Earth System Science for undergraduate Geology and Geography courses, Campinas, Brazil

Celso Dal Ré Carneiro
Dept. Geosciences Applied to Teaching, Institute of Geosciences, University of Campinas (Unicamp), cedrec@ige.unicamp.br
Pedro W. Gonçalves
Dept. of Geosciences Applied to Teaching, Institute of Geosciences, University of Campinas (Unicamp), pedrog@ige.unicamp.br

Abstract *A discipline as Earth System Science (ESS) is expected to give a deeper understanding of Earth as an integrated system and the function played by each of its different subsystems. A deeper and integrated view of the Geosciences branches should be developed instead of aproaching them as isolated disciplines. A proposal has been performed during the last 12 years with undergraduate geology and geography students at the University of Campinas, São Paulo, Brazil, adopting an understanding of field and laboratory activities as essential for Earth System Science teaching. Students are invited to explore each one of the terrestrial spheres, focunsing on interactions between them; they should also recover some relationships between nature and human society. This approach helps future geologists and geographers to construct a more informed social perspective and, at the same time, to enable a future geography teacher to better face his/her challenges, because they can accommodate the knowledge on ESS to their personal experiences and interests. Among the core concepts of the discipline is an understanding of links between science, technology, society, and environment, and the historical and epistemological aspects of modern studies on the dynamics of Planet Earth.*

Keywords *Education, Geology, Earth System Science, college level, sustainability*

Introduction

Teaching of geography and geology has been endeavored, during the past several decades, to keep pace with a fast increase in knowledge on the interrelated terrestrial systems, the diversity and complexity of Earth System processes (Rankey and Ruzek 2006). It is difficult to accommodate the advances, because they are both technological and conceptual. First, new knowledge is derived from faster data collection, and better quality of interpretation of images and other data obtained at many scales, ranging from the subatomic up to regional and megascopic scales; it includes images continuously acquired by terrestrial, airborne and satellite-hosted remote sensors. Second, a broad and diversified framework of information on the planet is to be integrated as new concepts, ideas and theories are developed; they allow a much better understanding of planetary natural processes to be achieved and a better picture on the past, the present, and future of Earth to be constructed (Drummond and Markin 2008). From this scenario, Earth System Science education emerges as a fundamental method and vehicle for fostering critical analysis and understanding of the Earth (Rankey and Ruzek 2006).

Each year we introduce geological knowledge to up to 70-80 new students who are enrolled in an academic program to prepare geologists, geographers and teachers of geography. The courses we are involved on – along a time interval of two successive semesters (thus the complement I and II after the name of the discipline) – are called Earth

System Science (ESS). They represent a formal introduction to the geological and geoscientific knowledge for the students.

The objective of this paper is to discuss how Earth System Science can be both a general direction and a framework to geology and geography undergraduate courses. We expose also a few methodological, historical and philosophical guidelines for development of similar or equivalent disciplines.

Earth System Science

The goal of Earth System Science (ESS) is to get a scientific understanding of the entire Earth System on a global scale by describing how its component parts have evolved, how they function, how their interactions have evolved and how they may be expected to continue to evolve in all time scales (Clark 2006).

Drummond and Markin (2008) point out that among 278 academic departments offering the Bachelor of Science in Geology degree in the United States of America only 5,2% include course titles as *Earth System Science* or *Global Cycles*. Up to 95.8% of them keep *Introductory* or *Physical Geology* between the required disciplines. We do not have any specific survey for Brazil, but we think that the situation – for a number of academic departments 10 times less – may be quite similar. A focus on core geological concepts and the geological history of Earth can benefit any approach on Earth System Science. On the other hand, this implies that a change of focus of the science establishment is required from its "concentration on the physical science and their methods, to an accommodation with the system sciences and their methodologies" (Mayer 2002).

The Earth System Sciences Committee (ESSC) have identified three reasons for adopting an Earth Systems Science (ESS) approach to science teaching (Lee 2003): Science for practical benefits, global change, and the Earth as a planet (ESSC 1988).

