Science, Society and Sustainability

Education and Empowerment for an Uncertain World

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6 Science Education for Sustainability

Teaching Learning Processes with Science Researchers and Trainee Teachers

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> In practice, institutions of education exist for teaching, rather than for learning or for learning to learn. What is learnt, above all, is information, routines and obedience, in other worlds, facts, procedures, and to do what one is told. [. . .]
>
> (Chambers 1997, 62)

INTRODUCTORY NOTES

This chapter presents some educational experiences conducted with postgraduate students engaged to become teachers and professional scientists. Such experiences can be seen as the practical application of the epistemological and educational reflections presented in Chapters 1 and 4, and they have the specific aim of supporting young people in the development of the required competences for building a participatory democracy and a sustainable society.

With respect to the experiences with future researchers, particular attention will be given to the relational aspects—in the interaction among lecturers and between lecturers and students—which have been quite interesting for us, but very little is written about this in the current literature. In relation to the courses with future science teachers, attention is focused on describing in some detail some of the activities that are proposed in the teacher education courses, with a view to illustrating the endeavor of building coherent links between learning and teaching processes and "transformative" educational aims, as described in Chapter 5. It was also our concern to bring to light and emphasize the variety and breadth of content—both disciplinary and transdisciplinary—that it is possible to deal with through this kind of reflexive and interactive educational approach.

TOWARD AN EDUCATING COMMUNITY

What choices of content and methodologies can teachers make when they want to address the issues raised by the new global era—both in science and society? This chapter looks at some of the educational approaches that our Science Education Research Group has introduced and tested over the years, with the aim of providing young people with the competences for becoming citizens of the "expert democracy" that was illustrated in Chapter 2. Our efforts were directed toward a transformation from a reductionist and objectifying view of the natural world toward a holistic and integrated view (Bateson 1973; Capra 2002; Gallopin et al. 2001; Manghi 2004; Sterling 2001, 2002 and Chapter 5). This view stems from an idea of the subject inquiring into the world, considering its aspects of ignorance, boundary and dependency, and valuing the sense of inclusion, wonder and respect—a view that is also in line with a post-normal science epistemology (Funtowicz 2001; Funtowicz and Ravetz 1999; Gallopin and Vessuri 2006).

The main principles informing our worldview and pedagogical practice are briefly summarized here:

a. Humanity is included in the natural systems and is totally dependent on them.
b. Natural systems have evolved over a long period of time and their structures and relationships carry the traits of their evolutionary path. This is currently expressed through their biodiversity, an ongoing result of both continuity and innovation of living processes interacting with the abiotic environment.
c. The relationships that humanity establishes with the environment are expressed through a multiplicity of channels, from the cognitive to the emotional. These, in turn, are shaped by the culture and the socioenvironmental context, so that what we know and how we know about natural systems is continuously shaped according to our worldviews, which nourish powerful narratives (Benessia, p. . . . in this book).
d. Because the Earth system is limited and interconnected, every reflection and every social practice can only be deemed democratic if it takes into account the link between ecology and equity.
e. Awareness of the consequences of one's actions is a necessary element for a sustainable life.

In the planning and implementation of educational activities, we gradually developed the approach of incorporating different elements and blending them in different ways—the idea of a bricolage (Kincheloe and Berry 2004; Chambers 1997), depending on participants' age, contexts and expectations. We can briefly summarize these as follows:

- A "basket" of choices: the underlying idea is that each person with whom we establish a relationship has different attitudes, interests and also things that one might not appreciate. All these aspects need to be taken into account and respected. If our educational offering is rich and varied, then it is more likely that each person will find something motivating that can help him or her to grow and develop confidence in his or her own abilities.

- A variety of strategies: silent, personal reflection, which allows one to get in contact with his or her deeper self; dialog and open exchanges with others to appreciate the variety of approaches and interpretations, and to reorganize one's own conceptual maps; working in small groups to cooperate toward a shared aim; searching for links between disciplinary knowledge and everyday events in order to learn to contextualize scientific knowledge and make sense of it in everyday life (Aikenhead 2006).
- A multiplicity of relational approaches within the group, which are useful in transforming hierarchical relationships into relationships of equivalence (Patfoort 2006), and may support the introduction of a nonviolent context (Galtung 1996). For such a transformation to occur, great care is taken in clarifying that, while people have different roles and responsibilities, it is important to respect and value the variety of characters, ways of expression and interests of each person.

In particular, our group has devised and widely tested role-plays on controversial socioenvironmental problems (Colucci Gray et al. 2006 and Chapter 8). These are complex activities, rich in opportunities with regard to knowledge and competences, as well as the multiplicity of relational approaches that are offered. In addition, such simulations not only deal with complex and controversial socioenvironmental problems and lead students to investigate implicit epistemic assumptions, but they also allow the tackling of the crucial aspect of conflict, proposing experiences of nonviolent transformation that are necessary in a framework of sustainability.

THE EDUCATION OF FUTURE RESEARCHERS

A few years ago, we were given the opportunity by the Piedmont region of Italy to design and implement a course on sustainability education addressed to young doctoral students and researchers from the University and Polytechnic of Turin, who were involved in research on environmental themes. The region had funded the researchers' studentships, and for this reason, they were interested in supporting our proposal of promoting, through an innovative course, a deeper knowledge of sustainability topics, and setting the basis for building a team of young scientists who were able to enter into dialog with one another and undertake interdisciplinary research.

The course ran for eighty hours, twenty of which were devoted to a residential stage in the mountains. It was an experience of great interest for all, students and teachers. Details of the organization of the course have been published elsewhere (Camino et al. 2005), and the final evaluation report is available from the Interdisciplinary Research Institute on Sustainability (IRIS) website[1]. In this chapter, we do not elaborate on the content of the course, neither do we focus on the students' learning process. Rather, we spend some time reflecting on the work of planning and coordination that involved a few of us as tutors in the course.

The majority of teachers/tutors were members of IRIS. The Centre has among its objectives not only the exchange of information, but also the promotion of dialog among different disciplines as a premise for the development of interdisciplinary research. While some of us had already entered some form of collaboration—i.e., Bravo, on the concept of Gaia as global commons (2004), and Bagliani et al., on a critical approach to the Kuznet curves (2008)—for other people, it was a new experience. Planning a course together did not imply reaching a shared idea of sustainability, but it certainly called for making explicit the research methodologies and the set of models, strategies and viewpoints—in other words, the interpretive schemes of each discipline—as well as their implicit assumptions and paradigms. Moving from a simple exchange of information (i.e., the results of empirical research or the references related to a topic) to a more intense dialog involving criteria for choices, discussion of the efficacy and reliability of methods and the inferential processes that were used to compare variables and produce results, generated controversies and many situations of tension. The efforts to listen to one another with humility and the desire to understand other researchers' perspectives were alternated with expressions of unease and mutual attitudes of de-legitimization and dismissal. It was interesting, if sometimes difficult to accept, to become aware that the so-called scientific premises of each discipline are carriers of worldviews and value-laden choices that were deeply rooted. Often, these assumptions would make it impossible to overcome controversies and resolve conflict.

In trying to understand environmental controversies, it does not make much sense to look for "what science really says." *Even the most apparently apolitical, disinterested scientist may, by virtue of disciplinary orientation, view the world in a way that is more amenable to some value systems than others. That is, disciplinary perspective itself can be viewed as a sort of conflict of interest that can never be evaded* (Sarewicz 2004, 392).

All the tutors involved have benefited from a great learning experience. The participation of a language specialist (M. Dodman, one of the authors of Chapter 4), a Jungian psychoanalyst and some scholars involved in artistic performances allowed the group of tutors to widen their perspective. The exchanges and interactions among them promoted a deeper insight into their own as well the others' disciplines, from both a methodological and an epistemological point of view. In addition, there was an opportunity to pose new questions to oneself about the processes of construction of new knowledge; about the role played by ignorance and the critical and crucial relationships between science, society and law within the perspective of a sustainable future (as reported in Chapters 1 to 4).

