Chapter 3
Questions Socialement Vives and Socio-scientific Issues: New Trends of Research to Meet the Training Needs of Postmodern Society

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1 Introduction

In this chapter, we first present the French framework of *Questions Socialement Vives* in education and show its underpinning links to the risk society and in the field of post-normal science. We develop two essential approaches to address education issues through Socially Acute Questions: a socio-epistemological approach and a psychosocial approach. Secondly, we present the diversity of educational stakes and pedagogies that can cover the teaching of socio-scientific issues as they are 'heated' or 'chilled' in the classroom and then we locate within this panorama the French field of Socially Acute Questions. We present the different epistemological positions that can influence the construction of didactic strategies in the teaching about SAQs. We describe four types of didactic strategies: doctrinal, problematising, critical and pragmatic. We propose that a critical pedagogy can be used to develop students' socio-scientific reasoning in the perspective of sustainability. We describe an analytical grid for this. Finally, we discuss the challenges raised by the implementation of a post-normal education.

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2 Socially Acute Questions and Socio-scientific Issues

2.1 Definition of Socially Acute Questions

Many science educators believe that one of the goals of science education is to help students develop their understanding of how society and science are mutually dependent. The notion of a socio-scientific issue (SSI) has been introduced as a way of describing how social dilemmas impinge on scientific fields (Gayford 2002; Kolsto 2001; Sadler 2004; Sadler and Zeidler 2004; Sadler et al. 2004; Zeidler et al. 2002). These issues are very often controversial and they have implications in one or more of the following fields: biology, sociology, ethics, politics, economics and/or the environment. Sadler (2009) posits that SSIs include two necessary elements: conceptual and/or procedural connections to science and the element of social significance.

Legardez and Simonneaux (2006) coined the term *Questions Socialement Vives* – in English, 'Socially Acute Questions' (SAQs) – to describe complex open-ended questions that bring out the uncertainties embedded in ill-structured problems relating to SSIs. These questions are at the heart of the problem of teaching and learning in an uncertain world influenced by the development of techno-science and by environmental and health crises. These questions situate social and scientific controversy, complexity, the building of expertise, assessment of evidence, uncertainty and risk at the very heart of the teaching-learning process. Because real-world contexts (global or local) are perceived through individuals' identities (linked to gender, culture, political position, profession), SAQs are positioned within the framework of situated learning. In fact SAQs are always controversial as they challenge social practices and reflect social representations and value systems that many in society believe are important to discuss. Consequently, because of their controversial nature, they have the potential for generating debate in classrooms.

SAQs are perceived as 'acute' when they are located in the following three areas:

– In society: They have the potential to stimulate debate – there is often media coverage of such issues and consequently students may have some superficial knowledge.
– In research and professional fields: This is when competing points of view and controversies can lead to debates on the production of reference knowledge within academia – for example, in human sciences, various paradigms can be in conflict and in sciences, this type of question forms part of 'frontier' science where the results are discussed in the scientific community.
– In the classroom: Often, they are perceived to be 'acute' because they are encountered during discussions about society and research. In this situation, teachers often feel unable to deal with them in class discussion as they cannot solely rely on the use of scientific facts and may be afraid that they lack the ability to manage students' reactions. Consequently some teachers choose not to teach them or will neutralise them ('to cool them down'), while others will decide to activate them ('to warm them up'). It seems that teachers will position themselves according to the 'degree of acuteness' they perceive and to the 'teaching risk' they can tolerate.

Because SAQs integrate learning of content knowledge both in science *and* in the humanities, and learning about the construction of knowledge (about humanities *and* science) they provide opportunities for an interdisciplinary approach. In the French context, SAQs have a wider educational span as they integrate Socially Acute Questions in humanities (e.g. globalisation or financial crises) and Socially Acute Questions in science. In this chapter, the latter group is the focus of discussion.