The importance of science education in schools has also been challenged by rapid changes in contemporary politics. Mayer and Fortner (2002) and Mayer (2002) showed that the philosophy of Global Science Literacy, if followed in the development of science curricula, can be consistent with the "changing nature of publicly supported science and consequently help to prepare citizens to influence and construct a peaceful and sustainable future". Thus, in geography and geology college courses, as well as in many other professional careers, many possibilities are opened for introductory disciplines to include topics on Earth System Science. They never have been so strong and useful.

Earth Sciences at Unicamp

Since 1998, the State University of Campinas (Unicamp), São Paulo State, Brazil, offers courses to support the development of professional careers in geography and geology, through the Earth Sciences Undergraduate Program at the Geosciences Institute. For Geology, it was the first undergraduate course created in Brazil after a long period of time (1976-1998). The objective is to help students to connect and integrate studies on systems and processes of the natural world to activities of human societies.

It seems relevant to explain reasons for building the course content and structure, as well as some educational reasons for this approach. Certain educational hypotheses for course content allow to discuss how these disciplines, along with the sequence of Earth System Science I and II, can influence Earth Science students to be capable to understand Earth as an interactive system (King 1990). Finally we pay attention to a few methodological issues, such as philosophy and history of geology, and on environmental analysis as well.

An Approach on the Earth Spheres

Students at Unicamp begin their formal education through a set of disciplines that belong to a nucleus which have common principles of knowledge; after concluding the first two semesters (common nucleus) they are able to choose a career path. The common nucleus provide a global and integrated view of the interaction of Earth systems. Earth System Science I and II disciplines integrate the basic principles of an Earth Science course (Carneiro et al. 2000, 2005), having the main objective of articulating contents of geology and geography disciplines to better enable students to understand the way the planet operates. The discipline must approach the nature of the knowledge and methods of inquiry of both geology and geography sciences, searching to make an appraisal on interactions among humans and terrestrial environments.

Geology is “at its heart an interdisciplinary and integrative science” (Drummond and Markin 2008); thus, one can argue whether is this possible in an introductory discipline at the college level. The Earth System Science approach on Earth spheres has been satisfactory because it establishes multiple relationships (Gonçalves and Carneiro 2002) about geosphere, hydrosphere (which includes the solid cryosphere), atmosphere, biosphere and anthroposphere. Fostering to reach such an integrative view, practical activities have been developed on introductory geoscience problems. They can pose general interdisciplinary aspects of geological studies, as for the case of the continental movements of Australia (Fig. 1) due to plate tectonics during Phanerozoic (Gonçalves and Carneiro 2008). The data were obtained from comprehensive paleogeographical reconstructions (White 1998).

More recently, Unicamp has responded to the legal requirements of adapting the Geography course for education of teachers. Classroom hours were reduced as to make room to acommodate new disciplines, but still providing suitable time for practical training on teaching issues.

The Brazilian university educational system: background and context

The Brazilian educational system is compulsory and universal for all children, during a 12 year-time interval, from K-6 to K-17; the Brazilian Educational Act provides guidelines for all educational activities and systems throughout the country (Brazil 1996). Basic Education is divided into two levels: fundamental and secondary (called medium-level). The objective of these levels is to prepare Brazilian youngsters to work and to citizenship. A minor part of the students go higher ahead to a college level.

The fundamental level of teaching (from 6 to 14 years old) is directed at developing multiple skills and gaining knowledge about many topics to be better-informed citizens. The curriculum includes the following languages (Portuguese, Spanish, and English), history and geography (Brazil, South America and global), mathematics, natural and experimental sciences (biological and physical sciences; technology, and work). In addition, the educational objectives are directed at preparing young persons to meet and understand social, cultural, and economical challenges, from an