With respect to the relationship with the students who had been involved in an interactive and reflective educational relationship, we report here some comments from the tutors:

> Caretto & Spagna (artists). We needed to meet with the students and the other members of the IRIS group, to bring a deeper critical reflexion on our personal artistic research and the relation between it and the theme of sustainability, and the possibility of contributing to a fruitful discussion within the group. We had to clarify with other members of IRIS the role that we artists are trying to play as regards the links between art, science and sustainability issues. Not only at a conceptual level, but also in practice. [. . .] Students were keen to dialogue with us about the controversial links between art, science and sustainability.
>
> Perazzone and Tonon (Natural Scientists). [. . .] our two lessons did not aim at the construction of new knowledge by the doctoral students (as some of them probably knew more than us about the carbon cycle!). Our idea was that of casting light on the complexity of the real in relation to the inevitable limitedness of our interpretive schemes and our modes of representation . . .
>
> Giunti (National Park Ranger). I tried to pass on the idea that the understanding of such complexity [of the ecological systems] is a fundamental premise—at least at the level of attitudes and dispositions—for making territorial and political decisions both for the long and the short term and scale.

Students were offered a broad overview of the meanings of sustainability (Tukker 2008), and of the approaches that the different disciplines have elaborated in order to deal with sustainability issues. Moreover, students were given the opportunity of developing metacognitive competences (Bateson 1973; Varela et al. 1991) for dealing with problems by going beyond the empirical evidence, and above all, for accepting—at least in part—the sense of limitedness of human knowledge and the importance of creativity and intuition in the production of new knowledge.

Doctoral students appreciated the fact that some tutors were walking the path along with them, witnessing that they were also engaging in a process of learning: doubt, critical self-awareness and acknowledgment of error were valued and practiced by all participants. At the same time, it was useful to refer to the synthesis made from time to time by the more experienced tutors. This helped to make links between themes and perspectives that were, in appearance, very different from one another.

Some doctoral students remarked that a total change of mindset had occurred during the course, and their view of things had changed. At the beginning, it was not clear to them that the course was aimed at providing

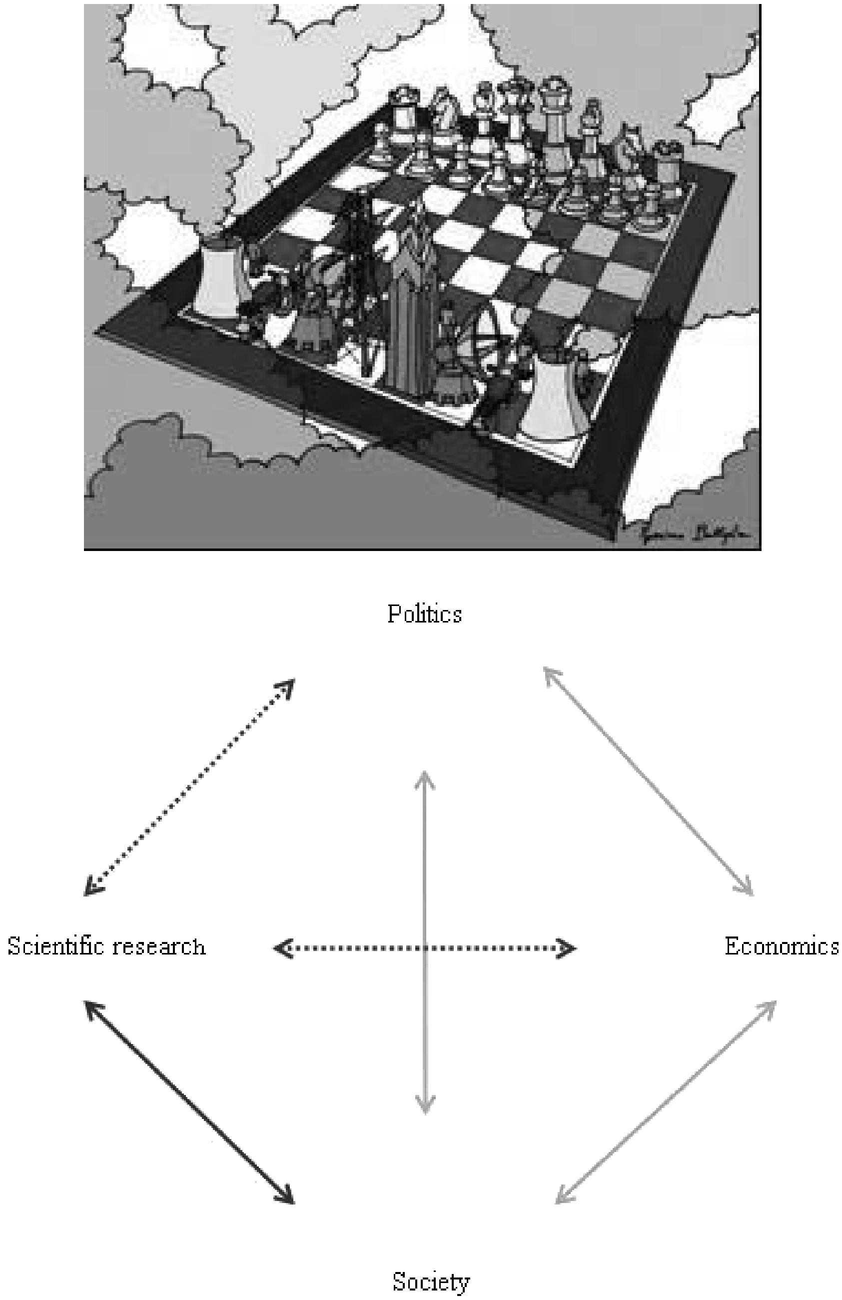

Figure 6.1 Two examples of "synthesis." (a) a cartoon that allowed participants to recall a debate on controversial issues. (b) a map underlying links between different perspectives.

new conceptual tools and promoting new interpretive schemes rather than simply transferring ideas. This had been said and repeated several times but it was not easy to understand. Only through experience and participation did they begin to make sense of it and appreciate it.

- At the beginning, it seemed difficult to link the information we were receiving with our own research field; only gradually it became "automatic."
- Numerous cues for reflection were offered to integrate the different aspects: a mental operation which I had not considered before and which is now occurring spontaneously.
- At the beginning I was asking myself what was the point of being there; I had difficulties in linking the topics with my specific discipline (chemistry). But then, when I understood that the barriers could be taken down and that there were significant links between science and art (which I used to keep strictly separate), I became very interested and I wanted to explore deeper.
- Listening to concepts which are used with different meanings by different tutors helps to de-familiarize some words, so that they are not too rigidly connected to "objects" or processes.

THE EDUCATION OF FUTURE TEACHERS

The Inter-University School of Specialization (SIS)

The members of the Science Education Research Group and IRIS lead several courses as part of the teacher training school in natural sciences. This school is characterized by two main educational strands: preparing teachers of mathematics, chemistry, physics and general science for the lower secondary school, and teachers of natural sciences, chemistry and geography for the upper secondary school. Students enrolled in a teaching degree at the SIS hold a science degree (i.e., natural sciences, chemistry, physics, biology, geology, mathematics etc . . .). Generally, biology and natural sciences postgraduates, enrolling for the teaching diploma in natural sciences at the upper secondary level, have a sufficient knowledge base for school teaching. In contrast, Italian school organization assigns only one person to teach both math and scientific disciplines (physics, chemistry, biology, geology) to students 11 to 14 years of age (lower secondary school). So, mathematics graduates, as well as any science graduate from the fields listed previously, can access this teaching job. As it is clearly an impossible task to adequately teach sufficient math to natural scientists or teach science to mathematicians within the two-year span of the SIS school, the science courses we are responsible for are perceived as an opportunity for introducing windows into transdisciplinary dialog. Through this approach, each participant shares his or her knowledge with a view to comparing and eventually integrating the different disciplinary perspectives.

Action-Research and Participation

The transdisciplinary research, as well as the teaching and learning activity carried out by our Research group is characterized by the practice of Action-Research (Marchetti 2008; McNiff 2002): "Transdisciplinary research is a form of Action Reseach. Participation and learning cycles have to start from the beginning" (Haberli et al. 2001, 9).

