From Scientific Literacy to Sustainability Literacy: An Ecological Framework for Education

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ABSTRACT: In this paper, we report some reflections on science and education, in relation to teaching and research in the field of complex and controversial socio-environmental issues. Starting from an examination of the literature on the epistemological aspects of the science of controversial issues, and introducing the perspective of complexity, the article argues for a complexity of content, context, and method in understanding current problems. Focusing on a model of learning which includes dialogical and reflective approaches, the final part of the article reports on aspect of the authors' experimental practice with role-play for dealing with complex issues. The review of the literature and our experience of action–research introduce a view of education which promotes young people's awareness of multiple points of view, an ability to establish relationships between processes, scales, and contexts which may be nonlinearly related, and practice with creative and nonviolent forms of interrelations with others. Such an approach in science education is coherent with a scenario of planet sustainability based on ecological webs and equity principles. © 2006 Wiley Periodicals, Inc. *Sci Ed* **90:**227–252, 2006

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INTRODUCTION

Teaching and Learning Models to Address Socioscientific Issues

The ability to deal with socioscientific issues, arising from the complex interactions of science and society, represents an integral component of scientific literacy and citizenship education in the Western world (Learning and Teaching Scotland, 2002; Millar & Osborne, 1998, Seibert & McIntosh, 2001; National Research Council, 1996). With the introduction of curriculum development projects such as Science and Technology in Society in the UK (Solomon, 1998), increasing importance has been given to approaches based on discussion of contentious issues, where values are in conflict and knowledge is contested. A recent review by Sadler and Zeidler (2004) reported on a variety of approaches for dealing with negotiation and resolution of controversial issues in the classroom. All such models addressed specific learning outcomes as for example: an appreciation of the nature of science (Bell, Lederman, & Abd-El-Khalick, 2000), learning of dialogic argumentation (Zohar & Nemet, 2002), and evaluation of scientific data and information (Jiménez-Aleixandre, Rodriguez, & Duschl, 2000). Also several interesting teaching models involving decision making on current socioscientific issues have been produced (Kortland & Lijnse, 1996; Ratcliffe, 1996; Ødegaard, 2003), addressing the multifaceted nature of the issues involved and the role of the public in assessing the impact of scientific and technological developments. However, as Kolstøe (2001) pointed out, many of these suffer from lack of discussion concerning the nature of science and of scientific knowledge in relation to the origination of such issues. Similarly, Sadler and Zeidler (2004) argued that a more complex pattern of interaction between science and society should inform the nature of science in socioscientific issues and their understanding. Furthermore, as Leach and Scoones (2003) remarked, discussion around science and technology issues so far has been largely confined to citizens' participation in the Northern hemisphere, while there is a need to frame such issues in the global context. In this article, we present the reflections that have emerged from 10 years of experience with interactive activities and role-play simulations to deal with complex and controversial socio-environmental issues. This article developed through two interwoven themes. The first is the recognition of the "complex" nature of socio-environmental controversial issues: the multiplicity of perspectives, the issues of risk, and the dimensions of uncertainty. This led to the search, illustrated in the second part of the article, for participatory and reflective activities, to promote understanding of socioscientific issues, and to address the dimension of conflict, an insofar unrecognized dimension in science education.

The Power of Techno-science to Transform Natural Systems at the Global Scale

Historically the relationship between science and society has never been simple nor unidirectional. The history of science abounds with examples of "societal interferences" that shaped the formulation of important scientific theories, and made the separation of a scientist's work from his or her society no longer tenable (Collins, 1982). In the currently defined knowledge-based societies, scientific knowledge has a central place. The human systems of economical productivity have acquired the definition of "scientific," based on increasing inputs of scientific and technological knowledge and, in a way that is totally different from the past, current techno-science (Ziman, 2000) is in the position of heavily interfering with the natural systems. Using a simple analogy, scientific and technological devices can be compared to a tap, which allows human beings to extract a variety of raw resources (wood, metal, fossil fuels) at an increasingly fast rate, in order to produce extensive quantities of consumable goods, to be consequently returned to the natural systems as "waste" (Wackernagel et al., 2002). Such activities are a source of transformations and change, at multiple levels. For example the accumulation of CO_2 in the atmosphere and in the oceans is a global result of a number of human activities in different "local" areas; moreover, such quantitative changes at a global scale are manifested in other local realms and under different forms, not always known. Indeed impacts are also produced at the qualitative level: for example scientists' capability of manipulating genetic material leads to interferences with replication and transmission of genetic information and—consequently—with the global processes of biological evolution.

The global scale at which such transformations take place and are spread, in the form of global transport, global communication, exchanges of goods, transfers of money, and mixing of various cultures, is ultimately turning the earth into a sole, immense "laboratory." Such a situation poses problems of different kinds, ranging from the ability to recognize the scale and the nature of the impact of humanity on the earth, to the need for society to make responsible decisions, to refrain from unsustainable actions. The main question which we intend to explore in this article is how science education responds to the need of preparing citizens to act in the new global context. We believe that schools should introduce students to reflecting on a number of different aspects, which are all inextricably linked with one another.

The proposal we outline in this article is located in some discernible developments: principally the re-thinking of scientific literacy to encompass the complexity of living systems and a notion of human beings as dependent on the natural context, while being able to reflect upon themselves. The awareness of complexity is linked with a notion of complexity of the educational process, through a greater and renovated use of interactive activities (as role-plays), able to involve and motivate students. In more detail the article will address three main aspects:

1. The notion of complexity: the part and the whole in complex interaction and the emerging epistemology of complexity;
2. Complexity at all levels: the implications for education.
3. Reflections stemming from our experimental practice in education.

THE NOTION OF COMPLEXITY: THE PART AND THE WHOLE IN COMPLEX INTERACTION AND THE EMERGING EPISTEMOLOGY OF COMPLEXITY

Complex Systems and System Thinking

The second half of the 20th century has seen the development of complexity theory: the writings of many authors, from several different academic fields, such as psychology, philosophy, and cognitive sciences, significantly contributed to cast light upon some aspects and qualities of living things and natural support systems, by considering them as complex systems (Bateson, 1972; Laszlo, 1996; Maturana & Varela, 1980, 1987). Reason and Goodwin (1999) summarized the qualities of living systems as *principles of complexity.* Complex systems present a rich pattern of interconnections between diverse components. This is contrasted with simple systems which can have many components, but they themselves, and their interconnections are simple, and uniform (a gas for example is made by millions of molecules, which are all the same and act in the same way). As opposed to this, in complex systems (e.g. organisms, ecosystems, societies), a knowledge of the properties of the components is not sufficient to allow one to predict future behavior (take for example the weather). The whole system has self-organizing properties of its parts (autopoiesis), a feature characterized by nonlinear and feedback relations. Complex living systems evolve through continuous self-organization along unpredictable, creative paths: hence, complexity theory describes novel, emergent form and behavior as arising through cycles of iteration (feedbacks) in which a pattern of activity, within specific boundaries, is repeated over and over again, giving rise to coherent order. Complex systems originate from multiplicity, and they originate and require a multiplicity of points of view to be described.

The study of organisms and ecosystems was fruitfully enriched by an approach that became known as "systemic": this significantly contributed to a re-conceptualization of some fundamental ideas in biology, from the molecular to the global scale. An example of this is a renovated interpretation of DNA as presented in Table 1.

Currently the academic community is endeavoring to develop new conceptual tools in disciplinary research, to find connections and patterns, recognize synergies, multiple influences and feedback, and to question boundaries, in order to move beyond simplistic explanations in the face of complexity. Natural systems, from bacteria to biosphere, which host life in various forms and continuously evolve, have been shown to be by far too complex to be handled with simple descriptors!