It is apparent that such questions are found more and more frequently in science curricula and are often referred to in the guiding principles of 'education for' programmes, e.g. education for the environment, for sustainability, for health, for (eco-)citizenship, for choice and for consumption. Because of this relevance, Tytler (2012) argues that science education might be, and should be, framed in order to engage students in a science that is relevant and powerful for them as future citizens.

2.2 The Underpinning Links of Socially Acute Questions

The French approach to SAQs emphasises the degree of acuteness of the question in the world of research and/or society. This SAQ approach has a common aim with the science, technology, society (environment) (STS(E)) model (Hodson 2003); it aims for students to be committed to make responsible decisions about SAQs. Although SAQs may contribute to scientific literacy, they also have the potential to develop students' political literacy by including such topics as risk analysis, analysis of patterns of political and economic governance as well as decision-making and action. Even though Zeidler et al. (2005) have provided evidence that SSI education is a better way than the STS movement to integrate the nature of science, arguments, values and moral judgements, Hodson has recently (2011) critiqued both of these approaches and asserts that STS and SSI education have given too low a priority to the promotion of critical thinking. He asserts that neither STSE- nor SSI-oriented teaching goes far enough.

The emphasis on how we try to minimise risk in our society means that SAQs provide an indication of the problems of our risk-aversion society. In his work on the risk society, Beck (1986, 2001) suggests that these days we are emotionally aware of man-made hazards. This does not mean that life is more dangerous to postmodern humanity but that the postmodern society is concerned about the risks posed by techno-responses to past problems. He says that the production of new scientific knowledge has to resolve the multiple impacts (waste, pollution, new diseases) that have been generated by techno-science. By placing uncertainties and risks in the centre of this discussion of philosophy of science, Beck supports a critical approach to scientific rationality**.** He postulates that institutions, including science, are struggling with the effects of what they have created, and even though they have begun to change, the scientific enterprise cannot be locked into a single theoretical production of scientific knowledge. Instead, he suggests that it is necessary that research anticipate the consequences, uncertainties and risks of scientific advances through what he calls 'reflexive scientification'. Beck comments that science answers questions that are not really raised by society so it ignores the real issues that are the source of its anguish. Furthermore, he claims there is a difference between scientific rationality and social rationality, although he does not deny that there are overlaps and dependencies when scientists are required to comply with social expectations and values when exploring the impact of industrial hazards and their evolution. From his perspective, it appears that the risks associated with SAQs are not generally understood and that unknown risks could generate outcomes that are irreversible, with consequences that are difficult to repair, perhaps affecting the whole world and future generations. Consequently, using Beck's analysis of our postmodern society, it seems that scientific rationality would not be sufficient to justify any techno-science and accompanying such analysis there would lead to a reflexive criticism of its impact.

In our view, SAQs lie within the field of post-normal science (PNS) as defined by Funtowicz and Ravetz (1993), because such a positioning acknowledges its strong links to human needs that involve large uncertainties, major issues and values and require urgent decisions. In fact we assert that the social dimension of this positioning of science is emphasised within PNS. Funtowitcz and Ravetz emphasise that within PNS, the decision process should involve open dialogue with everyone concerned and propose the concept of an 'extended peer community'. According to Ravetz (1997), the question 'what if?' justifies a strong consideration of 'extended facts', that is to say, data from sources outside the dimensions of orthodox research. We believe that it is important to train students to participate within the 'peer extended community' so that different perspectives can be taken into account.

2.3 The Socio-epistemological Approach

It is also important to acknowledge a socio-epistemological approach when examining SAQs. We assert that scientific research, cultural norms, sociopolitical contexts and their applications influence each other. This viewpoint has been backed up by researchers in science studies (Duschl and Grandy 2008; Latour 1999; Nersessian 2008) who have identified the complex, contextual, contingent and cultural representational practices that are used to establish and validate science knowledge.