We are in a situation in which the researcher is internal to the process: the teacher-researcher is part of the same teaching and learning process that is being observed, and he or she is often supported by an observer who is responsible for recording the events, the dialogs and the activities that take place.

Data consist of observations, written down by the teacher-researcher or the observers during the plenary sessions or the group activities; products from the students, elaborated during the interactive and reflective activities introduced during the course; individual responses to questionnaires, group worksheets and end-of-course assignments. Such data is also a form of feedback that impacts the course itself; for example, with regard to the planning of future courses and, at the same time, with a view toward building theoretical models of more general validity. The evaluation of the impact of the formative offering on the students is conducted at the end of a process of data triangulation, involving the observer, the teacher and the students themselves. The students in particular are always asked to comment on what had been proposed and how they felt and participated as a form of self-evaluation. Through such means the relationship with the participants becomes more inclusive and equal—as is documented in some of the comments from the students.

This approach also offers the possibility to promote involvement from the participants and to develop an active relationship between the researcher and the "objects" of study. Within the framework of Action-Research, the "reflexive capacity" is a central element: this is intended both as a form of self-awareness on the side of the researchers (awareness of one's own preconceptions, implicit curriculum, expectations and educational aims), and as an attitude and competence to be promoted in the participants/students.

Research is therefore conducted in "real world" conditions; in other words, open systems in which people, information and situations are continuously evolving, just as happens in every learning and teaching process. Because of the educational context in which we operate, research has both an "exploratory" and "emancipatory" nature: the objective is that of trying to reach a certain level of understanding of what happens as a result of the stimuli that had been introduced, yet without losing sight of the primary intention, which is that of offering students the opportunity to develop new competences and abilities. Research is guided at the same time by an idea of education as an evolutionary and shared process, and by specific problems to be solved or to be overcome through a collective effort.

Unveiling Approaches

For a few years, our research group has been reflecting on the possibility of helping future researchers and teachers tackle the fragmentation and compartmentalization of disciplinary knowledge. The reorganization and integration of such knowledge by the learner would make for a more coherent acquisition of new knowledge, and also a more efficient use of such knowledge for understanding oneself, natural processes and phenomena and socio-environmental problems (Marchetti 2008).

One of the strategies that has proved useful in "making order" in the broad and often messy field of the learners' knowledge has been that of identifying and bringing to the learner's attention the different approaches underpinning the disciplines in the natural sciences. As reported previously in this chapter, scientists—when looking to a new problem—are always guided by previous knowledge and assumptions of their specific discipline, and they (often tacitly) apply ways of looking phenomena and processes that affect the choice of significant variables and the methods for data-gathering and elaboration. From a student's point of view, becoming aware of what are the interpretive schemes guiding scholars in exploring the problems that are typical of their own discipline can be extremely useful for understanding the motives that guided, as well as for making the objectives of the inquiry explicit.

All experimental sciences (but most explicitly natural sciences) are characterized by a variety of different approaches (Mayr 1982):

- the *descriptive* approach looks at structures, allowing for comparison and classification of life forms on the basis of their similarities.
- the *functional* approach investigates the dynamic processes that allow the harmonic balance between change and invariance.
- the *historical* approach is set up for reconstructing the possible scenario of a unique story, which is both individual and collective, and which unfolds along various time scales (e.g., from human to geological).
- the *systemic* approach (Odum 1997) is concerned with revealing the web of connections that sustains each life form (including human life), and which connects them within a hierarchically organized whole.

Each academic discipline (e.g., anatomy, physiology, ecology etc.) emerges from applying a prevalent approach to natural systems. Scientists are aware that each approach is necessarily both limited and limiting, and each one is framed within historical, cultural and linguistic contexts (Wittgenstein 1969; Longino 2002). Any scientific undertaking makes use of the specific epistemological status of each discipline, which is applied as a flexible and changeable tool (Dodman 1999). Moreover, specialized languages have been created and are continuously transformed in order to support each particular view (Chapter 4).

Clarifying the chosen perspective is also a way of making apparent the limits of any approach: attention to structural details requires cutting out the part that is being studied from its relationships or interactions with the other parts. Conversely, such relationships are crucial for those who are interested in emphasizing the mutual interactions occurring between the different elements of the systems. Some investigations require the simultaneous measuring of events occurring within a short time, but obviously, synchronic measures need to be integrated by diachronic measures in order to reconstruct the time course of single processes.

So, the different "ways of seeing" (descriptive, functional etc.) allow scientists to identify, frame and separate, either physically or conceptually, objects and processes from their context. This procedure is based on the definition of boundaries, which are, in different cases, either understood as barriers, preventing exchanges between contiguous compartments, or as privileged surfaces, intersected by flows of matter and energy. Equally, practicing with synchronic and diachronic readings (Arcà and Guidoni 1987), comparing different time and space scales (Gallopin et al. 2001) and looking for patterns (Capra 1997) can help us to develop "conceptual tools" for a transdisciplinary approach to the observation and interpretation of the living systems. As we will illustrate in the following sections, a dynamic and fluid application of conceptual tools can be—in our opinion—an effective way for revealing the nature of each single approach (Volk 1998; Maturana and Varela, 1998), and for integrating the various approaches with one another.

Using Conceptual Tools

Awareness of the variety of approaches and conceptual tools used by scientists may help students to realize that science progresses not only by selecting the objects of study, but also the conceptual categories through which the world is interpreted (Cini 1994). This process can help them produce a less naive and more mature view of the nature of science (Aikenhead and Ryan 1992).

Recognizing the plurality of perspectives and the limitations of each one is also helpful in developing awareness of the systems that we are studying, and in which we are at the same time embedded as an intimately interconnected part. A reorganization of knowledge made on the basis of the various approaches can help reordering, but it may not be sufficient for recognizing the complement of each approach and promoting integration between them. In this regard, we have experienced the use of particular concepts that proved useful for this particular purpose. Such concepts can be used as "tools" supporting the development of mental connections, bridges between the different perspectives and approaches. These are not new ideas: quite simply, we try to identify and implement methods that are easy to understand and put into practice, which can support the construction of a framework in which different systems of thoughts (and the accompanying knowledge) can enter into dialog with one another.

In the following sections, we provide examples of two conceptual tools: the idea of "boundary," and the way of looking at the natural systems through the lenses of "energy flows and matter transformations." On a number of occasions, during courses addressed to future secondary school teachers, we have devised and tested activities through which we aimed at developing competences in the use of such mental instruments. These activities usually require a couple of hours and they take place according to the methodology described earlier: brief moments of individual introspection alternated with work in small groups, plenary discussions, deepening of concepts, metareflections. Usually, such activities begin with an open question and they end with a multiplicity of answers and new questions. Indeed, the objective of these activities is not only that of providing a more complete and articulated overview of a scientific concept or issue, but also developing abilities in finding new connections and posing questions in an autonomous and creative fashion. On several occasions during such courses, discussion and reflection are focused on the strategies, the choice of content and the objectives and evaluation criteria of the educational activities that the students will, in turn, propose to their own pupils. For reasons of space, we will not discuss this particular aspect in this text.

The Concept of Boundary

The concept of boundary is profoundly rooted in each one of us: it originates from the experience of perception, and it is part of the primary metaphors of our cognition (Lakoff and Johnson 1999). The continuous shuttling between the literal and metaphorical meaning makes it a very powerful conceptual tool, which is also easy to use by children and young people.

Awareness of our disposition toward seeing and setting up boundaries, and at the same time, the double meaning of the concept (boundary as a way to separate parts or to allow exchanges), makes this concept a useful tool for connecting different approaches.

Boundaries arise from the choices of the researcher: to trace boundaries is never a neutral act. The choice of boundaries isolates elements and processes we want to study, and cuts out links and flows that connect "internal" and "external" parts of the system. Such a choice depends on properties known or attributed to the object under test.