The understanding of the processes of life as developed by the emerging "systemic" vision, seriously questioned the traditional image of science as an activity of objective observation and unique description of reality.

Gregory Bateson was one of the first to point out the epistemological error in our understanding of the natural world. He showed how conscious purpose (in the form of selecting, categorizing, extrapolating predictions, and manipulating) creates errors since it abstracts small arcs of complex ecological circuits. He thus stressed the importance of appreciating the intricate networks of information and action, the circuits of mind, that characterize the living realm.

Elaborating the thinking of Gregory Bateson about the nature of scientific activity, Manghi (2004) points out the importance of context and of personal and cultural frames of reference: "Human beings (that are) constructors of images, are at the same time builders and carriers of discourses" (pp. 45).[1]

In the recent times in the social sciences there have been many moves toward what has started to be identified as an epistemology of complexity (Longino, 2002; Manghi, 2004; Morin, 2000). Heron and Reason (1997) assert that knowing lies not so much in the mind of individual actors, but arises in relationship and through participation. In the writings of the phenomenologists (Abram, 1996; Merleau-Ponty, 1962), this participation is extended to include the natural surroundings, as it arises from interaction and participation with the *context*: as Abram puts it: "[there is] underneath our literate abstractions, a deeply participatory relation to things and to the earth, a felt reciprocity..." (Abram, 1996:124). Writing in the context of participatory research, Park (1999) identified representational, relational, and reflective forms of knowledge. This latter arises, Park argues, through the process of consciousness raising, conscientization.

Decision-Making Processes Within the Framework of Complexity

Recognizing the role of context, the influence of culture and the limits of an approach based on linear thinking, has important implications in relation to the production of knowledge and to its applications.

[1] Translated by the authors from the original Italian: "Gli esseri umani costruttori di immagini, sono allo stesso tempo, e insieme, portatori e costruttori di discorsi."

TABLE 1
Addressing Complexity in Living Systems

The study of the living matter has been largely dominated by an empirical/reductionist approach, seeking linear relationships of cause and effect at the microlevel that can be applied to seek modifications at the macrolevel. An example of this way of thinking is Dawkins' theory of the selfish gene, where kinship, calculated in percentage of shared genes, is thought to be the determining factor in calculating behavior in the face of risk (Dawkins, 1976). A similar mindset has dominated the developments of the Human Genome Project, which has become an example of a situation where the analytical/reductionist approach applied to the concept of gene has dramatically revealed its limits, and a systemic view is introduced.

From the "central dogma" to a systemic view of DNA: The example of the Human Genome Project

The "central dogma" assumes a linear causal relationship between the genetic information encoded in the DNA, the codification by the RNA and the synthesis of proteins, according to the general formula: DNA → RNA → Protein	The Human Genome Project is launched
During the studies it clearly emerged that One gene → Many proteins (e.g., hybrid proteins) Many genes → One protein (e.g., immunoglobulins) Many genes → Many proteins (e.g., hemoglobins)	First signs of rethinking: –Multiple links –Feedbacks
And also: Less than 2% of human DNA was found as "codifying" for proteins	Crisis of the reductionist approach: –The number of genes is not a linear function of complexity –The greater part of DNA does not codify for proteins: 74% is intergenic DNA (i.e., transposons etc.); 74% is noncodifying DNA (i.e., pseudogenes, introns, etc.)
Haynes (1988, reported in Fox Keller, 2001) described gene stability as the final product of a "dynamic" process which requires a large number of enzymes, all organized in complex metabolic networks	A living being is the product of nonlinear and epigenetic processes. *A systemic approach*: The idea that a sequence of DNA can be isolated without consequences from the context where it evolved does not take into account the dynamic and delocalized interactions of the gene[a]

[a]"Genomes are continuously changing as a result of many processes, operating constantly on developmental and evolutionary time-scales. These processes destabilise genes and genomes, move genes around, mutate, rearrange, recombine, replicate sequences, delete or insert sequences, and even exchange and convert sequences" (Mae-Wan Ho, 2000, p. 121).

The systemic approach can be applied not only to the investigation of natural systems (with the study of the interdependences, feedbacks, variety of organizational levels etc.), but also to the relationships between the different human cultures and societies, and between humanity and nature. The more challenging and technologically advanced are the human projects and/or the prospective solutions, the more profound and extensive are the possible interferences with the natural systems. This can cause secondary effects and unexpected consequences, and new problems may be triggered in turn. In the face of such problems, political decision makers are confronted with the problem of *risk* associated with the new opportunities of science and technology.

Historically risk management was originally approached through mathematical models, aimed at estimating chance and probability of the occurrence of a risk event, and measuring the level of risk which is associated with a decision (Solomon, 2003). Over time it has become more difficult to assess the dimension of risk attached to complex technological systems, in which creativity, emergence, and unpredictability play an important role. The condition of interdependence within systems implies that any decision we may take includes potential for risk as well as of "ignorance", as we ignore what the configuration of the system may be (in this condition the impacts are "unknown" and therefore "unknown" are the probabilities). Additionally the validity of quantified risks can be discountable, in face of strongly cultural and ethical dimensions. Hence, such problems may require the need to reflect on new interpretations of decision making in the face of risk, which may account for a change in the nature of knowledge processes. An interesting classification is provided by Harremoës et al. (2001, pp. 192), which breaks the loosely defined concept of uncertainty into three elements: "risk," "uncertainty," and "ignorance." Public action can thus be related to these three different states of knowledge to acquire characteristics ranging from prevention, precautionary prevention, and precaution.

The Post-normal Science Approach

The reduction of a known risk or unknown probabilities of hazard has become part of common procedures in the handling and assessment of scientific and technological implementation. In contrast, the conditions of ignorance have so far received little consideration by scientific experts and policy makers alike.[2] In analyzing such issues, Funtowicz and Ravetz (1999) argued that current socio-environmental problems demand another style of both science and policy in order to deal with uncertain facts, values in dispute, high stakes, and the need to take urgent decisions (Ravetz, 1999, p. 649). Uncertainty signifies the limitations or the unavailability of confident knowledge about the ways systems function; stakes indicate the magnitude of consequences when adopting one view over another, i.e. the value-ladenness of policy decisions. As Funtowicz and Ravetz argued, when both uncertainty and stakes are small, traditional research and expertise do the job. When either one (or both) of them is medium, routine techniques may not be enough, making necessary the intervention of "professional consultancy." However within the new frame of reference, complexity and multiplicity of points of views are putting communities in the condition of having to undertake complex decisional processes, where "experts" have conflicting views.

[2] For example, the disastrous effects of the tsunami have been reinterpreted in the light of the complexity of the Indian coastal ecosystem. As reported by the *Nature* magazine (Pearson, 2005), the researchers are now keen to assess whether mangrove swamps cleared prior to the tsunami, to make way for hotels or other coastal developments (e.g., prawn farms, as reported by Naylor et al. (1998, 2000)), may have flattened a natural wave barrier, leaving the coastline more vulnerable.

From such considerations, they introduced the concept of "post-normal" science (Funtowicz and Ravetz, 1993; Ravetz, 1997) and declared that, when dealing with the complexity of socio-environmental systems (high risk, high uncertainty), the values become the "hard" components before "soft" facts. In such a context the hierarchical structure which attributes to the "experts" a superior decisional power, as opposed to the "nonexperts," is becoming far less rigid. Post-normal science recognizes the importance of complexity and context, for science alone cannot provide definitive answers nor "solutions," and there is a need for involvement of the "extended peer community."

