# Educational Tools and Methodological Approaches to Enhance Interest and to Grow Skills in the Teaching-Learning of the Earth Sciences: A Research in the Italian Schools

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**Abstract**

Earth Sciences teaching-learning process in the Italian schools, where the research has been developed, has highlighted a widespread lack of knowledge among students. This corresponds to a lack of sensitivity toward geological and environmental issues and to our territory, moreover, often characterized by widespread disruption phenomena and natural hazards. This lack of awareness is also widely spread in the society. The goal of this research is to contribute in spreading a greater awareness in Earth Sciences' different disciplinary fields. The aim is also in recognizing its concrete applications in our life and in its quality. The students' training is essential, but must pass through more operative educational tools and paths, based on more effective methodological and educational approaches: hands-on practices, active teaching, inquiry, and investigation. It is necessary to increase students' interest and passion to promote competences and skills. Research has shown that Earth Sciences can be a formidable tool for promoting these skills, but they require a systemic vision and a more solid epistemology.

**Keywords:** educational approaches, skills and competences, tools and paths, multidisciplinary links

## 1. Introduction

The paper presents a research developed in Italian schools over several years: starting from a proven lack of sensitivity toward geosciences, the work highlights the need to identify new effective educational approaches to promote interest toward a discipline so important for its strong ties to the territory. New approaches for new educational tools paths are necessary to promote this interest, basic in a country, like Italy, rich of cultural, natural, and architectural values, but brittle and highly sensitive to geological problems.

Earth sciences are in fact a subject rarely taught in schools, being students', and even teachers', feeling strongly conditioned by the idea that Geology concerns just "stones and catastrophes." Too often, they become aware of dangers only when something dramatic happens, when the damages to people and things have already occurred—even in presence of vulnerable assets and risks close to daily life. And, often, they are attributed to Earth's anger.

This lack of awareness, this general basic ignorance of natural phenomena, in a brittle country as Italy is, lead to a widespread difficulty in understanding the reason of dramatic events connected to geological events. The effects are unavoidable: on the safety of buildings, on the economy, on environmental protection, and ultimately, on the quality of life. The awareness of the fragility of our planet not only leads to a greater perception of natural risks, but it is also fundamental to understand the need for a more sustainable use of resources and a greater attention to pollution.

The research highlighted some theoretical, methodological, and practical aspects that, as correctly developed, can produce interesting effects on the teaching-learning of Earth sciences and, which is even more important, may have effects on the perception of the evolutionary dynamics of the Earth.

Even the strong links with the other scientific fields can be helpful to increase the growth of technical and citizenship skills.

## 2. Theoretical outlines

Earth Sciences are a young discipline: the theory of Plate Tectonics was processed, consolidated and shared only in the 1980s and a lot of phenomena has still to be defined and studied: new discoveries follow one another, without interruption, theories are still evolving in the field of Earth sciences, biogeology, and space science.

Precisely, because discipline is young, many areas still wait to be explored, being this an element that makes this science, even more than others, exciting and fascinating. It is well-known that Earth Sciences are a complex discipline: but the word complex should be clearly used in its real meaning, that, coming from the Latin *cum plicato*, which means bent together, not necessarily difficult. This word means, rather, a contest rich of relationships, interacting with each other in all their different components: together, they constitute a system.

In fact, as every scientific discipline, Earth Sciences consist of branches and sub-disciplines, increasingly specialized as the research progresses. It ranges from petrography, climatology, astronomic geography, soil science, paleontology, to name a few of them. Each of these disciplines, in turn, is subdivided into thousand streams and it is inevitably intertwined with other.

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This is the meaning of "complexity" of Earth sciences.

It explains the complexity of the relationships, the intertwining of natural phenomena and scientific laws, shared with Chemistry and Physics' world, even more with the world of living beings; inspected connections link geological phenomena and historical events. Earth sciences are, ultimately, the true connection between the "abiological" and the biological world, the inanimate and animate one.

Obviously, it is necessary to know the constituents and the properties of these relationships: it is the lack of this knowledge that makes Earth Sciences so difficult to be understood and loved, and, but, for the "initiates," geologists, geoscientists, teachers of the discipline, enthusiasts, all that represents its charm.

Unfortunately, Earth Sciences suffer to be considered as a "derived" science, compared to experimental counterparts like Physics and Chemistry: these disciplines are in fact endowed with their own methodology and logic. They are based on a millennial history and of great theories. They are studded of illustrious scientists and Nobel prizes.

