Framework on Geosciences Literacy Principles

Introduction

This guide is the proposal of the GEOschools project for a common framework for Geosciences Literacy at a European level. It is intended to help develop the scientific literacy of European secondary education students.

The booklet is based on a Comparitive Analysis of geoscience curricula in the partner countries (Austria, Greece, Italy, Spain and Portugal), the results of an "Interest Research" survey involving around 1,750 students and 60 teachers in these countries, combined with specific proposals by the project partners. A supporting bibliography is also included.

The GEOschools Literacy framework is summarized in 14 separate chapters, each including a brief description of the main themes of the subject, the intended learning outcomes as well as keywords and a bibliography.

WHY we should teach geosciences in compulsory (primary and lower secondary school) and higher secondary school education

Remarkably, even today, a debate continues on the necessity for geoscience teaching and some curriculum developers still appear uncertain as to whether they should include geosciences within compulsory and higher secondary school education. But even though this is an old question, the answer remains so clear: as global citizens, students need to understand and appreciate the materials and processes that make up their home planet, the Earth, and the way it can affect their lives.

It is also clear, that a good knowledge of geosciences is often lacking by a broader society and there is a gap in understanding between geologists and the public. This is one more reason for developing geosciences within national school curricula.

Geosciences link the biotic (i.e. living) and the abiotic (i.e. non-living) environment and are the key science to understanding the history of the Earth and the evolution of life on it. Evidence for continental drift, the evolution of life, climatic and sea-level changes, as well as volcanism, earthquakes, mountain building, erosion and other landscape changes and processes are recorded in the rocks, minerals, fossils and other geological materials all around us.

Students, as future citizens, need to be taught the basic geoscientific knowledge that they need for their everyday lives. They live on and use the Earth's resources; they witness the Earth's dynamic processes and they need to understand about natural hazards and how to protect themselves and their families.

Studying geosciences can also expand a student's interest in the natural phenomena all around them and provides them with opportunities to seek explanations. It engages them at many levels, linking direct practical experience with scientific ideas. They will also understand how the geosciences contribute to the search for the natural resources which are crucial to industry, commerce and improving the quality of human life. Through this process, they will also develop high level observational and interpretative skills, learning to question and discuss the issues that may affect their own lives, society and the future of our planet.

According to many educational researchers, geoscience teaching can develop a wide range of skills, underpinned by some key concepts and processes. These include understanding the Earth as a complex system through the spatial reasoning, direct field observations, analysis of datasets and the historical perspective that make the geosciences a distinctive and empowering curriculum subject:

Geoscientific thinking (retrospective reasoning and the historical approach)

Studying geology requires retrospective reasoning and a historical approach to interpret geological events. Frodeman (1995) observed that the distinctive features of geological reasoning as an interpretive and historical science are that it ...*offers the best model of reasoning for confronting the type of problems we are likely to face in the twenty-first century* and listed examples such as global warming, resource assessments and risk assessments.

In addition, Baker (1996), in attempting to summarise geoscience methodologies, wrote that: *The science of geology has long concerned itself with the real-world natural experience of the planet we inhabit. Its methodology more directly accords with the commonsense reasoning familiar to all human beings. Because its study focuses on the concrete particulars of nature rather than on abstract generalisations, its results are also more attuned to the perceptions that compel people to take action, and to the needs of decision makers who must implement this action*.

A fundamental aspect of the study of Geology is the Geological Record, a body of knowledge often perceived to be separate from the "natural" or biological components of the biosphere. Nevertheless, although approaches to environmental problems and processes may assume that the same basic factors operated in past and present day environments, the methodological process in Geology for the reconstruction of past environments can function differently. Geology may use some uniformitarian principles as a tool for geological interpretation of the past and to reconstruct the History of Earth, the methodological approach of Geology is based on the observation, the empirical testing and the logical interpretation of the Geological Record, including the rocks and fossils (Meléndez *et al.,* 2006; Meléndez *et al.,*2007).

In this context, the classic geological principle that the *"present as a key to the past",* is not always the case, and sometimes the situation is effectively the opposite. Many biological and environmental problems, as well as predictions on the future of climatic change, glaciations, geological risks and catastrophic events – including their consequences for life such as extinctions, ecosystem change and species renewal – can be better understood with a clear knowledge of past processes and events as can be interpreted from the geological record. This apparently opposite approach to Earth processes and their consequences for human populations establishes Geology as a fundamental scientific discipline with an enormous potential to help society face and solve environmental problems, literally *"the past as a key to the present"* (Meléndez *et al.,* 2006; Meléndez *et al.,*2007).