Democratic participation is given a renovated emphasis, as citizens may be directly called in to take part in the decisional process as they hold points of views which may contribute to the clarification of the issue and to a more rational choice.

Yet the accentuated intensity of these issues unavoidably raises inferences, which are necessarily conditioned by the values held by the stakeholders (in contrast with the value-free character of traditional science). One of the main implications derived from this thesis refers to the particular cognitive demands set up by post-normal science. The resemblance with the scientific peer-community is only apparent, as the extended peer community is guided by the assumption that, in face of the complexity of socio-environmental problems, "many different points of view can be expressed, none of which is wholly convincing (to everybody, all of the time), none of which deals entirely adequately with all aspects of the situation, but none of which can be wholly rejected (by everybody) as having nothing at all relevant to say about the situation and about what should be done and why (O'Connor, 1999, p. 674). For example, the people directly affected by a health problem will have a keener awareness of its manifestations and a more pressing concern with the quality of official reassurances, than those in other roles (Krimsky, 1984). Similarly people that have a direct knowledge of their local environment will have a better perception of its quality, being more sensitive to pattern changes (Goodwin, 1994) as well as interpreting their environment through cultural, ethical, and psychological connotations. Such broadening of the framing of an issue, to admit uncertainties, value loadings and recognition of the rights of all interested parties to speak out and be heard by policy makers, adds a tone of "openness" and "participation" in policy processes of decision making, otherwise condemned to failure if they were based solely on the purely technical dimensions of the issue.

Decoupling of Actions from Perceptions, and Recomposition Through Ethical Reflection

While the post-normal science approach prospects a decision-making process based on a variety of legitimate views, Wynne (1992) pointed out that this needs to be irremediably confronted with the variety of conceptualizations of "uncertainty" or "not-knowing." These are overlaid one on the other depending upon the degree of social commitments of the stakeholders, and they may range from the assessment of probabilistic parameters to contested meanings and language ambiguities (Camino et al., 2005). When dealing with local processes which have impacts on a global scale, and when lacking understanding of conceptual frameworks and value systems of different cultures and disciplines, uncertainties and ignorance add to decouple perception from action in the decisional process.

If—for example—we approach a decisional process according to a rational framework of cost/benefit analysis, it may be that what appears to be positive at a local scale turns out to have devastating effects at a global scale; alternatively a solution which creates well-being in one category of people may cause sufferance and hardship to others. We can suggest two examples:

- The availability of fossil fuels made possible the dramatic development of Western societies. Yet this caused environmental problems at a global scale, such as the increasing levels of CO_2, with impacts on human communities which did not directly contribute to such change;
- the increasing availability of opportunities for organ transplant originated a market of vast proportions, within which poor and rich trade body parts with money.[3]

This wider scale or wider scenario in which socio-environmental problems are located is the whole planet. As emphasized by Sachs (2002), it is within its limits that we need to locate our actions and their consequences:

> The insight that the globally available environmental space is finite has added a new dimension to justice. The quest for greater justice has, for time immemorial, required to contain the use of power in society, but now it also requires to contain the use of nature. The powerful have to yield both political and environmental space to the powerless, if justice is to have a chance. (p. 19)

According to a global system approach, ethical reflection cannot be pursued independently from the quest for knowledge and the awareness of the natural systems on which we depend: just as every local problem has global repercussions, in the same way the "local" ethics needs to be considered in a global view. Ecology and equity are inextricably and mutually tied in a vision of sustainability and inter-being consciousness.

Dealing with Conflict

The epistemological changes affecting the nature of scientific enterprise and the idea that there are multiple interpretations which are all equally respectable have a dramatic effect on our understanding of the relationships between individuals, groups, and nations. Establishing a relationship of equivalence[4] (Patfoort, 2001) between all the stakeholders involved in a problem does not necessarily imply that everybody will be in mutual agreement: the desire of cooperating can be confronted with the extraordinarily diverse experiences, interests, worldviews, and power relations that nations and corporations, communities, and individuals bring to bear. Also the elements of uncertainty and ignorance mentioned above, caused by the decoupling of perception from action, are identified as contributing factors in the emergence of conflicts. In the definition of Galtung (1996), conflict emerges where there is a relationship of interdependence between two or more actors, and whenever individuals and groups have goals that are felt as being incompatible and mutually exclusive. The more urgent the goal, such as the satisfaction of basic needs, the more any actor or party with unrealized goals may feel frustrated: unsolved conflicts may develop into complex conflict formations with many parties and many contradictory goals. The elementary conflict formation with two parties pursuing one goal is rare: the normal conflict has many actors,

[3] Thank to cyclosporine "the difference is selectively suppressed, so that specific sub-population become 'sufficiently equal' to allow their members to be surgically disaggregated and their components reincorporated. [. . .] Immune-suppression opened the way to a large population of 'sellers' which are 'living donors' of organs" (Scheper-Hughes & Wacquant, 2002, p. 21).

[4] According to Patfoort (2001), the condition of equivalence is at the roots of nonviolence. Within the model of equivalence, we can preserve ourselves and defend our points of view, behaviors, ideas etc. with assertiveness rather than aggression. In other words, the model of equivalence guarantees equivalence of power and it is aimed at preserving identity as well as difference for two positions which are considered as equally legitimate (E-E-). This model is offered in alternative to the more traditional model of dominance/oppression, in which one position (M) is presented as better or superior to another (m).

many goals, and many issues, in other words, it is complex. The approach developed by Galtung (1996) considers conflict as inextricably embedded in life and from such a vision he argues for the development of nondestructive approaches to its *resolution*. In particular, in this paper we intend to explore the approach of Galtung (1996) as he developed it from the principles of nonviolence. This option is well described and exemplified in the literature (Weber, 2001): the aim of a nonviolent approach to conflict is to transcend the conflict, through dialogue and creativity, in order to transform a situation of incompatibility of views and perspectives into a new, shared landscape for action. In this view, the aim of dealing with conflict is not only that of settling a dispute or eliminating the danger of violence, but that of exploring the opportunity to proceed toward change and development, including the human development of the individual actors involved, the social development of the collective actors, and world development:

> conflict resolution in a Gandhian sense does not come about primarily through confrontation of views, dialogue, bargaining and compromise, but through experimentation with new forms of social life: transcendence through imagination, destruction of a structure of exploitation, increasing autonomy and self-reliance for oneself and the antagonist. (Weber, 2001, p. 493)

While consensus is essential to governance, a large number of sociologists and educators have long been advocating for nonviolent strategies to handle disagreements and conflict, which would introduce new forms of democratic participation and societal organization (Moscovici & Doise, 1991; Pellow, 1999).

COMPLEXITY AT ALL LEVELS: SOME IMPLICATIONS FOR EDUCATION

Looking at Science Education from the Perspective of Complex Systems

As reported by Ziman (2001), science education today requires serious consideration of philosophical and ethical questions related to the production of scientific knowledge and its applications:

> What science education now requires is 'meta-science,' a discipline that extends beyond conventional philosophy and ethics to include the social and humanistic aspects of the scientific enterprise. Students need to realise that science is changing rapidly, not only in its research techniques and organisational structures but also in its relationships with society at large. (p. 165)

Recognizing the changes in conceiving and applying science and the implications that these may have for the human beings and the natural systems on the planet, may require the educational system to question, and eventually modify, itself. In science education, this involves a reconsideration of the traditional modes of

a. conceiving science (epistemological aspects), by declaring the values, limitations, and ambiguities of scientific knowledge in relation to complex systems;
b. conceiving science education, by seeking consistency between the methods, purposes, and modes for assessment of the teaching–learning process.

