-learning; inquiry-based learning; inquiry-based teaching; teaching practice; teacher education; professional development.; classroom teaching; informal learning.*

### I. INTRODUCTION: THE PATHWAY PROJECT DESIGN

Our study approach aims to contribute to a quality improvement of science teaching. Three main axes are supposed to facilitate the uptake of Inquiry-Based Science Education (IBSE): It a) proposes a standard-based approach to teaching science by inquiry that outlines instructional models that will help teachers to organize effectively their instruction, b) deploys a series of methods to motivate teachers to adopt inquiry based techniques and activities in their classrooms and c) offers 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. All stakeholders (teachers, teachers' trainers, curriculum developers, policy-makers) are supposed to examine their individual practices in the light of the best performing approaches that set the standards on what can be achieved and provide them with a unique tool to bring about improvements in their everyday practice [2]. A close collaboration with teachers may develop a set of support services which help teachers to implement the necessary changes, to develop the diagnostics and intervention skills necessary to best plan and then diffuse innovation in their own contexts. An effective training approach provides the starting point for equipping teachers with the competences they need to act successfully as change agents, developing a language/terminology necessary to describe the dynamics of change processes, and making them able to recognize different forms of resistance and addressing it in their own context.

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?" Introducing a Standard-Based approach views the situation differently and may overcome this dilemma: Such a perspective begins with the educational outcomes and then identifies the best strategies to achieve the outcome. In developing examples, 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 content for physical, chemical, life, earth and space sciences, provides teachers with an excellent set of fundamental understandings that could form their educational outcomes. After identifying the educational results, 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 [1, 4, 8, 11-14]. The teaching strategies include a series of laboratory experiences that may 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 (for instance, going back to [16]). By using individual

investigations when learning about new issues, first opportunities may arise for students to develop abilities necessary to do scientific inquiry.

For teaching science concepts, the use of technology may encourage to improve investigations and communications, the formulation and revision of scientific explanations and models by use of logic and evidence, and the communication and defense of a scientific argument. Another example is the use of the idea that reading authentic scientific texts is considered as inquiry by itself [15, 18-20], and especially those that are adapted to the students' cognitive abilities [6]. A second educational outcome, closely aligned with learning subjects, is developing competencies necessary to do scientific inquiry. Laboratories provide many opportunities to strengthen them as well as computer-based learning environments that simulate authentic scientific research (e.g., [9]). Science teachers could indeed base the activity 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 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 teacher's effort to cultivate 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 competencies necessary for scientific inquiry; but now students have opportunities to conduct a full inquiry, which they think of, design, complete, and report. They experience all of the fundamental abilities in a scientific inquiry appropriate to their stage of sophistication and current understanding of science. The science teacher's role is to guide and coach [24]. 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 [1, 2]. 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.

## II. OBJECTIVES: ESSENTIAL FEATURES OF INQUIRY

To begin shifting toward a more inquiry-oriented classroom, we highlight five essential features: (i) Learners engage in scientifically oriented questions. (ii) Learners give priority to evidence in responding to inquiry questions. (iii) Learners formulate explanations from evidence. (iv) Learners connect explanations to scientific knowledge. (v) Learners communicate and justify explanations.

### *(i) Learners Engage in Scientifically Oriented Questions*

Scientifically oriented questions centre on objects in the natural world; they connect to the science concepts described in the school curriculum. They are questions that lend themselves to gathering and using data to develop individual explanations for scientific phenomena. Scientists recognize two primary kinds of scientific questions. Existence questions probe origins and include many "why" questions: Why do objects fall toward Earth? Why do humans have chambered hearts? Although many "why"-questions cannot be addressed by science, there are causal and functional questions, which probe mechanisms and include most of the "how"-questions: How does sunlight help plants grow? Students often ask "why"-questions. In the context of school science, many of these questions can be changed into "how" questions and thus lend themselves to scientific inquiry. Such change narrows and sharpens the inquiry and contributes to being scientific. In the classroom, a question robust and fruitful enough to drive an inquiry generates a need to stimulating additional questions of how and why a phenomenon occurs. The initial question may originate from the learner. The teacher plays a critical role in guiding the identification of questions. Fruitful inquiries evolve from questions that are meaningful and relevant to students, but they also must be answerable by student observations and the scientific know-ledge they obtain from reliable sources. The knowledge and procedures students use to answer the questions must be accessible and manageable, as well as appropriate to the students' developmental level.

### *(ii) Learners Give Priority to Evidence in Responding to Inquiry Questions*

Science distinguishes itself from other ways of knowing through the use of empirical evidence as the basis for explanations about how the natural world works. Scientists concentrate on getting accurate data from observations of phenomena. They use their senses and instruments, such as microscopes, to enhance their senses; and instruments that measure characteristics that humans cannot sense, such as magnetic fields. In some instances, scientists can control conditions to obtain their evidence; in other instances, they cannot control the conditions since control would distort the phenomena, so they gather data over a wide range of naturally occur-ring conditions and over a long enough period of time so that they can infer what the influence of different factors might be. The accuracy of the evidence gathered is verified by checking measurements, repeating the observations, or gathering different kinds of data related to

the same phenomena. The evidence is subject to questioning and further investigation. In their classroom inquiries, students use evidence to develop explanations for scientific phenomena. They observe plants and animals, or individually measurements of temperature, distance, and carefully record them.