Earth Sciences are, with Biology, considered just narrative and not really experimental, by many scientists and educational researchers. In fact, some of its basic theories are considered fragile, because they are not applicable to all contexts, not repeatable which makes them unscientific for many: actually, an eruption or an earthquake is an example of this perception.

Earth sciences suffer, also, of a certain lack of sense of belonging and an inadequate pride for its knowledge. And, because of a certain rationalism and a concrete sense of priority, an epistemology of Earth sciences, necessary to support and to attribute its identity as a science, has never been developed.

The result is that Geosciences education, in terms of numbers of teachers, students taught, and perceived importance, has been lagging behind the other science disciplines for decades. This fact is harmful, if we consider that the geosciences are essential in order to know, understand, and protect our planet; they are can help to create a global perspective. Moreover, to grow an environmental awareness in young people is essential to understand that Earth is system, because, as future citizens, it will determine the quality of environment and life on our planet. Furthermore, Earth Sciences, with its wealth and complexity, its disciplinary plots and its links with many other scientific fields, constitute a remarkable tool to promote students' competences and skills.

## 3. Analysis of the contest

Unfortunately, the Italian education system does not support the teachers in this transformation, because it is still mainly based on the transmission of knowledge: most of the teachers remain anchored to a process of teaching-learning based on a transmissive approach.

The educational approach should clearly distinguish between goals and objectives, between knowledge and skills: it should be structured starting by identifying the priority skills, then the goals and, only later, the involved disciplinary objectives. Knowledge should be just a mean that allow these abilities transforming in skills.

Turning this traditional, acquired, and consolidated educational approach into a process, starting from skills, requires constant and strong commitment. If this does not happen, in everyday practice, the testing of acquired knowledge of their students seems to be the priority.

The Italian school system, with its encyclopedic content, does not facilitate the development of methodological approaches of active teaching-learning, such as problem solving, peer education, case analysis, and inquiry-based teaching-learning.

In fact, they require the teacher to abandon the traditional role of master of knowledge and transmitter of contents to become guide, collaborator, and mediator of the activities.

Earth Sciences are taught in all schools and all ages, with different levels of depth and of teaching quality. Plate tectonics and natural hazards, as volcanoes or earthquakes, are curricular topics; but people do not perceive the danger and the risk of living on the sides of a volcano, or in a seismic area, even when the area has already been affected by disastrous events in the recent past. Human memory is very short.

Many researches [1–5] have highlighted the poor skills of Italian students, in the Earth sciences field, during and at the end of their course of study, whatever is their school curriculum and level of scientific specialization. The knowledge is often superficial and fragmentary, due to the respect of the ministerial curriculum. This curriculum, in fact, although renewed in recent years, lacks of prerequisites and of coordination with other scientific disciplines, as Physics, Chemistry, and Biology, although taught by the same teacher.

Moreover, even today, even in scientific schools, it does not foresee neither the Biology, nor the Earth Sciences among the subjects of the written test in the final exam, and an inadequate knowledge does not allow the acquisition of effective and fundamental skills.

## 4. Working hypothesis

The training to promote the teaching-learning in Earth Sciences should pass by more effective educational approach. The use of educational tools and of learning objects seems to be particularly effective and involving.

It is a widespread belief, based on tested and shared practices, that Science teaching-learning should be based primarily on active teaching methodological approaches. In the case of the so-called hard disciplines, Physics and Chemistry, the experimental and laboratory approach is a widespread and shared heritage: the use of machines, tools, and objects allows to develop experimental activities with the increasing complexity. The approach is generally based on the scientific method of Galilean memory, scientifically correct but with little space left for intuition and autonomous reasoning.

In other scientific disciplines, as biology and geology, experimental practices are perhaps less widespread. But when they are used, they allow the development of operative paths favoring investigation and promoting curiosity: but especially they push the student toward the research, at first guided by the teachers/experts, then gradually let to become autonomous.

In Earth Sciences, the hands-on approach is naturally part of the teaching of petrography and paleontology, where the learning object can be manipulated, observed, studied, analyzed, and compared. On the contrary, complex phenomena, as global tectonics, earthquakes, or faults and folds, require a different approach.