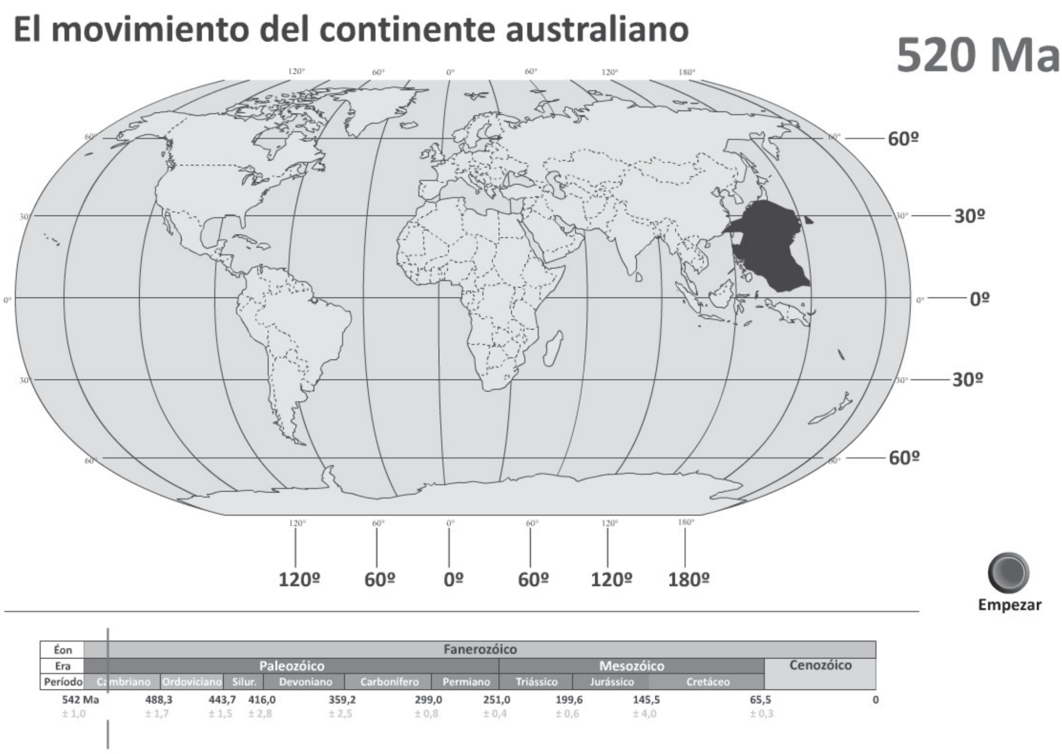

Figure 1 – Initial map from a flash animation on Phanerozoic continental movements of Australia (after Gonçalves and Carneiro 2008)

interdisciplinary perspective by addressing themes such as the following: environment, ethics, cultural plurality, health, gender questions, work, and consumption (Brazil 1998).

The secondary level (from 15 to 17 years) is divided into fields that guarantee an interdisciplinary approach and allow education of different disciplines. These topics include: languages, norms, and related technologies; natural sciences, mathematics and related technologies; human sciences and related technologies. This final level should prepare young people for a complete democratic citizenship and for work (Brazil 1999). When these secondary level students enroll in a university undergraduate course, such as Earth System Science, their abilities and specific knowledge often must undergo a complete revision. This suggests that the fundamental and secondary educational system do not meet all the objectives of the Brazilian Educational Act.

The students we teach are quite different from many points-of-view: different knowledge areas and diversified scientific training. They also have a variety of professional career objectives; they expect to get a more or less traditional "scientific" training in natural and experimental sciences. They study the basic sciences at an introductory level as well as taking geology, geography, biology, etc. A few of them will become researchers or other science professionals. Many will be geography teachers at the fundamental and secondary teaching levels (K-11 to K-17 years-old), probably with no interest in natural processes or professional motivation. These last students lead us to ask about what is fundamental in the education of a citizen, how can it be done, and what are the skills and topics that should be at the basic education level?

Holistic view of Earth Science

The results of a continuing teaching-learning research project at the undergraduate level allow us to identify key elements to explore the relationship between humans and the environment.

The primary method of teaching is based on active learning. We adopt the starting point that an investment of time on this direction can give best results when compared to a traditional lecture-based course. Many activities are preceded by a short introductory lecture and, in some cases, by a post-classroom activity, as to get a deeper involvement of a student with the subject (Kortz et al. 2008). We recognize, in agreement with the conclusions by Petcovic and Ruhf (2008), that more effort on class activities and group discussions, followed by selected readings, effectively help students to develop scientifically correct conceptions.