Following a conceptualization of knowledge processes derived by Habermas, Aikenhead (1997) distinguished between three contexts for science education: the positivistic, the interpretive, and the critical theoretical. While he developed his argument taking a focus on issues of assessment (which we do not directly address in this paper), it is possible to recognize that the current practice of science education in school is largely dominated by the positivistic framework. Viewing science according to this "normal" view implies a number of assumptions, such as

– there is a solution to every problem;
– knowledge of the whole can be achieved through the knowledge of the component parts;
– most issues and events may be regarded as discrete quantities;
– partition and segregation can ensure objectivity, by elimination of interferences and unknown disturbances;
– we can value something or define our knowledge of it, by making distinctions between what is not, or from its opposite, and that we can predict future outcomes by making a linear extrapolation from the past history and present conditions of the system (Sterling, 2002).

Transported to the realm of decision making, such an approach to science and education can lead to a number of implications. For example it suggests that citizens' representatives, democratically elected, take decisions according to the experts' advice (who can give the "right answer"), from which practical actions can follow. In the domain of the teaching of socioscientific issues, it is the model that puts emphasis on the cognitive aspects, and it is based on the assumption that there is a strong connection between the knowledge of the topic and the solution of the problem (Sadler & Zeidler, 2004). However when dealing with complex problems, such a "clean" and unproblematic approach may be unsatisfactory. Irreducible uncertainty, emerging properties on the one hand, and multiplicity of points of view on the other, call for a redefinition of the nature and structure of the educational processes, opening to new scenarios of participatory learning and including the dimension of conflict in the realm of relationships, in the construction of knowledge, and in the levels of communication within the teaching–learning process.

How to Deal with Complex Links Within the Educational Process?

In order to link the reflection on science and society to the aims and practices of science education, we need to consider two main aspects:

a. Teaching and learning in the classroom is viewed as a "complex" process, where the single "parts" of the educational process, goals, processes, are methodologies are considered as interdependent.
b. The cognitive aspects of learning are integrated with the social, emotional, and ethical dimensions (e.g., interdependence between knowledge and values; conflict and equity).

As reported by Lijmbach et al. (2002), if new aims for science education are identified, these will influence all other aspects:

> The relationship between goals (intended outcomes of the learning process), process (the dynamic nature of selected learning activities) and content (subject of the learning process) has a high level of interdependency: a decision as regards to one of these components of learning influences decisions with regards to the others. (p. 128)

These aspects were clearly described years ago by Claxton (1991) and also many others (e.g. Aikenhead, 2003; Hodson, 1998, 1999; Millar & Osborne, 1998) have given important contributions on the same topic. Indeed the elaboration of new curricula is the result of deep reflection and ongoing debates, on the aims of science education. Amongst such aims is that of providing young people with the tools for knowing themselves (from the study of physiology to the cognitive and psychological aspects), for acting as citizens with confidence and awareness in a society which is increasingly dominated by science and technology or for developing the necessary specialist knowledge and competences to succeed in the competitive arena of the economic world. In their variety, the aims of science education explicitly or implicitly refer to values which are traditionally recognized and accepted by our society: a system of human rights, such as the right to equality, health, and education, the importance of democracy, and the value of developing one's own potential.

More recently, authors such as Capra (1997, 2002), Cutter-Mackenzie and Smith (2003), and Orr (1994) have placed emphasis on the need for understanding the interconnections and interdependences between natural processes and human ways of living. In such a way a new value enters the panorama of education, which is that of the "well-being" of the ecosystems and the earth. In the same context, Sterling (2002) advocated for the need to recognize and acknowledge the roots of our worldview and ways of thinking, and to re-orient our own thinking toward a systemic-ecological-holistic approach. According to this author, the main aim of science education is to develop an ecological worldview, predicated on the idea of a co-created, participative reality. But is there a way to find a coherent relation in science education, between content, strategies, and classroom context, in order to overcome conflicting aims?

A recent issue of the *IJSE* (vol. 11, 2002) collecting a number of pieces of research, showed the difficulty of locating a variety of paths and research traditions within a coherent educational framework: Each contribution focuses on specific aspects (interdisciplinarity, local/global dimensions, relationships between concepts and values, separation between scientific education and environmental education and so forth), and it is difficult and problematic to integrate all different contributions within practice.

A Variety of Answers

In pursuing the quest for a suitable pedagogy, we considered a number of strategies which have been applied in different contexts (public policy and education) to deal with controversy by means of dialectical interaction. As it was recently pointed out by Carter (2004), science education has been largely silent "on the whole question of the broader structural and cultural processes transforming the practical and theoretical landscape which shapes science education and is expressed within it" (p. 821). The idea of science transmitted through the different uses of argumentation and debate may be hidden and implicit, and this has repercussions on the nature of education and the public decision-making processes related to socioscientific issues.

In the next paragraphs we try to cast light on the underlying ideas of science, but also education and nature of the social relationships, when dealing with controversies. We present them here in relation to their links with science education.

To Persuade About Truth. In the realm of public policy, argumentation and debate often coincide: they are the means through which groups or individuals compete for putting across their point of views, as if they were in a fight or a war of voices (Tannen, 1998). Such a setting is dominated by the assumption that one of the parties holds "the" correct vision of reality and the task is that of convincing the audience of the wrongness of the other real or imaginary counterparty. For example in the analysis of the political and scientific aspects of the history of the Human Genome Project, Huijer (2003) showed how public persuasion has developed in society and cross-fertilized the scientific discourse. The following quotation is from Weinberg (1967, quoted in Huijer, 2003, p. 488), who states

> When the end to be achieved is important enough, and when the state of the science suggests that more support will lead to more results (and both these circumstances apply to biomedical science), then we are justified in going all out in our plea for public support. (p. 488)

At the epistemological level, this kind of approach is based on the idea that it is possible to reach one single Truth (which can be scientific, spiritual, or religious) at the expense of the truth of others'.

Learning the Scientific Argumentation. Recent studies on the teaching of dialogical argumentation emphasized the need for introducing students to the nature of the scientific activity, and to appreciate the role of controversy and disagreement in the processes of modern science. Duschl and Osborne (2002) argued for improving the practice of argument in the classrooms as a way to create a learning environment which integrates both the cognitive and social dimension of students' learning:

> there is a tension between the common notion of argumentation as an adversarial activity, as opposed to the view of argument as the substance of any meaningful discourse that seeks to generate improved knowledge and understanding. (p. 41)

In this view the learning of scientific argumentation is a means for people to engage in speculative and critical arguments leading to a rational and reliable knowledge, which becomes superior to competing viewpoints. The achieved consensus is the consensus of science, within a specific disciplinary domain.