It is not easy, for an "uninitiated," to appreciate the history of a rock, the dynamics of a landslide, the richness of information and connections of a stratigraphic sequence, and the beauty of a fold. Then, the teacher's task must not stop to illustrate scientifically the phenomenon of the fold, the rock in which it was formed: he must also to discover the link with Physics (temperature and pressure), Chemistry (composition of materials), and geological history (the event that formed it); he should also help to discover the fold's beauty, as if it were a masterpiece of nature.

It is not easy to discover alone, the not always understandable beauties of geology.

## 5. The educational path

The educational path to promote interest in Earth Sciences, and then make grow students' knowledge and skills, should pass by some steps: they may seem obvious and even trivial, but are instead fundamental.

In fact, the lack of awareness toward Earth Sciences can derive from the lack of very simple tools; certainly, a part of the responsibility depends from the brittleness of teachers' knowledge, but also passion, effective educational approaches, educational tools, and even multidisciplinary links are needed.

The analysis is not exhaustive [4–8]; it should be extended to the history of Italian school, characterized, from its birth, by a prevalent humanistic culture. The reason why should be analyzed more deeply, despite the presence of great Italian scientists, from Leonardo da Vinci to Fabiola Gianotti, Natural Sciences, and particularly Earth Sciences, struggle to be loved.

The tools proposed below, already experimented and monitored, are certainly not sufficient to change this set-up, but they can be a valid starting point.

### 5.1. Passion

To propose, as the first instrument of educational efficacy, the passion with which Earth Sciences should be taught could seem banal and perhaps obvious: but to excite our students in this discipline, which seems too difficult and a bit boring, we must be, in turn, teachers passionate of the topic.

But it is necessary to be aware of the discipline to be passionate about it. If we want to be able to explain the contents and to answer to the inevitable questions, if we want to go deepen and to intrigue, it is obviously necessary to master the contents. Unfortunately, in Italy, sometimes sciences teachers are not masters of the discipline because they are predominantly biologists.

If using effective methodological approaches, innovative paths, engaging educational tools, developing and encouraging links with other scientific or humanistic disciplines, with the aim to promote skills and competences, is considered absolutely essential, teachers' work should be supported.

They should have more tools, more targeted training, and clear and experimented indications of work. Also, they should have less pressure from the system to achieve the disciplinary objectives required by the "program" and necessary to face the final exam. Finally, they should be seriously convinced of the importance, in a globalized system that is moving in this direction, of the priority of the skills toward the pure content.

But only a deep passion, and a great professionalism, allows to grasp the challenge that involves the experimentation and the use of new methodological approaches, of new educational tools. Obviously, the risk of not obtaining the desired effect, always remains: it is possible when we try and try again until we get the desired effect. We must overcome the concern of not being able to manage our students in new and less traditional contexts.

But the satisfaction of seeing their curiosity, their interest, and finally their passion grow justifies all the work that will be necessary.

### 5.2. Educational approaches

Frequently, Earth Sciences' theory is presented, in Italian schools, by not involving boring approaches, even a bit: they seem not useful to promote passion and interest. But the need to change the traditional transmissive and deductive approach with an active and inductive teaching-learning, although not yet shared and disseminated, is well-known and widely documented [6–8]. At school, many teachers and students, thanks to the cultural heritage deriving from the Galileo Galilei's principles, which consists in the use of the experimental scientific method, as the most correct methodological approach, believe that science advances linearly, following the hypothesis and testing model in the classroom.

But this view is increasingly inadequate to represent scientific inquiry: sometimes scientists have no hypotheses, other times discoveries are made by chance. It would be a challenge to find evidence of a linear scientific method in every research and in particular in the field of Earth Sciences. Moreover, the scientific experimental method of the scientific world, the basic tool of educational research and experimentation, is too often presented, in the daily work of the teacher, as a rigorous protocol to be followed. It should instead be considered as an opportunity for reasoning, for hypothesis, development, and formulation of the solution.

It is necessary to revolutionize, even if not always, our methodological approach, in order to involve and motivate students. It is enough to have few tools, few learning objects, but it requires, simultaneously and above all, the knowledge of the methodological approach from a theoretical point of view. Furthermore, a solid ability to manage the class, a talent for conducting activities and verifying any unexpected events during the course is required.

There is always an element of risk, as in any innovation, but, step by step, the teacher masters the class and the different ways of working and gains self-confidence. Unfortunately, there are no rules: we must experiment and find them in the practice of daily teaching. Teachers' mission should be to excite our students in the discipline, so that through the acquisition of knowledge it is possible to increase students' skills. Experiences and paths, with suggestions for their methodological approaches, are numerous and widely documented.