This invaluable body of knowledge goes beyond the mere objective of making a fully informed citizen. The challenge is to prepare better geologists and geography teachers in order to develop rich professional careers and to contribute to teaching at the basic level about the Earth Sciences, as well. The main aspects we consider for developing the Earth System Science teaching-learning approaches are driven by the following premises and objectives:

1) To enhance the unique characteristics of Geography and Geology careers for considering the relationships of Science, Technology, Society and Environment.
2) To integrate geological knowledge for teaching.
3) To understand science as research.
4) To understand teaching as research.
5) To emphasize environmental problems when doing Earth Sciences teaching.
6) To emphasize the contribution of geology and geography to understand the central role played by humans in the natural world.

An approach based on a holistic view of Earth Science

There is an extensive bibliography on science education and Earth Science teaching supporting approaches to Geoscience teaching upon the relationship of Science, Technology, Society and Environment. Many authors consider the relationship between history and philosophy of science and the teaching of science (Bezzi 1999, Matthews 1997, Hurd 1998, Solbes and Vilches 1997, Cuello Gijón 1988 etc.). Mayer (2002) has demonstrated many differences between Global Science Literacy (GSL) and the standard science curriculum "as it exists in most parts of the world today". According to Mayer (2002) GSL is essentially different from the Science/Technology/Society (STS) approach, althought there are some resemblances, as the learning environments and the environmental content that is included in the two approaches. GSL looks to the future challenges of science and science curriculum "in an era of social unrest and environmental change", as to focus on "the uses of technology for expanding our knowledge of the Earth system we all share" (Mayer 2002, p. 15).

Selected classic contributions are used to place the central themes of Earth System Science. The period span of the publications comprises the eighteenth and the twentieth century (e.g. James Hutton, Charles Lyell, Thomas C. Chamberlin and Grover K. Gilbert). We also use selected classic texts and papers on philosophy, epistemology and history of science (Hutton 1788, Chamberlain 1887, Frodeman 1995, Frodeman 1996, Gonçalves 1997, Anguita 1994 etc.) to illustrate a historical development of interdisciplinary questions, which became, during the last few decades, interdisciplinary problems to be solved in the study of the Earth System (Frodeman 2000). We concluded that these selected studies help students to be able to deal with information about social-natural environments and the planet.

The Internet and technologies of information and communication (TIC) may offer a way to renew or even revolutionize education. However, it is argued that part of the innovation they can impose is known since programmed education and "teaching machines" (Oppenheimer 1997) that follow the psychological behavior theories of the 1950s. Such conclusion contributes to weaken the hasty perception of the power of changes associated to the use of computers in education, if taken in an isolated way, without reference to a broader context, and independent of the use of computers to be (or not) associated to more or less innovative objectives (Carneiro et al. 2007).

Nevertheless, Earth System Science alone and related references on the worldwide web (web) have fomented a revolution in education. If a person does a Web search by google.com for something like "Earth+System+Science+teachi ng", up to 2.13 million webpages on topics related to the subject are available by this time (july 2010), but the number increases to 28,500,000 results by altavista.com or yahoo.com.

As the Earth is a multifaceted system with a complex interactions of its subsystems, curricula in Earth science must embody this holistic concept (Johnson et al. 1996, Hayes et al. 1996). A curriculum based on an Earth System Science approach should contribute to develop skills concerned with scientific literacy (Gonçalves and Carneiro 2002). As long as geoscientists are expected "to know more about atmospheric science, oceanography (...)", and other branches of human knowledge, undergraduate level courses should "integrate solid earth, atmospheric, and ocean science in a much more coherent way emphasizing their interactions and complementary roles in the Earth system" (web: Carleton College 2010). Teachers need:

> "(…) specific skills to be able to teach in a manner that develops in their students a deep and enduring understanding of scientific concepts, and develops the students' skills associated with the practice of science" (Owen 2004).