A holistic approach to the Earth system

Geosciences, more than any other branch of science, are concerned with developing a holistic perspective on our planet, including dealing with interactions between land, water, the biosphere and the atmosphere. This perspective means that geoscientists can readily support many interdisciplinary studies and procedures. The complex Earth system is dominated by feedback between these among component parts and the processes that characterise each of them. The interpretation of both positive and negative feedbacks are important for understanding this Earth system (Kastens *et al*., 2009).

Spatial thinking

Spatial thinking in geosciences requires a number of skills such as recognition, description, classification, locational and communicational, followed by mental manipulation and interpretation of what has been observed in order to deduce the properties, processes and prospects of an area (Kastens and Ishikawa, 2006).

Geology is arguably the most visual of the sciences, with visualization taking place at a variety of scales, ranging from the rock outcrop to the regional and back down to the microscopic. Many geologists have the ability to mentally transport themselves rapidly from one scale to another, using observations at one scale to constrain a problem that arose at another scale – and then back again. For instance, observations from the rock outcrop can be used to construct a regional geologic framework, which in turn feeds back and guides what additional features should be looked for at the outcrop (Frodeman, 1996).

The understanding of geological time including of large-scale geological events in time and space

The concept of "deep time", as originally developed by the great Scottish pioneer James Hutton in 18th Century, has fundamentally altered the perception of our place within Earth history. The concept of geological time introduces two key features into geological thinking:

a) The concept of very long periods of time between low-frequency but high-impact events and

b) the potential for such events in the future – as evidenced by their occurrence in the past - which are not possible to prevent or change, but only to prepare for – and hence reduce their impact (if negative) to the natural environment and our society (Kastens *et al.,* 2009).

Geoscientific fieldwork

In order to acquire a good understanding of geology, students need to explore geology *in situ*, acquiring a first-hand experience in the field. Geology is by definition a science which uses an empirical approach to help understand and interpret complex phenomena, which can be remote in time and space. Even for relatively simple geological concepts, it is most effective to demonstrate them within the school grounds, or close to the school, instead of attempting to describe them with words, drawings, models, etc. in a classroom (Meléndez *et al.,* 2006; Meléndez *et al.,* 2007).

Field work is fundamental for the geosciences. It expands students' curiosity about geological phenomena and processes and offers them opportunities to question and discuss after observation, testing and reasoning. Field based learning offers students an opportunity to see the world differently and develop, little by little, a more informed view of their "geoenvironment". Teachers and students collaborate closely and though appropriate guidance (such as mentoring) students (through *observe-test-reasoning*) develop an informed vision and understand of the Earth's complexity.

WHAT European citizens should know (i.e. knowledge) and do (i.e. dexterities/skills) and how they should relate (i.e. behavior/attitudes) to the geosciences

(- At the end of the Primary school
- At the end of Lower secondary school (= i.e. as European citizen)
- At the end of Higher secondary school)

One of the main aims of the GEOschools project is to investigate the interest that secondary school students have in the geosciences content of their courses and the teaching strategies used. In particular, the results of the GEOschools "Interest research" survey have shown that students show a higher interest in those topics which have a potentially higher social impact or profile, such as mass extinctions, dinosaurs, geological hazards and disasters and the origins and evolution of life (including of humans). These results provide an evidence base to justify why curriculum content and teaching strategies can be made more effective through developing such "interest topics", instead of trying to follow an excessively rigid or academic, development of teaching programs.

The challenge that the geosciences face, as a scientific discipline, is how to combine a well-structured and conceptual teaching programme, whilst maintaining links with attractive and interesting topics, i.e. making Geosciences something relevant to daily life (or, in other words, deconstruct the most spectacular and interesting topics, to extract the basic scientific concepts that lie behind). Fundamentally, this is about how to build effective and enjoyable learning thorough good, academic teaching practice, with students able develop a unique set of skills, combining geological knowledge with spatial and visualisation skills.

The 14 chapters of this guide describe what students should know and do, and how they should relate, as European citizens, to the geosciences. To face the challenges of the present and the future, modern citizens should be literate in natural sciences and in the context of the geosciences, be able to:

- Demonstrate a knowledge and understanding of the basic principles, models, laws and terminology of the Geosciences.
- Know how and where to find and access scientifically credible information about the Earth at a national and international level.
- Recognise their responsibilities concerning geodiversity and Earth resources as local, national and international citizens.
- Understand planet Earth as a system.
- Appreciate geodiversity and geoheritage as a key theme within local sustainable development programmes.