To Persuade About the Legitimacy of Science. In the past decade, a stream of public involvement was that of creating opportunities for the involvement of the citizens in debates on the ethical and social implications of science and technology. In this view the public is involved in expressing an opinion about a scientific and technological product by weighing up the cost and benefit of a scientific project against their value to society or humanity. The republican society constitutes the environment in which science interacts with other societal forces, and scientists make their entrance in the "agora" (Nowotny, Scott, & Gibbons, 2001): this is the public arena where transactions, communication, and dialogues between scientists and agents from a variety of sectors take place. In this view it becomes important for the educational system to provide citizens with the tools for understanding the processes of science as well as the abilities to evaluate scientific claims. Citizens' democratic action would thus be shaped by a set of definite preconditions, such as receiving the necessary information well on time, that such information is provided in a clear way and that the citizens themselves had developed the necessary competences to understand the problems. However as Huijer (2003) pointed out, participation of the public would still be affected by

> a demarcation between the internal cognitive activity of science and an external public sphere of moral reasoning related to humanity and lived experiences. Even if conceptualised as an artificial boundary, it limits public options for deliberation to questions of how to implement and govern the facts, knowledge, methods, theories, and technologies created by the sciences. (p. 491)

Language Use in Discussions About Socioscientific Issues. In recent years, in relation to the educational contexts in which the tools of debate and discussion are used, an extensive field of research has developed around the nature of language. Some approaches take into account the types of text sequences and the production of sound arguments (e.g. Adams, 1992, cited in Simonneaux, 2001), while others may look at the role played by "the orders of importance" in promoting or obstructing the reach of consensus in a debate (the "sociology of justification," according to Thévenot, found in Simonneaux, 2001). In addition, linguistic analysis has the potential to explore students' meanings and uses of analogies and metaphors, and so to find connections with the use of metaphors in science. This link offers interesting opportunities to reflect on the nature of science and on the implicit messages which are given off by means of linguistic choices (Sutton, 1996).

As some authors have observed, in school contexts which have become increasingly multicultural (therefore multilingual), it is more important than in the past to develop awareness of the particular scientific culture proposed in school as this may enter in conflict with the "norms, values, beliefs, expectations and conventional actions of a group" (Jedege & Aikenhead, 1999).

A reflection on scientific language (Fang, 2004), which allows the making of actions, agents and epistemologies explicit, should be encouraged in order to unravel the variety and multiplicity of scenarios, actions, and meaning (Barab et al., 1999).

To Express One's Ideas. Finally another purpose for science education would then be that of training students to articulate their thoughts in a clear manner, to sustain and express their own ideas, no matter of whether they are "right" or "wrong." It is common experience that people have enormous difficulties in expressing their own ideas to others. There may be a linguistic problem (e.g. finding the right words), as much as a lack of ability to clearly and coherently connect ideas and concepts. In summary debate and argumentation can be means for achieving a number of objectives, amongst which a distinction can be made between

- to discern between "right" and "wrong," and to affirm the "Truth" (i.e. a scientific truth, a religious truth etc.);
- to persuade and convince others who are less expert;
- to be able to express and communicate one's own ideas.

Following the latter, language abilities are included in the wider set of communication competences, which include also many other forms of language and expression (i.e. nonverbal language, artistic expression, and so forth), without which our communication would be extremely limited.

Practicing Complexity Within the Classroom: Science and Conflict. Beside the variety of ways of communication which are based on discussion and argumentation, also other forms of communication are possible: these are based on dialogue and on listening to each other. Such modalities lead us back to the culture of nonviolence, which stems from ancient spiritual traditions, and has been extended to the political and social realm by Gandhi and his followers (Gandhi, 1930; Pontara, 1978). In tune with the ethical values of an educational institution, we researched and introduced the option of nonviolence in dealing with conflict, in order to reflect and take action toward the various forms of violence (cultural, structural, and direct violence, according to Galtung, 1996) which are embedded in the means for affirming ideas and to make choices. According to such reflections, we gradually moved from an approach in science education which considers issues in Science, Technology and Society (STS), and Peace Environment and Society (PES) as simply accessory and alternative, or additional to the current school paradigm (Aikenhead, 1997), to a vision in which they constitute the grounding principles upon which knowledge is produced, scientific knowledge included.

REFLECTIONS STEMMING FROM OUR EXPERIMENTAL PRACTICE IN EDUCATION

Our reflections and practice in the classroom centered upon the use and development of a methodology for tackling complexity and sustainability at all levels, by linking the complexity of the natural systems with the quality of the teaching–learning process.

In the course of a developmental research model based on an action-research approach, as described by McKernan (1991) and Verhoeff (2003), teaching and learning materials on scientific and socio-environmental controversial issues were developed for a variety of users and they were progressively tried and tested in a number of educational contexts (secondary school students, university courses, and professional development courses for teachers). Central to this method is the assumption that a synergy of theoretical notions and practical experience is achieved through joint research and action. In our research, the combination of theory and practice was achieved by the collaboration of teachers and researchers in the field of the natural sciences, pedagogy, history, and peace studies. We would like to emphasize the search for consistency between particular educational "strategies/techniques" and the epistemological and ethical framework in which they are proposed, which is too often only implicitly assumed. For example an action–research approach may be used for collection of "objective" data about students' conceptions, or alternatively it may be a means for sharing a variety of conceptions/interpretations to enrich personal ideas through collective reflective activities. Following the latter, our developmental research approach was enriched by the use of a systemic approach on both the "outside" (e.g. the natural systems) and the "inside" (the teaching and learning process, which integrated cognition and emotions, and developed from the interaction between all the involved actors, who are the teachers, the students and the researchers). Over the past 10 years, we have been involved in the production of research-based teaching and learning materials (interactive activities and role-play) to approach complex socio-environmental issues in the classroom. As an example, we describe the development of the use of role-plays to deal with socio-environmental controversial issues (Camino & Calcagno, 1995). This allowed us to develop and reflect on the epistemological and ethical frameworks of complexity and sustainability, as we elaborated it over a period of time and which we describe below. The following questions guided our work:

- Which image of science do we want to elaborate for ourselves and transfer to others in our profession as researchers and educators?
- How can scientific literacy be effectively connected to the understanding of socio-environmental issues and the development of a view of sustainability?
- Which tools do citizens need to be given in order to play an active and responsible role within the new processes of participatory democracy?

From Scientific Topics to Socio-environmental Issues

Following the multidisciplinary approach of teaching issues in Science, Technology and Society (Solomon & Aikenhead, 1994), we devised a number of role-plays to simulate specific and clearly defined controversial situations, which students could approach by means of a schematic and concise representation of reality (Camino & Calcagno, 1995).

All our role-plays deal with complex and controversial socio-environmental issues in which different people or groups have a variety of different perspectives on value and use of natural resources and systems. Examples of controversies are water management in the African region of Sahel, the significance and value of trees and forests in India, or deliberations on thermo-installations with high emissions of carbon dioxide. While preparing to take on role, students are invited to collect information on the scientific content of the issue. The complexity of the topic requires selecting information from physics, chemistry, biology, and earth sciences. Moreover, the nature of such issues requires investigating aspects pertaining to the social, economical, and political disciplines. While they gather new knowledge in science, students also endeavor in producing interdisciplinary links and in recomposing the complexity of the issue.

The approach of our role-plays, with a plurality of actors engaged in searching different explanations and solutions for a problem, is particularly effective in framing the specific case within a more general context, in which the links between local and global situations are put into evidence. Often it is only at a global scale that the limitedness of resources and the emergence of conflicts about their distribution and use can be more strikingly perceived: in a closed system, like our planet, both the availability of resources (water, soil, minerals etc.) and the capacity of natural systems to provide services (i.e. from water purification to waste breakdown and nutrient cycles) are limited.

Evolving Strategies in the Role-Plays

Following a research tradition in science education which makes use of role-play to simulate public decision-making processes (Simonneaux, 2001), our role-plays were designed as simulations of public debates in which two or three groups of contrasting opinions presented their case before a panel of impartial judges. The controversy was resolved by means of a verdict, which would favor one solution, while disqualifying the other(s).