Planet Earth needs to be seen and to be studied as a holistic entity – that has a long history, environmental changes, processes, and cycles – which we need to study in order to understand environmental impacts, natural hazards, and the future of welfare of humans and civilization. One can recognize that the 21st century will be also critical "for the fate of Earth's biosphere" (Williams, Jr. 2000) because, in opposition to past *natural* mass extinctions, the most recent mass extinction, currently in progress, have causes definitely related to human modifications of the geosphere and biosphere. Williams, Jr. (2002) argues:

> Will humans effectively use our new knowledge of natural and human history to stop further degradation of Earth's ecosystems and extinction of its biota?

Along the Earth System Science II course students are introduced to the modern results from scientific research; they will need to be able to analyse, describe and understand questions related to natural hazards (such as earthquakes, tsunamis, floods), natural resources, namely the management of water and water supply, energy resources, and environmental impacts, specially these resulting from changes in land-use and cover and application of new technologies, such as geographic information systems (GIS), and remote sensing (RS). Students should identify what they need to learn as well as to acquire new information on these topics. It is fundamental for informed citizenship to face the present-day challenges of our society; this is also a component of democratic institutions.

Integrating geological knowledge for teaching

A special place in the Earth Sciences Undergraduate Program is taken by the *Earth System Science* courses (I and II) during the first year of studies in Earth Sciences (Figure 2). Carneiro et al. (2000, 2005) discuss the general approach of the course: to help students understand the relationship between the Earth System and the activities of human societies to meet and discuss problems of natural and social systems. The courses address to the historical development of studies of the Earth. Anguita (1994) argues that this study started, many decades before, by interdisciplinary approaches to locate and exploit mineral and energy resources. They became progressively more comprehensive, dynamic, and integrated as long as they involved the hydrosphere, atmosphere, and space studies, and interactions between the Earth Systems as well. By the 1980's, an integrated concept of Earth System Science was developed: the history of the Earth, its biosphere, humankind, and their interrelationships. This new way of seeing the Earth lets students focus on global and regional environmental questions (e.g. global climate change, air pollution, etc.). Moreover it brings an integrated way to think about Planet Earth.

Earth System Science I	
1	Foundations of the studies on Earth
2	Geosphere: The Earth's solid spheres
3	Hydrosphere and atmosphere
4	Geosphere: interaction of the fluid spheres
Earth System Science II	
5	Biosphere and the interaction of the Earth spheres
6	Introduction to the Geology of Brazil
7	Earth Systems and Human Systems

Figure 2 – The main conceptual units in the disciplines Earth System Science I and II at Unicamp

The progress in studies of the Earth leads us to prepare students to better understand the interactions of science, technology, society and environment. The skills, knowledge and approaches are needed to develop a scientific literacy: the capacity to understand, to analyse, and to make decisions on the scientific and technological problems regarding our terrestrial and marine environments.

A more detailed focus on Geosphere is delivered in the *Earth System Science II* course. The introduction of students to some general features of the Geology of Brazil is due to the fact that the Geography students need to get as soon as possible key concepts of historical geology to understand specific topics covered by, e.g., geomorphology.

Two guidelines organize the framework of the Earth System Science courses (I and II):

1) The first is to establish an interdisciplinary course which will emphasize geology and geography to focus on applied environmental topics. We found that it was possible to link geography and geology, because they are interconnected realms of knowledge. This perspective should be understood by all students, and it is essential for combining studies of the environment as relied in two disciplines (geography and geology). We also value a course that deals with local aspects of the environment where students can be able to collect data and draw conclusions by themselves from analysis of environmental data.
2) Second, we find it is important to relate theory and practical applications. These are inseparable aspects of science teaching because students will be able to acquire a realistic approach in the acquisition of new scientific knowledge.

The two guidelines help prepare students to understand the nature of the Earth Sciences. Laboratory conditions do not operate as exact reproductions of Earth processes, but provide a specific view of the way a scientist works; in other words, historical and philosophical aspects are highlighted.

It is an on-going challenge to apply the resources of teaching in classes and research to follow the teaching-learning process by our students. We work with teaching resources created by ourselves as teachers, graduate students (as games by Lopes & Carneiro 2009 or new activities, as those proposed by Martins 2010), undergraduate students and others. At the same time, to evaluate the teaching process we collect information about how students learn.