A clear example is that of the cell. The concept of "cell" was born following the identification of the boundaries that surround some "cells", but it was the difficulty in delineating such structures that led to various discussions among biologists in the nineteenth and twentieth centuries (Virchow 1856; Mazzarello 1999). When studied by the morphologist, the cell membrane separates the internal environment from the external one: this compartmentalization allows electrochemical gradients to be maintained, which are essential to life processes. But it is also true that the cell membrane is the crucial point of passage and exchange between inside and outside: because of the sophisticated characteristics of selectivity of channels, pumps and carriers, life functions can take place, such as the transmission of electric signals or fast ionic flows.

Once applied to the cell, the concept of boundary can become a conceptual tool to explore other borders at different scales: for example, what are the boundaries of an ecosystem? This question has been asked during courses with future teachers as a trigger for reflection (Camino et al. 2002), and it always generates a sense of puzzlement. The majority of participants provide a structural definition (the limits of the woods, the margins of the beach around the pond[2]): only a few people are able to put forward an answer that is in line with the relevant discipline—ecology—which focuses on relationships and flows. Starting from the definitions offered by the student teachers, it is possible to generate an interesting discussion, reasoning around the nature of hierarchical systems, asking about the difference between ecosystems and biomes, looking at disciplinary perspectives and approaches. The discussion can also be enriched by short explorations of textbooks, readings of scientific articles and interviews.

> Among ecologists willing to draw *any* lines between ecosystems, no two are likely to draw the same ones. Even if two agree, they would recognize the inherent artificiality of their effort, and probably make the attempt with only a few species in mind. [. . .] Different lines are not surprising, but rather are entirely expected, because of the intrinsic interconnectedness of living systems: *the discrepancies between scientists accurately reflect the diversity of the real world* (Corn 1993).

> Ecosystem processes are scale dependent and, as such, *the choice of boundaries for an ecosystem is of profound importance to the conceptualization of an ecosystem* and the scope and validity of questions being asked within that ecosystem. The process–function approach . . . addresses the functional role of constituent parts of ecosystems and, therefore, is often organized around understanding the cyclic causal pathways that maintain ecosystem functions. Energy flow and biogeochemistry are points of focus for ecosystem ecology under this approach (Post et al. 2007, 112).

Once the concept of boundary has become a conceptual tool, it can be applied to other fields and it can be unveiled where it is not explicitly defined. We can cite two recent cases in which the ambiguity in the definition of boundaries generated scientific controversies of great relevance given the socioeconomical implications. The first case refers to production of biofuels, which has divided the scientific community: on one side, there are those who think it is an effective solution for reducing greenhouse effects; on the other side, there are those who maintain their inefficacy. Nobody had done their calculations wrong, but each side reasoned according to different boundaries (Patzek and Pimentel 2005).

Reflecting on boundaries helps future teachers to not only reason about ontological aspects (the interconnected and interdependent nature of real world) but also on epistemological aspects:

> A useful practice in scientific research would be to always define the system within which we isolate or delineate the problem investigated, and to look for relevant interlinkages. In other words, look outwards to examine how the issue/problem is linked to other variables, issues or systems (horizontal and vertical or cross-scale linkages), in time and space. Only then we can meaningfully ignore the rest of the system (if the linkages are negligible) or decide how, and to what degree, to include the broader system in the research (Gallopin et al. 2001, 228)

A fluent competence in applying the concept of boundary can also help us move more easily along changes of scale. For example, what are the boundaries of our body and what do they consist of? Dealing with the topic of nutrition by looking at all the barriers that the molecules encounter in their journey through the organism helps to understand many processes: from the boundary of the mouth, perceived as the entry door, and where, through ingestion, food disappears from our perception to the long, slow and laborious process of breakdown and digestion. This process reduces food particles to the acceptable dimensions for getting through the "real" boundary—the intestinal walls—with their extraordinary selective properties.

Physically different but conceptually similar is the barrier that the molecules of air, oxygen, carbon dioxide and nitrogen have to go through, as they are also dealing with cell structures. Hence, the idea of boundary allows us to connect not only the knowledge developed from the different approaches (in the examples above we looked at structural, functional and systemic approaches), but it can also facilitate the conceptual leap from the explanations of processes taking place at different scales.

In conclusion, reflection on boundaries takes us back to a fundamental strategy for knowing: it depends on us wanting to see the world as all interconnected or divided. After all, if it is true that everything is connected, as some maintain, in order to make sense of our "dialog" with the world, it is important to be able to organize our view of the "undifferentiated phenomenic flux" (Cini 1990) by identifying and labeling parcels bounded in space and time; in structures or levels, phenomena, events or processes. In so doing, we can try to understand how some things are connected to others and to define, even if arbitrarily, at least something about the nature of their relationships (Arcà 1993, 1995).

Energy Flows and Matter Transformations

In a time when energy is one of the most talked about topics in society, it is sad to see how little schools and universities try and help young people to understand more about this concept. Particularly with respect to answering some key questions (Where does it come from? Why is it "consumed"? Why do we have an increasing need of it?) and, above all, to learn to link energy problems with other issues, which are closely connected, such as the transformation of natural systems, water consumption, the role played by food habits and international commercial trade.

School and university education in Italy provides a very fragmented, disciplinary approach to the study of energy. This often means that young postgraduates attending teaching qualification courses do not have the opportunity for a dialog among them about energy, even if they share a science background (if they are physicists, chemists, geologists or biologists). Each one of them refers to definitions, interpretations, physical variables and models that are so different that it seems they are speaking about processes and phenomena that do not have anything in common. There are interesting studies and educational reflections on this problem, which, unfortunately, are unknown to disciplinary specialists, in particular Keith Ross (2000a, 200b) and Doménech et al. (2007).

Smil (2003, 2008) presents the theme of energy through a historical perspective, and connects theoretical aspects with quantitative data and socioeconomical reflections. What is particularly interesting is Smil's effort to link energy use and ethical issues through a rigorous and quantitative approach to lifestyles:

> rich evidence leads to the conclusion that the average consumption of between 50–70 GJ/capita provides enough commercial energy to secure general satisfaction of essential physical needs in combination with fairly widespread opportunities for intellectual advancement and with respect for individual freedoms (2008, 352).

These data, accompanied and supported by a huge variety of information, lead to the writing of a striking conclusion to the book: "shaping the future energy use in the affluent world is primarily a moral issue, not a technical or economic matter. So is the narrowing of the intolerable quality of life gap between the rich and the poor world" (Smil 2008, 370).

Thus, a serious and detailed, scientific quantitative analysis leads us to confirm concepts that had been previously expressed in qualitative form about a century earlier by Gandhi: "Earth provides enough to satisfy every man's need but not every man's greed."

Given the scientific and social relevance of energy issues, it seemed important to us that our educational research included a study of the topic of energy. Among the various activities that we have tried out, some have proved particularly effective: for example, the presentation and shared reflection on the "scale of energies," which allows us to appreciate the enormous range of orders of magnitude through which energy can manifest itself, as well as the equally large variety of physical descriptors that have been introduced for the purpose of defining and measuring it. Through a reflexive conversation with the student teachers about the scale of energies, it is possible to find points of contact between the approaches of physicists and chemists (who think in terms of electron volts), physicists and biologists (with the conversions between calories and joules) or botanists and ecologists, who are dealing with the comparisons between the energy that is captured during each photosynthetic process and the energy that is gathered by the entire terrestrial biomass (Volk 2001): "the key concept is embodied energy, the portion of solar energy that comes to reside in the bodies of photosynthetizers as chemical energy and that is used to fuel the metabolism of other organisms" (157). The extraordinary dance of energy and matter, and the mutual influences and interactions connecting life and abiotic environment, are of crucial importance for understanding not only how the natural systems work, but also ourselves within such systems, as we have managed to increase our power from the modest 50–60 watts of our basic metabolism to 10,000 or more watts (Smil 2003), thanks to the availability of numerous "energy slaves." In the United States, each person has the equivalent of 100 energy slaves working 24 hours a day for him or for her.

Thinking together with future teachers about flows of energy and matter transformations—first through simple and well-defined cases, and then extending the reflection and exploring time and space scales of higher and lower orders—allows us to acquire a powerful conceptual tool that we can use to reorganize our ideas, makes us aware of our actions and inform our choices.