*(iii) Learners Formulate Explanations from Evidence*

Although similar to the previous feature, this aspect of inquiry emphasizes the path from evidence to explanation, rather than the criteria for and characteristics of the evidence. Scientific explanations are based on reason. They provide causes for effects and establish relationships based on evidence and logical argument. They must be consistent with experimental and observational evidence about nature. They respect rules of evidence, are open to criticism, and require the use of various cognitive processes generally associated with science—for example, classification, analysis, inference, and prediction—and general processes such as critical reasoning and logic. So explanations go beyond current knowledge and propose new understanding. For science, this means building on the existing knowledge base. For students, this means building new ideas on their individual current understandings. In both cases, the proposed result is new knowledge. For example, students may use observational and other evidence to propose an explanation for the phases of the moon, for why plants die under certain conditions and thrive in others, and for the relationship of diet to health.

*(iv) Learners Connect Explanations to Scientific Knowledge*

Evaluation, and possible elimination or revision of explanations, is one feature that distinguishes scientific inquiry from other forms of inquiry and subsequent explanations. One can ask questions such as: "Does the evidence support the proposed explanation?", "Does the explanation adequately answer the questions?", "Are there any apparent biases or flaws in the reasoning connecting evidence and explanation?", and "Can other reasonable explanations be derived from the evidence?" Alternative explanations may be reviewed as students engage in dialogues, compare results, or check their results with those proposed by the teacher or instructional materials. An essential component of this characteristic is ensuring that students make the connection between their results and scientific knowledge appropriate in their level of development [21, 22]. That is, student explanations should ultimately be consistent with currently accepted scientific knowledge.

*(v) Learners Communicate and Justify Explanations*

Scientists communicate their explanations in such a way that their results can be reproduced. This requires clear articulation of the question, procedures, evidence, and proposed explanation and a review of alternative explanations. It supports a further skeptical review and the opportunity for other scientists to use the explanation to go on to new questions. Having students share their explanations provides others the opportunity to ask

questions, examine evidence, identify faulty reasoning, point out statements that go beyond the evidence, and suggest alternative explanations. Sharing explanations can bring into question or fortify the connections students have made among the evidence, existing scientific knowledge, and their proposed explanations. As a result, students can resolve contradictions and solidify an empirically based argument.

### III. RATIONALE & RESULTS: NATURAL EUROPE AS A SELECTED BEST PRACTICE

Numerous Best Practices gather under the Inquiry-Based umbrella, originating from school settings or from collaboration initiatives or from connecting the gap between formal and informal settings [3]. The latter is presented example in more detail. Hereby, engagements of hands-on physical activities with virtual educational ones are combined to support a student's understanding. Main activities concentrate on designing stimulating lesson plans following an existing syllabus and adapting as many individual needs as possible. Those lesson plans are based on a museum visit (physically or virtually) and they are supposed to engage students' hands-on activities leading to realistic experiences directly connected to a classroom-taught lesson.

For a selection of appropriate Best Practices (BP), a template is needed to allocate "success stories". Thus, ten principles are labeled: (1.) BP should aim systematically to develop and sustain learners' curiosity about the world, enjoyment of scientific activity and understanding of how natural phenomena can be explained. (2.) BP 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.) BP must have multiple goals aiming to develop: (i) understanding of a set of big ideas in science which include ideas of science and ideas about science, (ii) scientific capabilities concerned with gathering and using evidence, (iii) scientific attitudes. (4.) The implementation of the BP 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 BP should result from study of topics of interest to students and relevance in their lives. (6.) BP should reflect a view of scientific knowledge and scientific inquiry that is explicit and in line with current scientific and educational thinking. (7.) BP should deepen the individual understanding of scientific ideas as well as contributing to others, such as fostering attitudes and capabilities. (8.) 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 needs to provide an integral part of the BP. The formative assessment of students' learning and the summative assessment of their progress must apply to all goals. (10.) Finally, BP may promote cooperation among teachers and engagement within a community which even may include the involvement of

scientists which otherwise would be out of reach for the group such as school students.

The proposed aims are threefold: Firstly, it's the increase of student involvement into the educational process as their role is regarded as most significant. Teachers just act as facilitators while students see their activities follow their individual educational needs. Secondly, it's the connection of formal and informal learning in real-world and digital environments; this approach allows students to enjoy an educational experience tailored to individual needs, preferences and expectations, again under the guidance of the teacher. Thirdly, it's providing fascinating opportunities for interaction with natural history (for both, physically and digitally). Since museums exhibits just because of its originality, authenticity grabs a student's interest and curiosity, the door to a self-sufficient learning more easily opens up [5]. Digital and physical museum objects, thus, enhance interests towards natural science [7, 8].

First empirical data interestingly point to a cautious optimism: Although the numbers of up to now involved participants just allow first conclusions merely on a case study level, however, 27 participants significantly learned by following the above described procedures (while 11 control participants did not). These first empirical numbers just begin to support our expectations compared to the already existing solutions but cannot yet substantiate a final prove. After completing our data collection (which is expected with both projects' ending after 2013 and which surely will easily outnumber case study levels), deeper conclusions will be drawn from an expectedly much broader data basis of so many partner institutions contributing.

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