To capture this complex skill, we need to renew the teaching of sciences; we must break the habit, encouraged by textbooks, of presenting science as a finished product, trying to show it as a passionate problem-solving, an adventure, that many have committed themselves to with passion: this is what we call an approach active. However, the term active in the daily practice of teaching has many ambiguities: it is not simply a practical, manipulative activity, although this is certainly useful in a school based mainly on transmissive teaching.

There are many requirements that make a learning activity really active:

- the activities must correspond to the tasks of the real world, rather than to the de-contextualized or scholastic works;
- the activities require the students to define the tasks and the related articulations;
- activities should involve students in examining work from different perspectives, using different resources to solve and separate relevant from irrelevant information;
- collaborative work is basically required to solve the task;
- activities should promote interdisciplinarity and allow students to have different points of view: this helps develop skills more than a single well-defined field;
- activities that allow a series of results open to multiple solutions, rather than a single correct answer obtained from the application of predefined rules and protocols are preferable.

Active and survey-oriented laboratories stimulate students to develop independence and can improve subjects' understanding and promote positive attitudes toward science and science learning. These approaches are generally focused on investigative processes, such as problem-based learning, which requires the identification of driving questions, and fundamentally the development of pathways through practical laboratory activities.

Other approaches have been tested: the traditional "application of experimental protocols" is generally simpler, but less effective and less enjoyable; "formulating and testing hypotheses" is more complex and formative, but involvement depends on the topic or issue; "practical experimentation" is undoubtedly the most popular, even if it presents the risk of being a little playful. Also the Inquire Base Science Education, known as IBSE, has been experimented: IBSE is the most widespread education approach, thanks also to the extensive literature that has seen it as the protagonist, but in my opinion it retains much rigidity and does not always help promote passion and autonomy among the students.

In fact, my experience has oriented me in time toward the Problem-based learning approach, which is generally based on an abductive approach. The process is aimed at using the power of authentic problem solving to engage students and improve their learning and motivation. From my experience, it has proved to be the most effective for developing critical thinking and creative skills, to improve problem-solving skills, with the aim of making students apply their knowledge to new situations. Facing situations in their context and appropriately structured problems, students must investigate and discover meaningful solutions.

Indeed, it is an approach that is rich in meaning and potential results, but requires commitment, time, and passion. Moreover, it is obvious that it cannot completely replace the more traditional lessons in our school system. It is important not to confuse PBL with simple practical activities included in the traditional education system, just to vary educational communication or as the culminating event of a training unit. However, PBL poses challenges for teachers. In fact, the role of the teacher changes significantly as it becomes a facilitator of learning, promoting an investigation environment rather than providing facts, thus testing the student's ability to remember these facts through memorization. The teacher loses the role of lecturer, culture transmitter, the holder of power in the classroom: he must be open to his constructivist nature, be able to take a student-centered approach.

Furthermore, this approach requires much more material than a course based on conventional lessons. Finally, it requires a great sense of responsibility and professionalism, which is acquired through competence and experience: in short, it requires being a professional.

### 5.3. Educational tools

In the teaching-learning of Earth Sciences, the main goal is the understanding of complex phenomena. Despite the availability of useful and engaging software, it is sometimes very effective and interactive. My personal experience has shown that the use of hands-on tools is often the most effective with the students. Secondary schools in Italy have, very often, in their scientific laboratories, high quality instruments such as seismographs, weather stations, or telescopes. Often, we can also find historical collection of minerals, rocks, and fossils. Both typology of tools are essential for the approach to the contents of the discipline, and are useful because they allow students a manipulative approach. But a deep change of mentality is needed: in fact, while it is easily possible to be fascinated by the beauty of a mineral, from the history contained in a fossil, it is less easy to discover what "hides" a rock sample. Too often, this appeal does not emerge, and a rock remains a simple stone.

In the Earth Sciences teaching-learning, it is necessary to find a different approach, which is able to make students understand the richness and variety of the relationships between the biotic and abiotic world, the contribution that each piece of rock can have in the complex system of the Earth [2].

As it is not possible to reproduce in the laboratory the real movement of the plates, the eruption of a volcano, or the movements of the air, it is necessary to use models. In my personal experience of researcher, with the aim to support teachers' work, I have focused the attention on finding more effective ways to create teaching tools and paths. To be effective, the different tools should primarily have the function of

- stimulating observations,
- hypothesis,

- reasoning and,
- to help the formulation of more general rules and, when possible, of laws.