In the following sections, we will describe some examples of activities carried out in the context of one of the courses addressed to future teachers of mathematics and science in the lower secondary school. The activities that are described here are relatively simple: once more, they can be enriched and made more complex depending on the way they are being proposed and on the level and degree of students' participation—individual reflexion, exchanges of points of view, dialog, formulation of new questions, updating through recent scientific research, social and economical implications . . .

Behind the History of Things

The reflection that inspired the activity we describe here stems from two considerations. On the one hand, many science teachers still hold tight to a transmissive teaching style. They also continue to use explanatory language, by means of which natural processes and phenomena are described as simple, noncontroversial facts. This deprives students of the opportunity of being genuinely involved and expressing their points of view as individuals contributing to knowledge construction. On the other hand, the central role played by narration in learning processes has been widely described by many authors (e.g., Cladinin 2006), and it is considered again in this book in Chapter 8.

In our courses, we have tried to give space to narration: we started from the observation that often, the stories of "objects" are focused on their movements in space and time, from the past to today, as if they were products with stable identities. We wondered if, by means of different modes of narration, we could shift attention from products to processes (from conservation to transformation, both at the micro- and macroscopic level) and from matter to energy (i.e., to the causes of movements and transformations).

Some familiar objects are taken to class and randomly distributed among the participants (some are natural objects; others are artificial ones); for example: a bird's feather, a piece of plastic, a pine cone, the plastic wrapping of a mail packet, a bottle full of mineral water, a seed. In the first part of the activity, students are invited to work individually and write about the following points (each request is given only after the previous task has been concluded):

1. Tell the story of . . .
2. Extend from past to future
3. Tell a new story in terms of processes of transformation
4. Identify the causes of such transformation

This activity is welcomed with curiosity by participants, and it is usually carried out with interest. By comparing the different stories, it is possible to appreciate the variety of ways in which the students have interpreted their task, the tendency toward looking at the products or the processes, their creativity. The written texts are great stimuli for connecting different perspectives: on the one hand, there is the story of the dead leaf "which lived in a park, it fell from the tree when it was not yet completely grown, and it was carried by the wind to the feet of a person who picked it from the ground"; on the other hand, another contribution refers to transformations of a plastic spoon with an industrial past and connections to the oil factories, the oil rigs and even further past, the sedimentation and diagenetic origin from a very ancient plant . . .

Through the search of what is behind the stories, it is possible to make links with the transformations of matter and energy that were necessary to produce them. These are the premises for acquiring the concept of Life Cycle Assessment, a technique to assess the energetic and environmental aspects associated with a product, process or service by compiling an inventory of relevant energy and material inputs and environmental discharges, and evaluating the potential environmental impacts associated with identified inputs and outputs.

The sharing of the texts written by student teachers, and the discussion that follows, helps to cast light on the role of energy (in its various forms) in any process of matter transformation, either in the living world or the world of manufactured objects. Knowing such concepts can help inform choices in everyday life. For example, it is sufficient to think about the increasing number of products that are now sold with the logo "ecolabel." The close interactions between energy and matter also emerge, and together it is possible to touch upon the concept of eMergy: this is the energy required directly and indirectly to make something, or the energy of one type that is embodied in any form of energy, good or service (Odum 1998). Up to now, we are not aware of such a concept being introduced in university courses and known to our students, even those holding a degree in physics. Yet, it seems crucial nowadays to reason not only on quantitative aspects, but also about the quality of energy (which was the motive behind Odum introducing this new concept).

Reasoning about eMergy offers the opportunity to analyze significant themes in ecology, which are often dealt with in a superficial and inappropriate manner at school. According to most textbooks, the food chain and the biomass pyramid can be explained as a linear energy transformation chain; at each step, some energy is degraded and some is passed to the next step. These concepts can be clarified and enriched through the emergetic perspective that reveals qualitative as well as quantitative aspects. A teacher aware of the implications of such knowledge will be able to develop among their young students an appropriate reflection on this fundamental topic in ecology, which is too often reduced to a mechanical scheme in school textbooks. Energy flows along a food chain are interconnected with huge matter use and transformations, as with carbon dioxide production and water consumption[3].

The City Under the Dome

The conceptual tool of energy flows and matter transformations can help connecting processes that take place on very different scales of time and space. Often the explanations of textbooks keep such processes strictly separate because they are dealt with by different disciplines. Aspects of thermodynamics and ecology can be integrated with the physiological perspective through the concept of metabolism. Here, we briefly describe the main points of an activity that was taken from by the book by Wackernagel and Rees (1996): the book that signaled to the general public the birth of the now widespread concept of the ecological footprint (EF).

Participants are invited to form small interdisciplinary groups, then they are asked to answer some questions:

1. What would happen to any modern city [. . .] if it were enclosed in a glass or plastic hemisphere that let in light but prevented material things of any kind from entering or leaving?
2. Then, let's assume that such a city is surrounded by a diverse landscape in which cropland and pasture, forests and watershed are represented in proportion to their actual abundance on the Earth, and that adequate fossil energy is available to support current levels of consumption using prevailing technology. Let's assume our imaginary glass enclosure is elastically expandable: How large would the hemisphere have to become before the city at its center could sustain itself indefinitely on the land and water ecosystems and the energy resources contained within the capsule? (Wackernagel and Rees 1996, 9–10).

The teaching/learning context and approach are as already described, alternating reflection with small group work, debates and collective discussions. By starting from the exercise described here, we have built up a learning experience that allows participants to become aware of the extraordinary increase of energy flows, transformations and transfers of matter that have become possible by means of technoscientific development and the expansion of industrial societies.

The move from the almost closed ecosystem (in terms of matter cycles) of ancient human settlements—from the prehistoric to medieval ones (King and Monger 1986)—to the open ecosystems of modern cities has implied a progressive increase in the EF, alongside a parallel impoverishment of the availability of goods and services for "peripheral" populations.

This activity allows future teachers to reflect on two important and complementary aspects: on the one hand, the total dependency of humanity on global natural systems (the inhabitants of a city "under a dome" would perish within a few days); on the other hand, the relationships between ecology and equity. In a closed system, such as the Earth, with a fairly constant flow of energy from the sun and a limited availability of matter and natural processes, the perspective of equal distribution of resources for satisfying everyone's needs is critical.

Real Leaf, Fake Leaf

The capacity for artificially reproducing natural "objects" is extraordinary: artificial flowers can be produced that are almost indistinguishable from the real ones. It is not unusual when entering the lobby of a hotel to be welcomed by a wonderful fichus . . . made of plastic! The eye, perhaps, is satisfied, but something subtle has changed. .

Student teachers are invited to make a list of the similarities and differences between a real leaf and a fake leaf, which is identical with regard to shape, color, dimensions, thickness and consistency, but it is made of plastic. This activity leads future teachers to apply the interpretive approaches of their respective disciplines (physics, chemistry, natural sciences) in order to carry out the task. As often happens when proposing activities that appear quite simple in the beginning, this exercise progressively generates a series of open questions and mutual learning. This happens because the language and models of physics (i.e., the selective absorption of electromagnetic waves by molecular structures) cannot be easily integrated with the perspective of chemistry (i.e., the absorption function of chlorophyll: "120-plus atoms arranged into a binary structure [. . .] absorber extraordinaire used by virtually all photosynthetizers" [Volk 1998, 128]). Even among the same group of biologists, there are those who choose a structural approach and those who prefer looking at the functional aspects about the occurring processes. The different disciplines guide the choice of different space scales: there are those who look at the relationships between the molecules, yet neglect the macroscopic morphological and functional aspects (the stomata, the lymph), and the role that the macrostructures play in the processes of photosynthesis and respiration: the study of such processes makes quite apparent the inseparability of living beings from their context and their mutual modifications. Active debates arise about the fluctuation of temperature in the real leaf and in the fake leaf. The approach of thermodynamics (the vibrational levels of molecules) is compared to the interpretive schemes of biology (the homeostatic systems of control, water movements etc.). As the analysis develops, the differences between the characteristics emerge, as well as the stories and the functional properties of the living tissue of the leaf as compared to the thin plastic sheet.