The most recent global environmental and social issue we have undertaken deals with the intensive production of prawns in aquaculture ponds (Coppo, 2005; FAO, 1999). This development has spread massively—during the last 10 years—along the coasts of many tropical countries. As part of a large development project, funded by international institutions (Food and Agriculture Organization (FAO); International Monetary Fund (IMF); World Bank (WB)), aimed at improving the protein balance in the diet of people in developing countries and in boosting their economy. Prawns are now globally exported from southern countries (most of all Asia and Latin America) to developed countries—USA, Europe, and Japan, while the prawn farming activity has produced widespread damage to the coastal ecosystems, weakening the subsistence economy of local populations.

In the role-play (Colucci & Camino, 2000) participants are taken to the southern Indian state of Tamilnadu, where the local villagers organized themselves in a nonviolent protest against the growing shrimp industry, according to the Gandhian tradition of satyagraha (Rigby, 1997). This new aspect of conflict and Gandhian thought inspired us to modify the decision-making models of our role-plays, in order to adhere to such a different scenario. Besides the "win–lose" situation, a further decision-making process was proposed: a round table where all the participants cooperate to reach a positive outcome (the win/win model). This form of participatory democracy (Davies & Kauffman, 2003), and bottom-up decision making was inspired by a practice which has been established since ancient times in non-Western cultures: in particular in India, it is manifested with the gram sabha, the assembly of the village, which is still today recognized by the Indian Government. Such an approach to the decision-making process is also in line with the recent trend to resort to nonviolent resolution of socio-environmental conflicts, at the micro- as well as at the macro-level.

With the aim of introducing a nonviolent approach to dealing with conflict, role-play was used to work toward the development of a variety of competences: dialogue, active listening, empathy, respect for others, and identification of basic, common needs. The role-play activity was therefore aimed at creating participatory contexts in which students practiced with "listening to others," by being in other people's shoes, and becoming aware of the preconceptions, interests, and values that implicitly shape our views. In the following paragraphs, we will focus on some aspects that characterized the progressive growth in complexity of the activities in which students and teachers were involved, and the related opportunities and problems.

Interwoven Problems

Among the variety of topics and issues we explored and discussed within our research group and the teachers involved in the course of our research, some interesting points emerged in relation to the connections and reciprocal influences between the idea of "post-normal" science and the nature of the decision-making process that we summarize as follows:

- The epistemological shift in the idea of science: from the search for truth to the explicitation of a multiplicity of legitimate views.
- The shift in attitudes and behaviors that occurs when moving from debate to dialogue, and from a representative to a participatory model of democracy.
- Nonviolent conflict transformation: the development of a new frame of thinking.
- The implications of conflict transformation within a planet with limited resources.

The Epistemological Shift in the Idea of Science: From Certainty to Uncertainty and Multiplicity of Legitimate Views. In the first phase we concentrated on the means for gradually changing the ways of teaching and learning science. The activities of role-plays were aimed at getting students actively involved in the discussion of the controversy. In groups, they were encouraged to go deep into the issue, selecting the relevant information from a variety of sources, and dealing with contradictory data and disagreement amongst the experts. These first role-play activities cast light on the nature of the decision-making processes, in which knowledge is bounded with interests and power relationships. The purposes of this educational intervention were

- to introduce participants to the complexity of socio-environmental problems;
- to give the scientific knowledge a relevant but not conclusive role;
- to raise awareness on the difficulty of finding "the right solution," but only one that is temporarily considered the most acceptable by the majority.

In particular the students were presented with three types of tasks:

- to put oneself in someone else's shoes;
- to cooperatively work in their groups to clarify the various aspects and devise a common strategy;
- to take part in a public debate.

It was our intention to give those activities a common educational objective, that of developing critical skills and sense of responsibility in relation to environmental problems of social relevance. In other words, our objectives included that of developing those "civic abilities" that the Science, Technology and Society curriculum considered the fundamentals of an active and responsible citizenship. In those first years of experience we developed reflection on and awareness of a variety of aspects: the nature of science, the interconnections between science and other dimensions of living and knowing, the problems of the teaching and learning process. Our thoughts were in line with those expressed by many authors, and they can be summarized by a recent quote from Lijmbach et al. (2002):

> the recognition that there are various, equally acceptable views [. . .] leads to respect for pluralism. [. . .] One of the aims of a discussion about diverging views is that people learn to understand the differences between these views and whether or not these differences can be reconciled." (p. 126)

After the debate students were guided through a process of meta-reflection examining the risks and the benefits of the decision they had taken. Such reflection involved the scale and persistency of the possible risks, from the point of views of a variety of stakeholders, each of them pointing out the risks on the basis of their own personal experience and values. In such a process, participants could develop awareness of the limits of making reliable previsions, with a shift in focus from quantifying the risk to the application of a precautionary principle. The complex nature of socio-ecological systems in fact leads to

> consider the possible repertoire of behaviour of the whole system, as broadly as possible. On this basis, prepare for novelty, structural change, and surprise (Gallopin et al., 2001)

Another element of reflection which emerged with our role-plays was the comparison between different knowledge systems and the possibility for students to appreciate the theoretical validity and respectability of "indigenous" knowledge systems, which in our society are often mistaken with superstitions and flawed knowledge. The possibility of experiencing a problem by putting oneself in someone else's shoes makes it more meaningful the contents of comparisons, as shown in Table 2.

Indigenous and community knowledge emerge from a close relationship with local ecosystems. This offers the opportunity of multiplying the viewpoints about any complex environmental issue, which may range from a disciplinary scientific approach to narrative accounts of personal experiences of people rooted in nature. Acknowledging equivalence of respectability of all involved people, and the legitimacy of different points of view, may contribute to reducing the unbalance of power between techno-science, on the one side, and other systems of knowledge (comprising of techniques, political decisions and actions),[5] on the other. In tune with the general framework of nonviolence, we argue for a relation of equivalence between human groups, in order to contribute to the emergence of new and shared frames of knowledge and understanding.

The Shift in Attitudes and Behaviors That Occurs When Moving from Debate to Dialogue, and from a Representative to a Participatory Model of Democracy. The objective of our first role-plays was specifically that of helping the students to talk by using both cognitive reasoning and emotional involvement (as the opinions they were

[5] Western-based formal knowledge tends to be supported by written documents, rules, and regulations, and technological infrastructures. Informal, indigenous, or local knowledge refers to the complete bodies of knowledge, know-how, practices, and representations that are maintained and developed by people with long history of close interaction with the natural environment. Indigenous knowledge and modern science should be seen as two systems of knowledge that can supplement, rather than compete, with each other (SciDev.net, August 2002. http://www.scidev.net/dossiers/. Website visited on April 21, 2005).