Finally, models should be able to stimulate the abstraction and the ability to identify connections between different elements and principles, intra- and inter-disciplinary.

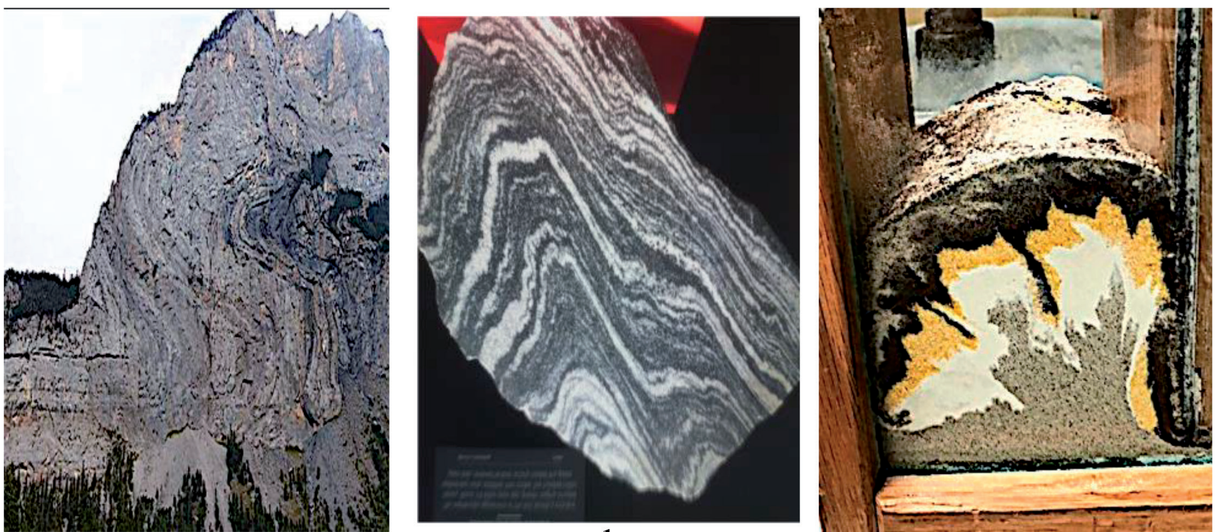
It was possible to verify that more simple, rough, self-produced, even banal were the models, the more effective the results. Of course, they must be compared with the events to which they correspond in the Earth dynamics. The use of learning objects was actually experimented in various contexts: using models and tools, the utility of hands-on in the growth of knowledge, in understanding phenomena but also in the importance of emotions in the learning process, was demonstrated. This seems strange and unpredictable, particularly in a subject such as the Earth Sciences that generally seem rather prosaic and rigid for students, where nothing can be misleading or disruptive.

It might be useful to show some easy and tested examples of the different materials produced. All these tools are intended as learning objects to apply the principles of Problem-based Learning and the use of driving questions (see above) (**Figures 1–3**).

The educational paths and the kits have been tested for their feasibility in various aspects: with students of different ages and different contexts, monitoring the understanding process, and evaluating the contents and the skills acquired [1, 2, 4].

### 5.4. Multidisciplinary connections

If we remain closely connected to Earth Sciences' contents, at first sight, it seems not easy to find relationships and links with other disciplines. Earth sciences, so *cum plicate* (see above) and sometimes closed on themselves, do not seem to have such tight ties, links, or connections with other disciplines: few efforts are made in both directions.



a b c

**Figure 1.** (a) A fold in lower Jurassic limestone layers of the Doldenhorn Nappe, Switzerland. (b) A bent gneiss sample. (c) A model of fold, made with cocoa, white and yellow flour, and sand.