SAQs also question the foundations of science and the rationalist utopia according to which reason and truth emerge from the confrontation of ideas. Therefore, if we are consistent with Beck's argument (1986/2001), we must go beyond the 'successive attempts to rescue the "underlying rationality" of scientific knowledge' (p. 360) which occurs whenever science is confronted with failure or adverse effects.

We assert that the traditional image of academic science has changed and the dividing line between the sciences and their application is becoming blurred with the acknowledgement of the increasing importance of techno-sciences. In fact trends in science are now criticised as being more and more determined by economic interests, and numerous studies have shown the links that exist between science, politics and business. For example, Salter (1988) uses the term 'mandated science', Ziman (1996) acknowledges these wider dimensions with the term 'post-academic science', and Slaughter and Leslie (1997) call such influences 'academic capitalism'. However, Beck denounces the view that research should be increasingly at the service of an economic project, noting that the sciences have 'entered into a polygamous union with the economy, politics and ethics – or, more precisely, they live in a sort of "sustainable cohabitation" with all of these areas' (Beck 2001, p. 53). Ziman recognises these tensions when he asserts that (1998, p. 1813): 'Universities and research institutes are no longer deemed to be devoted entirely to the pursuit of knowledge for its own sake. They are encouraged to seek industrial funding for commissioned research, and to exploit to the full any patentable discoveries made by their academic staffs, especially when there is a smell of commercial profit in the air'. Hodson (2011, p. 126) is also aware of such influences when he notes that 'The vested interests of the military and commercial sponsors of research (…) can often be detected not just in research priorities but also in research design, especially in terms of what and how data are collected, manipulated and presented. More subtly, in what data are not collected, what findings are omitted from reports and whose voices are silenced'. Acknowledging the difficulty in trying to distinguish science from its technological applications, Ravetz (1997, p. 7) sees science as 'a total system including research, R&D and innovation'. He asserts that it 'is primarily valued for its contribution to industry and economic growth; and it is from just those forces that our major environmental problems arise. To enforce an assumption that the scientific tools should be studied in isolation from their practical uses, is to create an innocence that is artificial, temporary and ultimately false'. These writers seem to agree that the domination of capital over science does not weaken as knowledge, and nature itself, are seen as 'goods' and are turned into saleable and purchasable things. This raises the question of the moral responsibility for the use of scientific applications. Who is responsible? Society? Scientists? Technologists? The state? Ravetz (1975, p. 46) raises this issue in his own way: 'Scientists take credit for penicillin, but Society takes the blame for the Bomb'.

We consider that many different actors take part in knowledge production. These include scientists, citizens, philosophers and even whistle-blowers. Consequently, we assert that the knowledge involved in SAQs can be conceived as plural (polyparadigmatic) and/or engaged (analysing the controversies, uncertainties and risks) and/or contextualised (observing empirical data within a given context) and/or distributed (constructed by different knowledge producers).

The socio-epistemological inquiry into the SAQs is not easy to carry out; Latour talks about constructing a cartography of controversy. This process is always subjective and involves continuous updating. However, such a construction is not simple. How does one conduct a socio-epistemological inquiry? How does one know when and where to temporarily close it off? How does one assess the expertise, the 'evidence', the risks? How does one identify the uncertainties?

Agnotology (the science of ignorance) has emerged (Proctor and Schiebinger 2008); this discipline studies the techniques used by certain economic interests to cast doubt on well-established knowledge. This area is connected with the industry of doubt that was presented at this conference by Isabelle Stengers, when discussing the issue of creationism.

Then a question may be raised about SSIs/SAQs: do they develop the critical study of controversy or do they contribute to the spread of ignorance? And how can one contribute to the former instead of to the latter?

2.4 The Psychosocial Approach

Given the nature of SAQs, it is also necessary to analyse the psychosociological factors that determine the positions and behaviour of the actors involved in the activity. We assert that learning through SAQs has affective and social dimensions. For example, one learns from the points of view of one's social groups and from one's identities. Consequently we assert that one's perspectives are influenced by value systems, cultural and socio-professional identities, perceptions of norms, cultural bias in particular concerning risk perceptions (Douglas 1992) and future projections.