TABLE 2
Knowledge Systems (Modified From Sachs, 2002, p. 44)

Many of the successful systems of indigenous and community knowledge about the natural world share the following characteristics:	*The modern system of biological knowledge has specific characteristics:*
1. are community based	1. are globally applicable
2. display diversity, both biological and cultural	2. allow worldwide reproduction of results under defined experimental conditions
3. define biological knowledge and resources as commons[a]	3. privatize biological knowledge and resources as intellectual property
4. deliver to subsistence and local markets	4. deliver to the world market
5. are largely based on women's stewardship of knowledge and resources	5. are based on expertise predominantly fashioned by men
6. focus on resilience and food-security	6. maximize short-term yield and performance experiment under laboratory conditions
7. optimize in context rather than maximize single variables	7. have a high financial and cultural threshold for reaching expert status
8. offer field-evidence for viable long-term solutions at a particular location	8. depend on short replacement cycles of hypotheses, scientific knowledge, and products
9. are highly contextualized biologically, socio-economically, and culturally	9. often lack a sufficient period of experimentation until the relevant field evidence of long-term impacts is available
10. represent knowledge in community practices	10. decontextualize genetic information, often neglecting local ecological, socio-economic, and cultural specificities
11. communicate knowledge orally	11. communicate knowledge in written form
12. use biological diversity in mass-selection and in cultivation and integrate aspects of crop cultivation, food preparation, and healthcare	12. separate agriculture, nutritional sciences, and medicine into different departments
13. are neither capital- nor energy-intensive.	13. are capital- and energy-intensive

[a]For a discussion on the concept of "Commons," see Sachs (1999).

sustaining would not necessarily be their own personal ones). However, the results of our research showed that if on the one hand the students were actively and pleasantly involved, on the other hand the context of the simulated debate would not promote the development of an important social dimension: the ability of listening to each other. In the win/lose setting of the debate, we observed the use of an argumentative language, the venting of emotions, and a tendency from the participants to repeat the same concepts only with increased emphasis. The group members would mainly address their talk to the decision makers (as it was established by the rules of the game, in order to keep order) and very rarely the arguments expressed by one group were continued and expanded by the other group, except for addressing criticism. By means of direct observation (confirmed by the video-recordings), it was found that the groups would not pay attention to "adversarial" contributions.

In relation to some of our goals, such as

- to increase students' interests and motivation for school subjects,
- to help students to take on a role and engage with the task,
- to develop empathy with the character, and
- to effectively sustain one's opinions,

The results showed that students were easily involved by the competitive setting and this motivated them to speak their mind and to look for relevant information, thus increasing their knowledge about the issue. However, the implicit message that was unintentionally delivered was that of the decision making as being some sort of endurance test, in which the ones who were able to sustain their own opinions for longer also stood a better chance to "win." When involved in debate and argumentation, the intention of the participants is single mindedly that of defending one's own position or attacking that of others, with the aim of shifting the opinion of their adversary or persuading a third party: "They are entirely resistant to the merits of the opposing opinion or demerits on their own except insofar as these represent tactical problem in their task of persuasion." (Bridges, 1979, p. 15)

More difficult was to train people to carry out discussion, as described by Bridges (1979) in the form of a "give" and "take" activity in which one is disposed to understand, to examine, and to "take" or be affected by opinions other than one's own. Bridges describes discussion as being an ethically bound kind of activity as it is relies on "a fundamental preference for nonviolent politics which may be held even at the cost of delaying what are considered to be the right solutions" (p. 31).

During the second phase of our developmental research, we introduced modifications on both the structure of the role-plays and the content, such choices being the springboard for a profound change in our educational activities. Whereas in the first role-plays, the decision-making process and the verdict of the panel was the culminant and conclusive point of the activity (as it was taken for granted that the decision would have operational power), in the last role-play the central aspect was no longer "the solution," but the recognition and handling of the conflict. In line with the nonviolent approach of Galtung (1996), the theoretical premise of this new version was that conflicts generally cannot be "solved," but gradually "transformed." In such a view, focus was more on the process than on the product, such is the proposed activities aimed at addressing people's attitudes toward conflict, their perception and the strategies they adopt for dealing with it. During the exploration of conflict, participants were deeply involved in reflection upon deep-seated values and beliefs. While the debate was effective in stimulating participants' involvement, promoting abilities to sustain a point of view (which could have been personally shared or taken on by means of empathy) and to develop the view of a "team," the transformation of the conflict required deeper investigations at a personal level, involving aspects such as

- the reflection on oneself (what do I desire? What do I need? What is my idea of well being?);
- the relationships with others (who are "the others" for me: my peers, as well as the variety of other nonhuman living things? How do I relate myself to them?)
- the relationship with conflict (what do I feel? Which are my attitudes when I am in conflict with somebody? What is my behavior?).

When we modified the setting of the role-play and we suggested the simulation of a co-operative search for "transcending" the conflict and find consensus, the aims of the verbal interaction were substantially transformed. A fundamental rule was that of ensuring that all participants would make a contribution to the creation of a clear and articulated picture of the problem in hand. To achieve this goal, it was necessary that participants practiced a careful listening of each other's views and that they showed responsive attitudes toward others' contributions. The second stage required reflective abilities (to imagine the situation in the future) and creativity, the two key elements of nonviolent conflict transformation. The Buddhist tradition[6] brings in the epistemological value of this type of interaction, building on the awareness that it is not possible to get access to the absolute Truth, as infinite interpretations of the same reality may be possible. In this view, the aim of debating is that of enriching one's personal opinion with the multiplicity of interpretations offered by others. The complexity of reality does not allow for simple and straightforward answers to problems, but many voices are needed and so are deep listening and a respectful interaction among participants.

Nonviolent Conflict Transformation: The Development of a New Frame of Thinking. So far, our experimentations of the role-play and the win/win decision-making scenario have encountered several difficulties. The specific educational objectives for this type of activity were

- to reflect on one's own feelings and behaviors in situations of conflict;
- to think of positive and mutually shared future scenarios.

What appeared most evident to us in our research in the Italian context was that both students and teachers lacked familiarity with reflecting on the topic of conflict. Although peace education activities have been introduced into Italian schools for many years, curricula do not yet contain any specific activity about dealing with conflict: its nature and dynamics, the feelings involved, and the strategies and attitudes for approaching it. During the activity, participants were required to use a systemic approach: they had to understand the interconnections between local and global contexts, look at the actions of the different stakeholders (local people, traders, consumers etc.) and their mutual interdependences. A creative transformation of the conflict in fact was not based on free fantasy, but it required the creative effort of establishing a context for participation and communal action, as the participants sought to accomplish a shared project. The small sample of students and teachers that worked with us appreciated the introductory activities on conflict transformation that we proposed (for more details see Colucci, Camino, & Perazzone, 2001; Camino & Marchetti, 2003; Camino & Marasso, 2004). Those activities invited them to reflect on their personal situations: emotions, attitudes, and behaviors in situations of conflict. However, both students and teachers had difficulties in carrying out the group activities regarding the creation of a future scenario for the fulfillment of everybody's needs in the global issue about prawn farming. Participants often felt overwhelmed by the complexity of the issue, and they found it hard to think of practical/feasible actions. We attribute such difficulties to the unfamiliarity of working with extended temporal dimension, and to the limited time available for a thorough reflection on personal beliefs and images of the future.

[6]A rather different vision of debate is given by Daniel Goleman in his interview to the Dalai Lama. In his writings, Goleman reports that the practice of debate was central to the education of the Dalai Lama and it was defined as a football match. "When the Dalai Lama was growing up, watching debates was a popular pastime among lay Tibetans, who would spend part of their leisure time in a monastery courtyard observing the intellectual acrobatics of the sparring monks. [. . .] Those who sit with the Dalai Lama [. . .] need to come with an attitude much like that of those monastic debates, where new insights emerge through the back and forth of point and counterpoint" (Goleman, 2003, p. 29).

Problems also emerged with the use of the role-play, as many of the younger students did not understand the new task: as they fatigued with coping with dysfunctional group dynamics and the new sets of responsibilities (i.e. developing one's point of view and supporting it in relation to the points of view of others), they disengaged with the task and they lost motivation. Current research from one of the authors is exploring the use of this methodology to develop learning contexts of increased interdependence (e.g. a combination of role taking and discussion in small groups), which may be created to prepare participants to address conflict.