These guidelines lead us to provide a broad view of Earth Sciences that is at one time a single knowledge unit and an essential tool for understanding natural processes. The results have been quite promising and stimulating.

To understand science as research

Science is a human activity of research and generation of new knowledge. It is the result of the interaction between subject, method, and subject matter of science. The scientists work within a historical and cultural context and they establish new concepts and terminology which change from time to time; it means that ideas of Planet Earth are limited by the trajectory and momentum of scientific, economic, and cultural development and these ideas change together within social milieu in which science operates at a given time.

This modern view is especially valid when we consider the development of Science and Technology and their implications to humankind. We can have an idea of that from Norberto Bobbio's (2000) realistic words:

> "(...) what can signify a danger to mankind is the scientific and technological evolution! Firstly, it overcame all limits and its speed does not have break. Secondly, there is not way to stop it. Just there is not Hercules' columns farther of the Odyssey of curiosity will have to sink. And, thirdly, the advance of scientific and technologic knowledge is irreversible. There is not way to come back. After the atomic bomb was invented it became impossible to ignore it."

On the one hand, the teaching of science should accompany research and the advance of scientific and technologic knowledge, using a process of research to update and reorganize the disciplines; on the other hand, it is necessary to criticize scientific knowledge and its applications.

To understand teaching as research

Every teaching event is a kind of laboratory experiment, where the teacher is a producer of teaching and scientific knowledge, languages (overall a visual one in the Earth sciences), teaching resources, etc. There is a dynamic relationship among practice of teachers, scientific knowledge and teaching knowledge. This dynamic interchange needs to be researched to improve learning by the students and teaching by the teachers, as revealed by Anne Tweed (2004):

> The conversation must focus on identifying strategies that promote learning that is *active*, not *passive*. Effective science teaching combines both exploring *and* explaining, along with various other successful strategies. Research tells us that an inquiry-based approach promotes a deep, comprehensive understanding of science; we also know that some data and facts can be taught more efficiently through a teacher's direct explanations. Our challenge is to learn more about the effective balance of *all* teaching approaches as they relate to the science classroom and – more importantly – to student learning and understanding.

This approach is equivalent to the value attributed by Schön (1983) to practical activities and similar with Elliot's (1998) concept of a researcher teacher.

To emphasize environmental problems when doing Earth Science teaching

Natural systems are in a state of constant flux, involving many of long-term and short-term processes that can be thought as different stages of quasi-equilibrium, a sort of dynamic equilibrium. Changes in the water and rock cycles affect all the terrestrial and marine environments on Earth. The interactions of internal and external energy fields alter the Earth's landscapes over time: from building large mountain chains to hills, formation of topographic relief, and coastlines, etc. The evolution of the material composition of Earth can be considered as a by-product of the persistent effect of physical and chemical forces acting on the Earth's materials. Knapp et al. (1989) suggested this approach as a way of showing interrelationships between natural processes and human activities.

The discipline of geology, which provides historical knowledge of the Earth's past, can provide an understanding of natural phenomena on temporal and spatial scales of the whole planet. Geography is more concerned with natural resources and human settlement of diverse regions of the planet. These two scientific disciplines can benefit from their specific approaches to achieve a better understanding of the environmental crises under which humans live nowadays. Earth System Science fosters the integration of these two fields of knowledge, because they provide a means of understanding human's relationship between society and nature. If included in geology and geography undergraduate curricula, it may produce a change in the way of thinking about the best educational approach to addressing the environmental issues regarding humans and Earth.

To understand the role played by humans from the perspective of Geology and Geography

Within our modern societies there is currently a minimal state of insight into global sustainability (Johnson et al. 1997), not only for dealing with factual information but also to the interpretation of involved processes and nature cycles. From the undisputable point-of-view that the Earth is permanently subjected to change, geology and geography provide an integrated concept of nature because they are historic. They emphazise the links between social activities (noosphere) and all the Earth's spheres (geosphere and lithosphere; atmosphere, hydrosphere and cryosphere; biosphere etc.). This view of the concepts of space, time, processes and balances, which take place on Earth, make a person capable of understanding the human impact on the natural world, the impact of exploitation of natural resources and related problems, facing a long-term sustainability (Diamond 2006).