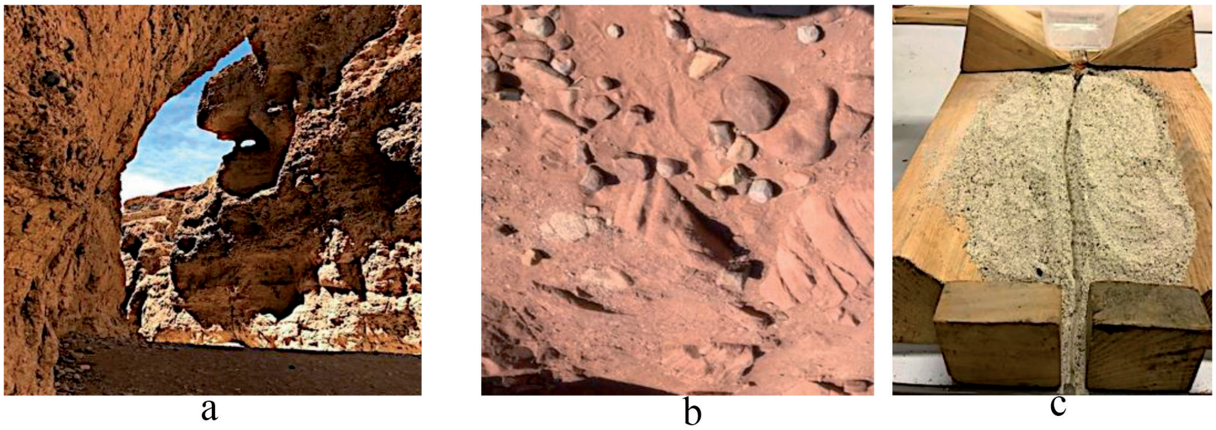



**Figure 2.** (a) A deep alluvial Ouadi-Namibia. (b) An eroded rock sample. (c) A model of water erosion—regional scientific laboratory.

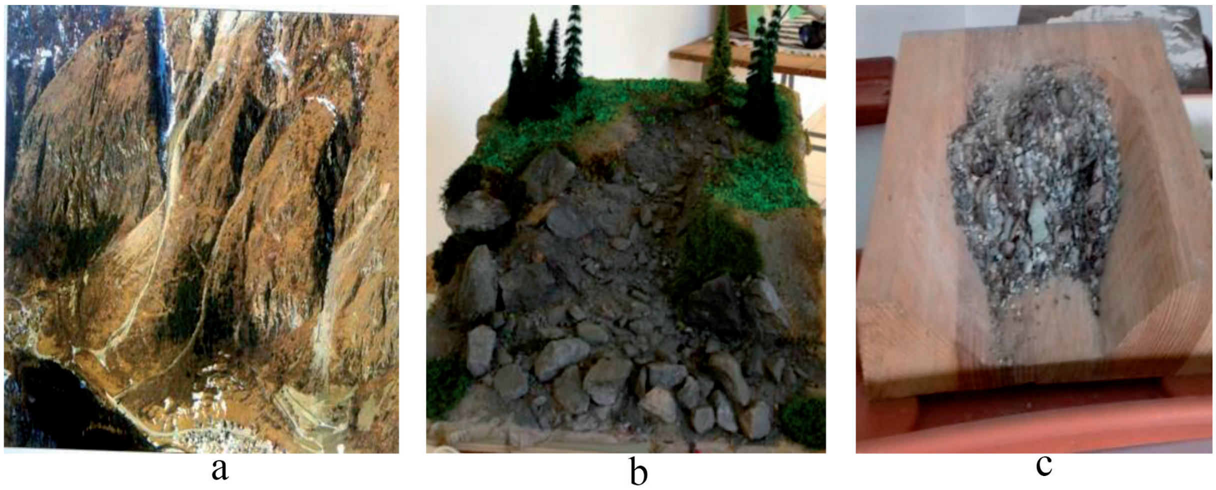



**Figure 3.** (a) A landslide, (b) a landslide model, and (c) preparing a landslide.

We are realizing that new scientific discoveries in the research' world derive more and more from the boundaries of the disciplines, more and more distant from the traditional and well-known contents, or the intertwining of different scientific areas. It is from the astrophysics, from the astrochemistry, from the molecular engineering, from geobiology that interesting and amazing data are emerging. Even in the Earth Sciences, the most intriguing aspects can be derived from these plots. The discovery of connections, of relations of cause and effect, of relationship between seemingly distant topics, make every subject a source of amaze.

I personally have always found the proposal of these connections fascinating especially when unexpected; even among the students, the discovery of these connections has given surprising answers, an occasion for motivation and re-motivation toward Earth Sciences. It is possible not only to bridge the gap between the various disciplines, which is surprisingly very narrow, but also discover that Geosciences are at the basis of many events in the natural history of the Earth, just like in the history of the human species. Many events in the past, eruptions, earthquakes, and major disasters that may have strongly influenced the climate in geological eras, had also a strong effect on organisms' evolution [1, 2, 4].