Thanks to the dialogic approach of the educational process, the compartmentalized vision of the graduates is enriched and made fluid. Identifying the flows of energy and matter transformations at the different space and time scales acts as a powerful conceptual tool that helps to grasp the complexity and the interconnections between the different levels of the natural systems in which both we and the objects of our attention are a part. This competence is very much a necessary one for the citizens of the global world. It helps them to grasp connections that often are not made explicit. For example, it drives us to grasp the relationship between energy production and water consumption[4], or between the power supplied by an engine and the amount of exhaust gas, or even between food choices and energy input.

Global Issues

The conceptual tool of energy flows and matter transformations can be applied to a great variety of processes, phenomena, situations and systems. It is not a matter of looking exclusively for "science" topics; on the contrary, everyday life, both at the personal and collective levels, can be effectively explored through this conceptual tool. We refer here to two activities. Both were undertaken by starting from two open questions expressed respectively in a graphic and iconic form. The activities were carried out as previously described: an initial moment of personal reflexion, then sharing, discussion and gathering of further information until new connections are made and new questions are formulated.

Oil Eaters

> *Some authors maintain that we—inhabitants of modern industrial societies—can be defined as "oil eaters." Why? In your opinion, is the sentence to be interpreted literally or figuratively?*

This activity is part of a research strand that we have been pursuing for many years and that is looking at the level of awareness that science teachers have of the role that the natural sciences can play in promoting understanding of socioenvironmental problems. Thinking in terms of energy flows and matter transformations in following the chain of processes of food production and consumption can be very useful for understanding that the consequences of the energy crisis are not only manifested in the transport and industry sectors. A reduced availability of oil can have a dramatic impact on global food production. In vast areas of the planet, in fact, this is totally dependent on fossil fuels to provide petrol for machinery and harvesting systems, and it is also dependent on their byproducts for the production of fertilizers and pesticides. "The most damaging, dangerous and certainly the least noticed aspect of the contemporary food system is the extent to which the supply of even the most basic food has become dependent on petroleum" (Jones 2001).

Indeed, future science teachers to whom we have proposed these activities have so far shown to be generally unaware of the dependency of the modern agricultural system on nonsolar energy inputs. By reflecting with them on the energy flows and matter transformations in the processes connected with food production, it gradually emerges that it takes energy not only to transform matter, but also to acquire, transport, store and even use energy. Such invested energy may be compared to "returned energy," and a new powerful conceptual tool can be applied: EROI (energy return on investment); that is, the ratio of the energy delivered by a process to the energy used directly and indirectly in that process (Cutler 2004).

This concept can be simplified, made usable also by younger pupils and applied to illuminate some inconsistencies of our affluent society:

Eo/Ei expresses the ratio between the energy content of food product and the energy that was required for producing, processing, packaging and preserving it. By simple calculations, we can discover that in traditional and pre-industrial societies, Eo/Ei is approximately equal to 100; for the products of mass distribution, Eo/Ei can shrink to values that are even less than 1! (Jones 2001).

Reflecting on the relationships between food and oil can be used to widen the discussion to include the extraordinary possibilities acquired by technoscience for the transformation of matter by means of an increasing power density (W/m^2) and energy intensity (J/g) (Smil 2008): corn can be used in baking tortillas, as well as for ethanol in cars and power plants; natural gas can be made into fertilizers for food output. New avenues have been opened for the deployment of matter and energy, yet with some unexpected outcomes for those who did not take into account some fundamental concepts: each new usage is located within a closed system—the Earth. In such a system, the availability of matter is limited and the eXergy—that is, the capacity of energy to produce mechanical work—progressively decreases.

Interlinked Ecosystems

One of the IRIS members, Massimo Battaglia, architect and cartoonist, endeavored on various occasions to represent by means of vignettes some of the themes dealt with during our courses and stages. Some of these vignettes appeared to be particularly effective in generating open questions and therefore we used them for educational purposes. We present here one such vignette, which proved useful in relating two conceptual tools: the "boundary" and "the energy flows and matter cycles."

The cartoon was presented to all participants at the beginning of a lesson and it was accompanied by a particular task: "to give a title, write a caption and list some topics of the life sciences which have relevance for the depicted scene." Such an iconic suggestion elicited a variety of interpretations that

Figure 6.2 Vignette for "boundary" and "energy flow and matter cycle."

were provided by the participants. The analysis of the answers given to the questions from the cartoons showed a rich variety of explanations/interpretations, which provided cues on the underlying views and value systems of the participants (e.g., "natural world against modern world"; "equilibrium between production and consumption"; "North and South"). With regard to this vignette, interpretations that were opposed to one another were also given. It was interesting to see how this made an impact on the participants and made them more interested in listening to the voices of others. This was not to be taken as a premise for counteropposition and argumentation, but as the start of a growing awareness of the limitations of any single interpretation and the potential of a plurality of ways of seeing[5] (Volk 1998; Ravetz 2005; Chapters 1 and 2). Exploiting the possibility to represent metaphors and paradoxes by means of images, the vignette allowed teachers and students (after the sharing of the different perspectives) to cast attention on two elements. The first was explicit and it referred to the possibility to draw as adjacent two environments that, in reality, are geographically distant. The other (that was only subtly hinted at and was not grasped by everybody) referred to the energy flow and the transport/transformation of matter between North and South on the planet. With the extraordinary increase in international transport, both in numerical and power terms, enormous quantities of goods are transported everyday from one side of the world to the other. In this process, the closed cycles of natural ecosystems are made linear and, by opening the boundaries, they contribute to creating a unique, global ecosystem. The final, collective reflection allowed the group to develop a greater awareness of the interlinking of scientific knowledge, technological applications, energy resource use and everyday choices in modifying ecosystem boundaries (Odum 1997), as well as in redesigning the web of life at a global level. Moreover, some students enriched their final report by creating new cartoons that they proposed as examples of effective teaching tools for secondary school students.

Playing with Language

> Understanding is fluid, flowing like water,
> while knowledge is like blocks of ice that prevent the flow.
> Such is the difference between knowledge and understanding.
> (Thich Nath Hahn)

One of the risks of a transmissive approach to teaching is that of contributing to "fix" concepts in a process whereby the signifier and the signified become "stuck" together, leading to the "thingifying vision" of science (Chapter 4). The risk is greater the more the concepts concern phenomena, processes and events that escape our direct perceptual experience. Offering opportunities to reflect on concepts—even on a few, selected examples—can help students develop, not only a more adequate scientific knowledge of those concepts, but also a more general awareness that will enable them on other occasions to distinguish object from concept and understand how every concept has a historical development, is dynamic, transitory, as well as often being a vehicle for multiple meanings. Above all, it helps to recognize how concepts are powerful and flexible tools that facilitate new mental connections (*cum–capio* = I connect), not, as often happens, a rigid product to memorize.

Towards Making Concepts Fluid

The Concept of Gene

The activity begins by encouraging student teachers to write down their own ideas about the concept of gene. The ideas normally range from, most commonly, that of an object (a piece of DNA, a cluster of molecules, a particle, a structure) to that of a process (a factor that permits the expression of characteristics, a unit of genetic expression, a hereditary unit). Comparing the ideas and categorizing them during a plenary session creates the basis for further steps. First, particular linguistic features can be identified (e.g., the presence of metaphors); then, a search is performed with books, websites, recent publications or books on the history of science (e.g., Keller 2000). Each time new cues can emerge and different aspects can be investigated, depending on the interests and competences of participants. The teacher helps to develop the emerging ideas by asking open questions, underlying ambiguities, offering citations from authors embracing different views etc.

> It may well turn out that all we can say about genes is that they are continuous or discontinuous DNA segments whose precise structures and specific functions are determined by the dynamics of the surrounding epigenetic network and may change with changing circumstances (Capra 2002, 177).