Teaching about scientific research and environmental problems are central to the Earth System Science I (first term) course.

> The aim must be to develop understanding of the interplay among the relevant societal endeavors of Global Change in relation to the Earth System and global sustainability (Johnson et al. 1997).

The teaching activities are organized around well-defined problems and topics: erosion, pollution of underground and surface waters, impact of landfill and waste, reclamation of mining areas, etc. Towards promoting an active learning some field activities are included during both semesters (Carneiro et al. 2008). The emphasis on articulating geologic and geographic disciplines as a better way of understanding Earth is the basis for the Earth System Science II (second term) course. Human and social challenges also are central topics of this latter course.

Main Findings

In the beginning of a year, we apply a test with questions about the expectations on the discipline from the students, as well as on subject areas of Earth Sciences: systemic thinking, geologic time, knowledge of regional geology, understanding of concepts of terrestrial materials and visual representation.

This test has been applied to groups of students since 1998. Knowledge of regional geology by all students is null. The results show up that most part of students are able to work with temporal narrative ideas, but can not apply them to visual schemes commonly used in geological language. Poor and fragmented appear for systemic notions of the water cycle, solar irradiance balance, cycles of erosion and sedimentation; most students understand a few processes but can not combine these parts in an integrated way. Frequently, students repeat incorrect information from media vehicles. Concepts on terrestrial materials (rocks and minerals) are incomplete; moreover, not even a single student realizes that geology builds knowledge from these materials. This fact is to be clearly stated to them.

At the end of one year of activities, most students improved significantly their concepts in all these aspects. The best improvement is on Earth materials, mainly identification of rocks. As "the human mind is arguably the geocientist's most important tool" (Kastens et al. 2009), they become able to use different time scales, they understand the notion of deep time, and they are able to use tools to build the temporal sequences in geologic materials (outcrops, geologic sections and simple geologic maps). As proposed by ESSC (1988) the disciplines do offer many examples of practical benefits from science, causes and consequences of global change, and a perspective of the Earth as a planet. Although there are noticeable results in the development of systemic thinking, very few students acquire an integrated view of the water cycle and its spatial scales. It is interesting to notice that many students ask to review, by the end of the year, their former answers to the preliminary test on expectations and on subject areas of Earth Sciences. After evaluating their own progress, they often feel stimulated by the proper unexpected advances.

Discussion

Johnson et al. (2009) suggests five levels to evaluate the quality of a lesson. It helps to indicate the effectiveness of science teaching. The paper shows up that through certain indicators involving attitudes of the teacher, student participation, use of materials and lab activities it becomes possible to characterize the education and, somehow, to reveal levels of learning by students. In summary, the procedure yields an idea on levels and quality of teaching and learning, by five categories: 1. *ineffective instruction*, 2. *elements of effective instruction*, 3. *beginning stages of effective instruction*, 4. *accomplished, effective instruction*, 5. *exemplary instruction*.

Johnson's (2009) indicators help a careful examination of each conceptual unit of discipline. The first unit, *foundations of studies of the Earth*, theoretical and practical classes exhibit a clear proposal and most part of students are highly engaged in all subjects. Students participate actively in the work that by themselves perceive as meaningful. Education is very well designed, the content and pedagogy are adapted to the needs of students. Activities can be changed to evaluate whether a teacher realizes the difficulties of students. Many students start building a capacity to think under the geological point of view. This set comprises investigations, oral presentations, discussions (with teachers and colleagues), readings, field activities, maps and visual representations. This part of the discipline reaches level 5, i.e., is an *exemplary instruction*.

The second unit, *Geosphere*, is more standardized and the content design is more rigid. Most students actively participate and many consider it a meaningful work. The content and pedagogy are adapted to the needs of students. They comprise investigations, oral presentations, discussions (with teachers and colleagues), readings, field activities. This part of the course reaches the level four of Johnson et al. (2009), as an *effective instruction*.