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In the Earth Sciences, complex relationships link the different scientific branches that characterize it: geochemistry, volcanology, petrography, and geophysics. Ever more complex and surprising bonds are discovered between volcanic eruptions and the climate, between geological evolution and paleontology. But many others increasingly unpredictable are discovered in the field of different scientific disciplines. But it cannot be so surprising, indeed, if we think that all living beings, the autotrophs and the heterotrophs, depend strictly on the soil, on its chemical composition and on its structure, which in turn depend on the substrate and therefore on its geological history and from the age of the minerals and rocks that compose it.

Other links, more transversal, subtle, and even more surprising are interconnected with different disciplines: history, literature, and art. They have conditioned, modified, and transformed them. And vice versa, a historical event could have favored new discoveries and new theories: the exploration of the ocean floor for defensive purposes during the Second World War was the occasion to clash with the oceanic ridges at the center of the Atlantic and to favor the development of the plate tectonics theory.

The relationship between the early stages of the hominization process and the opening of the African rift is quite documented; recent discoveries are correlating the impact of a meteorite and the shift of the Earth's magnetic field with the extinction of Neanderthals for genetic mutations. The relationship between the impact of the Cixculub meteorite in the Jucatan peninsula, highlighted by the rich level of iridium studied by the Alvarez, in Italy the Bonarelli level, with the extinction of the dinosaurs is known and quite documented. The relationship between the formation of the Dekkan Traps and the great extinction of the late Cretaceous is less known, but perhaps chronologically more coherent.

But the unexpected connections that very often we can find in all the subjects we daily face are even more surprising. Many know the relationship between the eruption of Tambora, in April 1815, and some English literary works, such as Mary Shelley's Frankestein and John Polidori's Dracula. The two authors, in the cold summer of the "Year without summer" that followed the eruption of Tambora in 1915, were passing their holidays in Switzerland. Without the possibility of excursions, because of the bed weather, they could not spend their time outside; then, they challenged those who had written the best horror novel. Less well-known is that even the Fairy Tales of the Grimm Brothers resented the special cold climate that marked that year, or how it influenced the colors of the well-known paintings of William Turner and migrations of many Italians, forced by famine toward America and, when arrived here, the Conquest of the West.

And it is known to many, the impact that the Little Ice Age had on history and society between 1650 and the end of 1800; less known is that the harsh climate marked the growth of the trees, making the growth rings smaller and the wood more compact, allowing the creation of musical instruments, the Stradivarius violins, particularly precious for its exceptional acoustics.

### 5.5. Competences and skills

The traditional definition of competence, which comes from literature, is the implementation of a performance in a given context that involves the use of attitudes and motivations, knowledge, competences, and skills, and is aimed at achieving a purpose. More precisely, competence is, "What, in a given context, one can do (ability) on the basis of a knowledge to achieve the expected goal and produce knowledge. It means to choose, use, and master knowledge, skills, and abilities appropriate in a given context, to set and/or solve a given problem" [7] The acquired experience has shown that Earth Sciences are the discipline that more promote citizenship and transversal skills and, furthermore, develops the ideas of system and complexity. It is surprising how these skills can be easily applicable, malleable, and adaptable to different contexts and contents of Earth Sciences, where they become tools to think, observe, connect, relate, research, solve, and communicate.

The goal is to be able to understand that every single phenomenon, a landslide, a flood, a volcanic eruption, or an earthquake, is part of the global system: all are connected to each other. It is possible to pass from a single case to a general law of nature. In the case of the approaches traditionally used in the sciences, inductive and deductive reasoning, in which the rule is given from the beginning, the definition of a law occurs regularly, and with relative ease. In the case of the abductive process, such as in the Problem-based Learning, ability to synthesize becomes an essential element: understanding why landslides can fall or earthquakes occur requires a general ability to synthesize [8, 9].

More precisely, the analysis of the phenomena studied by the Earth Sciences, phenomena are not always predictable but interconnected, allows to promote:

- the ability to synthesize and generalize, which implies being able to collect many cases in a more general case that involves them all;
- the capacity for abstraction, which implies being able to formulate a rule that describes the events of the case: the characteristics of a rock, the morphology of the slope, and the geographical position.

In the case of natural phenomena, of course, the variables are many and not always easy to connect: this represents a challenge for the scientist and for the student. It is not always possible to define a law, but we can always find a cause-effect relationship. Each landslide or any meteorological phenomenon can be triggered by a person kicking a stone or by the beat of a butterfly's wings.