Alternatively, the history of the evolution of the meaning of gene can be reconstructed, providing illustrations of the way in which the gene has been interpreted in different ways by different authors over the past 100 years, a situation that continues today (Fox-Keller 2000, 31):

- The "gene" is nothing but *a very applicable little word*, easily combined with others, and hence it may be useful as an expression for the "unit factors," "elements" or "allelomorphs" in the gametes.
- There is no consensus opinion among genetcists as to what the genes are—*whether they are real or purely fictitious*.
- Watson and Crick convinced biologists that genes are real molecules, and this was followed by *the identification of DNA as the genetic material*.

- We are far from the idea of a self-contained, stable DNA. *DNA alone cannot even copy itself*; besides, without a complicated system of monitoring, revisioning and correction, replication would encounter many errors.
- The stability of gene structure thus appears not as a starting point, but as an *end-product*—as a *result of a highly orchestrated dynamic process* requiring the participation of a large number of enzymes organized into complex metabolic networks (. . .).

Finally the participants are asked to reformulate the concept of gene within an interdisciplinary perspective through the construction of concept maps (Novak and Gowin 1984). Here is how some trainee teachers commented on the activity:

> To our surprise we realised that our first ideas of the map were a disaster! The word gene didn't even appear and the central element involuntarily became DNA [. . . .] We tried to rethink our mental schemata. Time and space are the basis for all the concepts introduced which, even if retaining some important structural and functional aspects, open up to other epistemological fields that lead to the reconstruction of the history of life, ethics, relationships with culture, medicine . . . (participant to a SIS Course, A060, 2006/07)

In this way, significant results are reached through the deconstruction and reorganization of scientific knowledge within the group, through the development of linguistic competence and the ability for epistemological reflection, and through the opportunities for applying interdisciplinary approaches.

A complementary exercise that can be proposed refers to the idea of gene as investigated through the conceptual tool of "boundary." In the science community, three models of genes are held up (Barbiero et al. 2006): they differ on the basis of the boundaries that are established to define the gene: (1) exon model; (2) genic DNA model and (3) integrated model. According to the first one, the only significant elements of a genome are the exons—the DNA sequences transcribing for a specific gene (Crick 1958). This model does not take into account the links between gene products nor the networks with the organism: a boundary is established by translating the DNA sequence (exon) to a gene product without considering networks between gene products. The "genic DNA model" includes DNA sequences transcribed to RNA but not translated into gene products: such a model, though still excluding intergenic DNA (over 70% of the human genome), is extremely complex, and so far it has been impossible to exploit knowledge coming from this approach. Finally, the "integrated model" considers the genome as a whole, including intergenic DNA, its evolutionary process, its links with the host cell and its exact copies in all other cells of the organism. This model shifts the attention from objects (genes, proteins) to the circular relationship between organism and genome.

A Plurality of Signifiers and Meanings

Many of the words in scientific language are used to express a literal meaning, whereas the same words used in everyday language express a figurative meaning. For example, in scientific language, "vital" refers to something living, whereas in everyday language it is used to refer to something very important. There are numerous examples of this phenomenon in science education literature, and teachers should be very aware of the need to define meanings in context. With postgraduate student teachers of science, we have based a rethinking of the concept of evolution of living beings on a comparison of the different uses of the word "evolution" in everyday and scientific contexts, such as the evolution of the embryo, the psychology of early age (childhood and youth) and evolutionary biology. In one of our courses we distributed individual questionnaires: all the questions elicited some reflection upon words concerning the evolution of natural systems. We report here two questions that stimulated answers that gave rise to lively discussion and helped—through a linguistic approach—to develop knowledge and awareness of various evolutionary biology issues.

> *The words "evolution" and "revolution" are both connected to the idea of change, but express different types of change. Write two sentences using these words and explain how they exemplify the difference.*

Through a participative reflection focused on language, it was possible to enlighten some implicit assumptions held by student teachers. Most of them held a deeply rooted idea of evolution as a slow and gradual process, and were not aware of the model of punctuated equilibria, proposed by Eldredge and Gould in 1972.

> *What is meant by "species A is more evolved than species B"? Is this expression scientifically correct?*

We collected many varied answers that were shared and gave rise to much debate. The majority believed the expression correct, but with different supporting arguments: if A is more complex, more ancient, modified more times as regards ancestors, more similar to man, more specialized. Those who believed the expression incorrect affirmed that it is not possible to measure a level of evolution, or that it makes no sense to compare the evolution of different organisms.

These activities share a number of aspects: they stir up cognitive as well as emotional involvement, offer opportunities for peer education and promote genuine motivation for deepening one's knowledge of issues. After such inter- and transdisciplinary activities, bringing linguistic and epistemological reflection together with rethinking scientific concepts, the majority of the participants declared they had built new and significant knowledge and developed greater awareness of the dynamic nature of scientific knowledge itself, as well as being more motivated and ready to work on the theme of evolution with secondary school students (Cerruti 2007).

Nominal Language Hides Subjects

As we have seen in Chapter 4, nominal language has a great synoptic capacity, gained, however, at the cost of hiding processes and agents (Dodman et al. 2008). The following is a simple activity that can help become aware of implicit assumptions about worldviews (sometimes also antithetical, depending on the participants). First, there is a brief discussion of some features of language: for example, how words are sometimes used literally but more often figuratively, or how context is all-important in determining meaning. Then, in groups, students are invited to write sentences on strips of paper containing words derived from "sustain." The sentences are grouped and categorized on the basis of any criteria the students wish. Next, the different criteria are illustrated and discussed. Among the most common are usually those of literal/figurative meanings, grammatical categories and fields of use (psychological, environmental, political etc.). Finally, the participants are each asked to write a way of expressing in verbal, everyday language the synoptic expression "environmental sustainability," making agents, processes and objects explicit. Normally, two types of sentences are produced: one of which considers that human beings sustain nature, while the other states the opposite. From these differences emerge questions for reflection and discussion, with a subsequent decision to further investigate the issue from a scientific and philosophical point of view. The following are three sentences written by young scientific researchers working on environmental issues:

- The earth sustains our use of its resources, even our exploitation of them.
- We sustain each other reciprocally. The earth sustains us and we should sustain the whole system.
- Man sustains the environment by conserving the resources for future generations.

Reconnecting Outside and Inside

We have come to the boundaries of our planet—the exploration shifts from the external world to the internal world.

Human beings live in a world which is
in some way mysterious;
new things that happen and which can be experienced in it
cannot be explained and
not only those things which happen in the realm of what is expected.
The unexpected and the absurd
belong to this world.
Only then, life is complete.
C. G. Jung

While it is still widely practiced, teaching based on representation and transmission, explanation and demonstration of the scientific basis of the single disciplines has limited effectiveness and negative consequences, although often involuntarily so. Transmission-based teaching is one among many strategies; it serves precise and limited purposes: for example, to introduce a new topic, summarize or reconnect to previously met ideas. A vast literature produced by research in science education has illuminated the risks of rote learning and superficial understanding. The abilities to generalize and use information acquired in other contexts are limited, and students elaborate, often unconsciously, an idea of science that is objective, neutral and that describes reality "as it is."

As a consequence, young people develop the tendency to perceive scientific knowledge as the knowledge of *something,* rather than knowledge that is socially constructed and negotiated. Teaching strategies that are heavily based on explanation and demonstration contribute to offer a *"thingifying"* view of science (Larochelle and Désautels 1991; Désautels and Larochelle 1998), which is often accompanied by a sense of alienation, if not fear, toward nature (Chapter 4).

Giving value to personal experience, the development of critical and reflexive attitudes, the openness toward listening to others, the bringing together of specialized approaches within a transdisciplinary perspective, the importance of context, the seeking of a plurality of points of view, the acceptance of limits, the awareness of the possibility of going wrong . . . in all these aspects we recognize precious elements that every teacher can use to propose educational experiences within a perspective that we can define as "post-normal" (Chapter 1).