The third unit, *interaction of the fluid spheres*, and the fourth unit, *biosphere and the interaction of the Earth spheres,* stimulate students to participate actively but, because the contents are too much complex, students have difficulties. Education is standardized and well planned. This makes effective instruction to be restricted to students who are able to develop relational thinking. Our understanding is that this part is between Johnson's (2009) level four and three, which is between *effective instruction* and *beginning stages of effective instruction*.

The fifth unit, *introduction to the Geology of Brazil*, requires students to manipulate large diverse spatial and temporal scales to understand the development of intracratonic sedimentary basins, sequences of events of folded ranges etc. Many didactic texts are included as to yield specific geological information on the Brazilian tectonic evolution, but most students remain passive and try to strictly follow the lectures. In spite of the fact that classes include well-designed activities, use recreational elements, and perform field activities as well, only a small part of the students understand the complexity of the related phenomena. We that this part is at Johnson's (2009) third level: *beginning stages of effective instruction*.

The sixth unit, *Earth systems and Man*, seeks to focus on relationships between human and nature on wealth and natural geological risk. The content and pedagogy are designed to the needs of students. Most students actively participate in the work that they themselves perceive as meaningful. Thus, this unit is at Johnson's (2009) level four, i.e., *effective instruction*.

Teachers search for improving learning results by means of continuing evaluation of the activities and lectures; such reflexive approach is highly positive, but many improvements are still needed. Our classes are given by one teacher and one assistant attending a group of up to 35-50 students. We are aware that in many universities one teacher attends more than one hundred students. Such magnitude of student-teacher ratio would make proposal impossible. So, the main limitation of this application may be indebted to its intrinsic qualitative character, which is a primary indication that some of the present findings can not be generalized.

Another specific fact refers to the Brazilian examination process to select the best candidates to enter public universities. Up 11 to 14 candidates dispute each position offered by Unicamp, as a generic rate of candidate/place; some courses are more disputed, and others are not. Geology is currently at the upper segment of this rating. The process involves hard competition to enter the university and, therefore, it probably classifies the best candidates. The better the knowledge level and abilities of the group of students are, the higher is the positive impact of this factor for accomplishing the objectives.

A statement of reliability may thus be postulated from the above data. The curricula is effectively productive and may be tested under different conditions. The framework of the course is presented in all classes by means of primary ideas that may be replicated under distinct content and methodological guidelines, and a lot of practical activities built from strategies seeking to promote *active learning*. In summary, the main ideas and understandings are: (a) teaching can be seen as research; (b) teaching of Earth Systems and Earth sciences is benefited by the perspective of environmental problems; (c) the interconnections of geology and geography help understanting the role played by humans in environmental changes. This reference is therefore changeable to fit specific conditions to prepare geologists, geographers, biologists, engineers and other professionals, which will deal with the complexities of the natural Earth Systems and the interactions with man's activities.

Concluding Remarks

The practical experience allows us to suggest that a curriculum structure in Earth System Science shall be organized in accordance with an approach that starts from the very basic principles of geology, towards achieving a more comprehensive factual and conceptual coverage of the natural processes which interact at the Earth's surface. Geology yields a historical approach which provides an integrated concept of nature because Earth is permanently subjected to change. ESS can emphasize links between social activities and Earth spheres: geosphere, crust, atmosphere, hydrosphere (which includes the solid cryosphere), biosphere, anthroposphere etc. A broad view of processes that take place on Earth and the related concepts make a person capable to understand human impacts on the natural world, and the impacts of exploitation of natural resources as well. This is one of the potential contributions that ESS can do for upgrading the people's state of insight into global sustainability.

The transformation and "permanent" changes in the shape (landscapes, relief, coastlines etc.) and evolution of the Earth's material composition are considered a by-product of the continuing impact of forces and processes acting on the Earth's materials, which, in turn, are driven by internal and external energy fields. Our findings demonstrate that, after an ESS course plenty of practical activities under a strategy devoted to active learning, the enrolled students have been able to better understand the human activities around them and to look at the natural world from a more critical point of view, as relied on Earth System Science.

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