Other interesting avenues for future investigations are offered by the use of role-play to deal with intercultural conflict. An interesting reflection may be developed from the practice of intercultural mediation, in relation to the influence of language to recall particular styles of interaction. Hence in order to initiate a constructive mental habit, the process of *nonviolent discussion* may be replaced by that of a *table of reconciliation* (Marasso, personal communication). This second approach focuses on reflective action, and it progresses through participants' exploration of their interdependent interaction. The following questions give an example of how participants may be guided and guide themselves during the process: *What did I do to cause the conflict? What could I do now and which I did not do before? What can we do together?*

Conflict Transformation Within a Planet with Limited Resources. The context of the role-play offered the opportunity to reflect on one's own beliefs and of the variety of relationships that can be established among individuals and groups. Meanwhile it allowed us to observe difficulties and conceptual obstacles in dealing with the complexity of socio-ecosystems embedded within a closed system, the biosphere. Much of such difficulties related to the need of developing an awareness of different levels of organizations, ability to recognize nonlinear interactions, webs and circular causalities, and to think about local and global connections and boundaries.

On the other side, while progressing in our experimental research we developed an increasing awareness of the potential of such methodology: role-play appears to be a tool for introducing an holistic approach to understanding complex issues related to STS and PAS problems, and to respond to the need of coherently link together aims, methods, context, and processes within the scenario of the planet.

CONCLUSIONS

In this paper we described an "ecological framework," which we developed in the course of our teaching and research on complex and controversial socio-environmental issues. Our activities developed over time, gradually describing changes in the understanding of the relationships between science and education, to fit in with the wider scenario of sustainability.

Role-Plays: From the Win–Lose to the Win–Win Option, and System Thinking

Within the scenario of our first role-plays, with debate and people taking sides, students were acting in a setting of representative democracy, in which science and society interacts via members of legislative bodies and interest groups with a decision that is taken in the form of "victory of the majority." Such role-plays proved to be effective in exposing the students to a multitude of interests and points of view, and in developing critical attitudes toward different forms of knowledge and ways of knowing, with scientific knowledge as one of them. However, the win/lose setting proved to be an obstacle to the full understanding of the issue and the ethical implications of the decision.

The awareness of complexity and the approach of post-normal science brings the democratic process into a new perspective. The hierarchical organization gives space to a systemic network, where all stakeholders not only have the right to express themselves, but are the depository of a legitimate, crucial, and unique point of view. At the epistemic and methodological level, this corresponds to the development of a system of thinking which looks at connectedness, relationships, and context: "system thinking."

Ecology and Equity: A Nonviolent Perspective on Sustainability

Our research and our educational activities, addressed to both teachers and students, stemmed from the fundamentals of the natural sciences, which recognize the finiteness of our planet, and refer to a system of values which has emerged in recent years as a result of a new sensitivity toward the earth. This particular ethical framework emphasizes the value of the natural ecosystems as being the necessary support system on which human beings (seen as one of the "guests") depend for all their needs. From this, it follows that human beings hold the responsibility of finding peaceful ways of living in coexistence with other living things and in managing common goods, in order to guarantee a sustainable future for all the inhabitants of the planet. This includes the variety of human cultures and the variety of living things that populate the different ecosystems. In this paradigm it becomes important to develop nondestructive approaches to dealing with conflict. Nonviolence represents one of the most articulated steps in this direction because it proposes a method for containing the destructive potential which may be present in every conflict situation. Moreover, it offers us some hints for assuming a rational attitude in conditions of ignorance, with the view that our actions will still be reversible in case the choices we made proved wrong. In the light of our previous considerations about the globalization process and the interconnections between populations and ecosystems of the whole planet, the view of nonviolence can support the design and implementation of our educational action in accordance with an "ecological literacy" and an "ethics of the planet." This further conceptualization opens new opportunities for scientific research and practices, such as studies which recognize the monetary value of ecosystems' services and the dimension of equity, to those which emphasizes the spiritual dimension in the production of goods and set the basis for a nonviolent spirit in economics: "self-interest and self-preservation demand complete nonviolence, cooperation and submission to the ways of nature if we are to maintain permanency by non-interference with and by not short-circuiting the cycle of life" (Kumarappa, 1929, as found in Padmanabhan, 1993). In the realm of cultural change, the ethics of the planet implies a recognition of the relational context between humankind and nature, in the evolution of language, thinking, spirituality, and ethics.

Complexity and Nonviolence as Educational Values

In line with findings from the cognitive sciences, our experimental data suggest that in order to internalize the idea of complexity it can be useful to integrate the more traditional ways of teaching science (i.e. the linear relationships of cause and effect in knowledge, separation between holders and receivers of knowledge, partition of knowledge in disciplines etc.) with direct experience of complexity, as for example:

- the study of complex issues (i.e. controversial issues);
- the use of complex teaching methods (simulations, group discussions, debates);
- the involvement of different levels of personal development (the cognitive aspects as well as the feelings, values, opinions, dreams, aspirations and so on).

Complexity can be introduced within the school context at different levels: the object of the study, the processes as well as the aims and purposes of the learning process. This can be of great usefulness for reducing the gap, which both teachers, students, and educators perceive as problematic, between the world of the school, which is presented as "neutral," "simple" and foreign to the reality of things, and the life outside, which is full of stimulation but where we often find ourselves lost and without the necessary tools for understanding and acting. The classroom is in itself a good example of a complex system consisting of people with interests, abilities, and values, all very different from each other. Many traditional teaching practices tend to simplify this system, in an artificial way, and so miss the opportunity to realize its full potential: the top–down lecture is carried out at the expenses of the interaction amongst peers, the close-ended questioning prevents the expression of new and creative ideas, disciplinary teaching is an obstacle to the creation of transversal links, the emphasis on memorizing facts and information interferes with possibilities for meta-reflection.

In conclusion while there may be different and valuable teaching and learning approaches for handling a socioscientific issue which focus on specific learning outcomes, we believe it is important to acquire awareness of the complexity of the teaching and learning process in its interrelated learning dimensions. Specifically considering the ecological thinking framework, we can now ask ourselves: "What does this say about ourselves?" How can we develop awareness of the ways in which we perceive and interpret the world, and take part in the interaction which constitute our life?" To this respect, the reflections presented in this article could inform further research on the development of a rationale for assessing new competences that today's citizens are required to develop. In the realm of education, our reflections on the teaching and understanding of complex and controversial issues led to a formulation of an approach to learning which enhances our own personal enquiry about ourselves and the world. As Morin (2000) had expressed it:

> we are contemporarily within and outside nature. We are at the same time cosmic, physical, biological, cerebral and spiritual beings. We are children of the cosmos, but because of our own humanity, of our own culture, our own mind and consciousness, we have become foreign to this cosmos, from which we were born but which at the same time remains for us secretly intimate." (pp. 34–35)[7]

In order to progress along this path, our further investigations will concern the exploration of our *sustainability*, or how to be sustainable with and within ourselves. For example, our research started to provide some evidence of a process of self-reflection in the participants, as they prepared themselves to deal with conflict. However, our experimentations were severely constrained in their scope and impact, and further research may be addressed to build upon the dialogical and interdisciplinary aspects of this personal and collective investigation.

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[7] Translated by the authors from the Italian version: "siamo contemporaneamente dentro e fuori la natura. Siamo esseri nello stesso tempo cosmici, fisici, biologici, culturali, cerebrali, spirituali... Siamo figli del cosmo, ma a causa della nostra stessa umanità, della nostra cultura, della nostra mente, della nostra coscienza, siamo divenuti stranieri a questo cosmo dal quale siamo nati e che, nello stesso tempo, resta per noi segretamente intimo" (pp. 34–35).

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