- Know how to predict and mitigate the impacts of natural hazards and evaluate the most appropriate measures for changing circumstances.
- Demonstrate an ability to apply geoscientific knowledge in the real world and take appropriate decisions.
- Describe and explain basic geoscientific phenomena and procedures in familiar and unfamiliar contexts.
- Interpret, evaluate and synthesize geoscientific data from a range of sources and in a range of contexts.

HOW to teach geosciences

The challenge and the question that arises next is: How can educators, capitalize on the existing interest of school pupils in the geosciences in order to make geoscience teaching more effective, comprehensive and attractive? And as part of this question, a consideration of the teaching strategies which can transform geoscience knowledge and thinking into school knowledge, whilst demonstrating the links with biotic features of the environment as well as relationships with society and everyday life.

The GEOschools "Interest research" study has also shown that teaching strategies are very important for generating a high level of interest between students and teachers, as these were one of the three most selected topics within the research. In particular, students chose "Experiments", "Simulations" and "Fieldwork" as the most interesting teaching strategies amongst the 17 listed.

The Geosciences' laboratory is the Earth and the field is the place where students should ideally be taught, but with support from active learning in the classroom (including through problem-solving and project activities). Through such teaching strategies, school students can learn how knowledge and understanding in the geosciences are rooted in evidence.

Taking into consideration student preferences, experimentation and simulations could be used in geoscience teaching in order to develop and evaluate explanations and encourage critical and creative thought. Visualizations (static, animated or interactive) are appropriated for teaching about large scale events through time and across geographical space. 3D geological models are especially useful and can provide an aid enabling students to observe, manipulate and interpret geological features and processes. Such models offer students an opportunity to instantly switch from two dimensional to three (or even four, including time) geological views. This multidimensional perspective can be very difficult to demonstrate through more traditional teaching methods, even through field work. Nevertheless, the best and most appropriate way to teach geosciences is the study of a geological feature in situ. Such study can help develop an understanding and awareness of more complex geological processes, even on a global scale.

Educational geotopes are appropriate tools for field work. As geological sites identified for their educational value, and set in both rural and urban environments, then can play an key role in geoscience teaching, often showing the link between ecology and geology, as well as with human activities and generally increasing an awareness for geoconservation (Fermeli and Meléndez, 2011).

Educational geotopes can cover a variety of geological themes and process and in order to succeed in their educational aims, they need to be supported by:

a) Appropriately trained educational specialists, able to engage in developing local environmental education projects, and

b) educationally robust and flexible modules that can be used effectively in a wide variety of settings (Fermeli and Meléndez, 2011).

The future of geosciences in Europe and the world

In recent years, interest in geoscience education has increased, as evidenced by the greater number of sessions dedicated to this theme in educational initiatives and congresses worldwide, as well as in educational and geoscience journals and conference proceedings. At the same time, national and international bodies have developed discussions about learning and teaching and the assessment of practice in the Geosciences at the K-12 stage. Despite this increase in interest, however, much still needs to be done to improve the effectiveness of geoscience education for the future.

Today, a wealth of geoscience knowledge is available, for instance through the internet, and it is crucial for geoscientists to help make this information accessible and understandable, including "investing" in education to provide the next generation of geoscientists that society needs. It is necessary, therefore, to start teaching geosciences in schools and increase the interest of school pupils in the key geoscience concepts, theories and skills that effective global citizens should possess.

In the past, however (and in some countries this continues), geology has often had a minor role in school curricula, which has created serious concerns amongst the geological community. In particular, a substantial reduction in geological content of secondary school curricula can lead to a drop in the number of geology students in universities and hence a lack of geologists in society where they are increasingly needed (Meléndez *et al.,* 2006; Meléndez *et al.,* 2007).

Whilst working within schools is crucial, it is first necessary to convince educational policy makers and communicate effectively with the general public in order to reverse any such trend. In this context, it is important for geoscientists to look outward and avoid becoming isolated from Society and regionalised rather than internationalised. However, inadequate geoscience content in school curricula continues to make an understanding between geologists and the public if not impossible, still very difficult - and hence Society pays a cost through inappropriate decision making concerning geological matters.

Geosciences are playing an increasingly important role in the understanding of the Earth and are becoming more and more multidisciplinary and oriented towards solving the great challenges facing modern society. In this context, we should consider the Earth as a system in which geoscience research and teaching needs to be prepared to deal with much greater complexity, hence linking and integrating with the other natural sciences: physics, chemistry, and biology. Such an approach could be a valuable tool for creating a greater social and political interest in and concern for the geosciences, as well raising the interest and enthusiasm of secondary school teachers and students about the Earth.

Education is the key for a sustainable future and it is well known that the future lies in the hands of children and the future of geosciences lies in their hands too.

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