## 6. Epistemology

It is not superfluous to recall the strong cultural importance of Earth Sciences, which is not obvious: in the past, too many have considered that the science of the Earth, like other scientific disciplines, is simply "technical" and has no cultural depth. Instead, Earth Sciences offer a unique possibility of a conceptualized phenomenon through time and space, in a complex and interactive historical approach.

Understanding how the Earth works requires the retrospection that makes inferences about the past; it requires to interpret the present as the result of large-scale natural experiments: Earth Sciences prepare the ground for understanding the complex relationships between the sciences and for making hypotheses about the possible future.

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But the promotion of Earth Sciences as a discipline that most develops ideas of system and complexity, whose understanding is essential to promote scientific skills, requires a strong disciplinary epistemology. Unfortunately, the level of research on epistemology of Earth Sciences is very weak. Earth Sciences, like any scientific discipline, should be based on their epistemology, necessary to face the fundamentals of the discipline, and to define the conditions that allow to build scientific knowledge and to develop methods to reach this knowledge.

But Earth Sciences, unlike other scientific disciplines, have a complex history: from time to time they have faced sociological, economic, technological, and human aspects, from which it has been difficult to break away to develop an abstract epistemological theory. This resulted in a lot of explanations concentrated more on the various components involved, that a search for universal laws, typical of other scientific disciplines [10, 11]. While the philosophy that inspired the work of the founders of modern geology, from Steno to Lyell, between the eighteenth and nineteenth centuries, led directly to a discipline characterized by the principles of identity and unity, in the following years, up to the twentieth century are characterized by research by many of specialists, each attentive to their field, certainly not interested in the epistemological theories of the discipline.

As a global geological theory was far away in time and would still have required many years, everyone was focused on building their own small model, in a reductionist approach, away from the idea of the complexity of the knowledge system. The same happened in the past for Chemistry and Physics. Later, however, chemists and, above all, physicists were able to construct a common language and vision, which led philosophers and historians of science to use these sciences as an epistemological model. In the current model of science, there is a sort of hierarchy that separates the hard sciences from the soft ones, like the natural sciences: Biology and Earth Sciences.

But the specificity of Earth Sciences derives precisely from this fragmentation. It seems particularly useful to develop an epistemology of complexity and in particular it allows to support the idea of non-linearity, useful when the linear model seems too simple and not adequate. In a non-linear model, every component and every phenomenon must be related to other systems, and it is not possible to find a separate law for each fact. A complex system cannot be static or linear: it is a combination of random processes and non-linear interactions. It is the result of an evolution of the process, in which sometimes it is not possible to recognize relationships of cause or effect between the different components, because both are the result of their common history.

The complexity that characterizes the Earth sciences does not allow to identify a single formal structure of the discipline and is the responsible of its weakness; however, this complexity, due to the presence of so many fields of study that even if in different forms, have to do with the Earth system, is also his wealth [1].

## 7. Conclusions

The promotion of Earth Sciences' teaching-learning in Italian schools requests to pass through tools, both theoretical and practical. On a practical level, it is necessary to identify effective educational tools: objects, models, and paths, similar to those presented. At the theoretical level, it is necessary to reconsider the different educational approaches, choosing the most effective ones, the ones most closely related to the own way to teach, the most consistent and significant with respect to the topic we want to develop.

Teachers must naturally be aware of the system of knowledge that constitutes the discipline and of the innumerable interconnections that exist among the different branches of the Earth Sciences. A sector of educational research should be dedicated to research what to teach/learn because it is particularly meaningful and identifies the different conceptual nodes: deep time, flows, relationships, and complexity.

This requires a network of resources to build relationships between universities and schools, trying to bridge the gap between research and education. Only clearly defined and strongly shared objectives can bring teachers and geologists, aware of the importance of this discipline, of its field of research and of its development, for the protection and enhancement of the environment, natural or artificial.

Finally, it should be a priority for all those who are interested in this discipline to define a shared, coherent, and focused epistemological state for the Earth Sciences. This will allow to recognize that all the disciplines that constitute Earth Sciences are interconnected: only then, we would be closer to a model and a unified vision of our discipline. But everyone must be equally aware that this knowledge, with its plots and intuitions, is essential to develop basic skills for the student and for the citizens of today and the future.

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