Recognizing and appreciating the different approaches that sciences make use of to explore the natural systems, as well as using conceptual tools for integrating knowledge, can give more meaning to our vision, but this is not sufficient. These are mental operations that engage us mainly at the cognitive level, while other dimensions (which are unsaid and unrecognized) are left in the background: emotions, artistic intuition and experience. In order to help future teachers also make use of these other approaches to knowing, it is important to get them personally involved and explore the dimension of the internal self. So far, we have described steps toward the visioning and promotion of an "educating community," in which each participant feels at ease, shares experiences with peers, is willing to explore the natural systems and understand their functions. In achieving such an aim, the emotional dimension of our knowledge of nature plays an important role that, perhaps, has been underestimated.

Retrieving Memories of Childhood

We mention here briefly an activity that we have been proposing for many years to future teachers of secondary schools, with outcomes that move and encourage us. As for the other activities described in this chapter, this is a fairly simple one; however, proposing it within an academic context, giving it as much time and respectful attention as for the more traditional activities, acts as a stimulus for the participants. In particular, they are invited to reflect not only on the specific task given to them, but also more widely to ask themselves why in schools—and particularly during the hours of science—there is very little opportunity to express our most profound feelings toward nature, to talk about oneself and the emotions generated in our encounters with nature.

The task is the following: after a short moment of silent concentration, we ask student teachers to write about a vivid memory from childhood that is connected to nature and to explain why it has remained so strongly impressed in their memory. We transcribe here some of the comments:

> The only but precious memories of my childhood are the summers I spent on the alps with my grandmother. I remember in every detail the days with the animals, the food I was eating, the games I was playing and my stick. Memories of Turin—almost none.
>
> When I was playing football in the wheat fields near my house. The wheat had just been harvested and the stingy bits were left (it was sore running over them).
>
> Afternoons spent at my uncle and aunt's country house in Sicily. A swing made of a wooden board and hanging from a tree—the wild asparaguses, the places where I was running.
>
> The color of the bluebottles which I have never seen any more in the fields. I was going looking for them on my bicycle.
>
> When I was playing with my brother in amongst the tall grass: we would dig out a kind of hole in the grass. We would stay there I don to know for how long. It was springtime, with the sun, the ants, the bees buzzing . . . it was very nice, we would play with the grass, we would not get bored at all . . .

This activity can be reconnected to the vast literature on the role and importance of the experiences of nature in childhood (e.g., Nabhan and Trimble 1994; Sobel 1993; Thomson et al. 1994; see also Chapter 7). This is a fascinating and important theme, which the scientific education of future teachers of secondary school often does not take into account. And yet, these are experiences of crucial importance that contribute to the construction of that worldview that will shape the choices, values and even ways of doing science when becoming adults.

The now extensive collection of such memories has allowed us to identify some regular patterns. In addition, the comments that are expressed in the conversations following the phase of sharing have induced us toward drawing a few conclusions.

After an initial moment of embarrassment and wonder, almost everybody is willing to write. The memories are generally associated with complex experiences, an element of intense sensory perception (colors, smells), a human presence (children, friends and grandparents) and a dimension of doing (running, building, hiding, rolling). Such memories trigger strong emotions, a sense of astonishment for having temporarily forgotten about them and a desire to narrate them and share.

Following this activity, future teachers appear to have acquired greater awareness of the importance that such experiences have had on their lives and on developing one's ecological identity (Thomashow 1996).

In addition, becoming aware that an increasing number of children will not be able to live such moments—which, at one time, were usual and frequent for all—saddens and worries them. It is almost as if only now they are gaining consciousness of the gravity of the loss caused by the urbanization processes in children's psychophysical development.

Scientific knowledge is interwoven with worldviews; it is shaped by them and informs them in turn. In the path toward sustainability, it is therefore important to develop both vision and knowledge together.

> To act well, we need to experience the Earth not as "nature" out there, nor as an "environment" that is distinct from us, but a mysterious extension of our very own sensing bodies that nourishes us with an astounding variety of intellectual and aesthetic experiences (Harding 2006, 244).

The Voice of the Protagonists

In a perspective—as we have repeatedly underlined—that proposes to the students, future teachers the opportunity to participate in an active and reflective manner in the learning and teaching process, their words are perhaps the most appropriate means for concluding this chapter:

- The interdisciplinary and reflexive approach proposed during the course is in my opinion useful for putting into perspective our position as human beings: nature is not dominated by us, neither is benign or malignant towards us. This is not because nature is an entity which is indifferent to us, in a Universe which is even more indifferent. Rather, it is because nature is not an entity which is separate from us, or better, we are not separate from her, but we are part of a single system.

- Perhaps our peculiarity is the fact that we can become conscious of ourselves. In this case the word we can use is mandatory: in truth, we are aware of being able to impact on the system, we are somewhat conscious of how much we are effectively acting upon it but totally unconscious of how much the system is actually impacting upon us. (participant to SIS Course, A059, 2006/07).

- I liked the phrase which came out during one of the first lessons that the "world is non-disciplinary", that is it does not belong to any discipline and therefore each discipline are glasses which can be used to observe the world and see different things depending on the lenses (of the chemist, the physicist or the biologist) which are used. It is fascinating to know that the same event can be studied by a mathematician and by a biologist because one point of view does not exclude the other, rather, they can complement each other (participant to SIS Course, A059, 2007/08)

- A striking aspect is in my opinion that of the uniqueness of living beings: what characterizes each life form—a human being, a single flower, even an insect—is indeed the fact of being exclusive and impossible to repeat. [. . .] A lesson in the Life Sciences can be a suitable context for initiating a reflexion on emotionally involving matters. In this regard I would find it appropriate to tackle the theme of the diversification of the living, introducing the concept of biodiversity. In addition, this could be an opportunity for talking about the importance of being different, which is not a limit, but a noteworthy opportunity. This can make us reflect also on the differences that exists within the human species, the differences of personality, capabilities, interests which should not isolate people but bring them together, with a view of cooperation and sharing of resources (participant to SIS Course, A059, 2007/08).

- Twenty days after I had experienced the birth of a new life (my first baby), participating in the course of didactics of the life sciences has been an emotionally charged experience. In those months I have been experiencing and I still do such an intense psychophysical change that my reaction to such lessons has been totally unexpected. As a student I would find the study of biology quite boring. I had received a traditional education, based almost exclusively on a systemic-descriptive approach.

In the course of such lessons I have realized that biology is a complex, dynamic and changing science, which can give many opportunities for ethical reflection (participant to SIS Course A059, 2007/08).

NOTES

1. http://www.iris-sostenibilita.net/iris/docs/formazione/cfd2–2006/valutazione-finale-CFD-mag07.pdf
2. The ideas expressed by future teachers in relation to the question "what is an ecosystem, how do you define its boundaries?" are extremely varied and they offer numerous opportunities for discussion and further deepening of knowledge. Here are some examples:
   - *It is the totality of the animal and plant communities that occupy a particular area, e.g., the fluvial ecosystem (shoreline vegetation, macro-invertebrates, birds nesting along the shores . . .). The boundaries are given by the particular physical characteristics of that environment and that makes it different from other environments (i.e., lake ecosystems or the sea ecosystems etc.).*
   - *It is the web of relationships between the abiotic environment and the life forms living on it, organized according to more trophic levels. The boundaries can change depending on the phenomena that is being examined, i.e., a bush can be considered an ecosystem, but the planet Earth can also be considered an ecosystem.*
   - *It is the whole of the biotic and abiotic factors in a particular territory. An ecosystem has boundaries that depend on how much it has evolved to support the survival of each living being.*
3. Perhaps a more revealing approach is to compare the overall land claims between largely vegetarian and highly carnivorous societies. An overwhelmingly vegetarian diet produced by modern high-intensity cropping needs no more than 800 m^2 of arable land per capita. A fairly balanced Chinese diet of the late 1990s, containing less than 20 kg of meat, was produced from an average of 1100 m^2 per capita; the typical Western diet now claims up to 4000 m^2 per capita (Smil 2000). China's move to a higher meat diet impacts water security (Liu et al. 2008).
4. The energy problem cannot be dealt with separately from the problem of water: in the United States, for each kilowatt hour of supplied electricity, 8 L of water are consumed.
5. The truth resides in the very fact of the multiple viewpoints (Volk 1998).

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