We note that exploring futures with students about SAQs can sometimes be counterproductive and can lead to feelings of despair. On the other hand, exploring alternative futures also helps students 'to clarify their hopes and fears about the future in order to move beyond passive forecasting about "how it is likely to be" to the generation of ideas about the sort of future they want in the basis for planning and action' (Hodson 2011, p. 159).

Also it is important to be able to analyse the impact of emotional points of view. Many studies have been made from this perspective, in particular Sadler and Zeidler (2008), who emphasised the important role of moral reasoning. They note that decisions related to SSIs can reflect the moral principles and qualities of virtue in learners. They also emphasise the role of education in the formation of conscience and the development of character. They assert that emotions and moral-ethical reasoning play an important role when taking stances and action on SSIs.

As already noted, context and identity are of importance when studying SAQs and various contextualisation impacts linked to the imprinting of values on learning have been identified.

For example, if the context presented to the students contradicts their system of values, it can hinder knowledge learning and critical reasoning, blind the participants to the issues as well as build a resistance to changing their minds. However, if the context allows them to defend their sociocultural positions, it stimulates their critical analysis (Simonneaux and Simonneaux 2009).

3 Curriculum Orientations: To 'Cool Down' or to 'Heat Up' the Questions

3.1 Diversity of Educational Stakes and Pedagogies

In the literature on the teaching of SSIs, we can observe very different objectives. There are many different dimensions to the concept of an SSI. Similarly there is variation in the extent to which teachers 'heat up' or 'cool down' these issues.

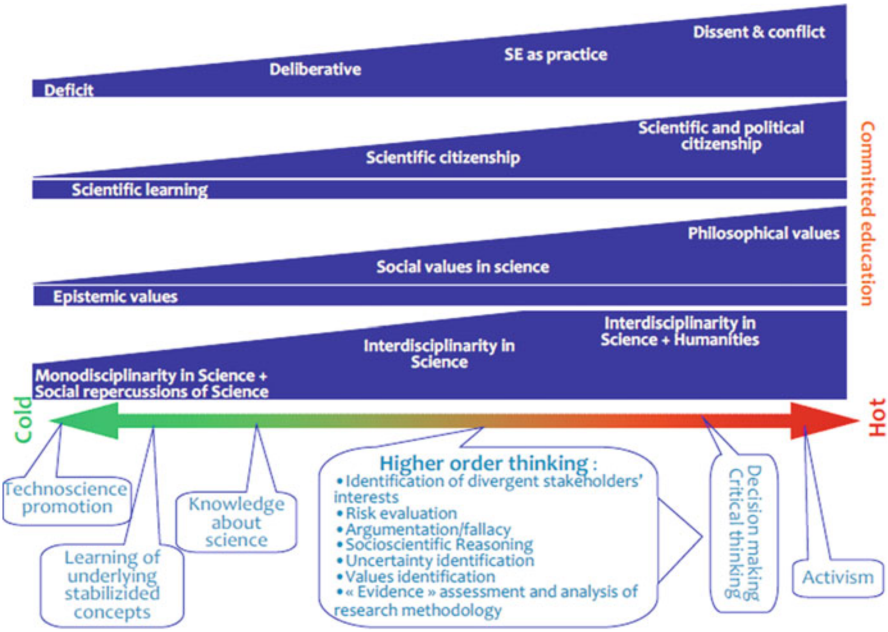

Fig. 3.1 Educational stakes and pedagogies beyond SSI education

There are different ways of teaching SSIs according to the teacher's view of the main educational stakes. In an attempt to map out the landscape, these different dimensions are represented as continuums in Fig. 3.1.

At the 'cold end', an integration of SSIs into a teaching programme is used to motivate students learning science or even to convince them of the merits of techno-sciences. At the 'hot end' of the continuum, the teaching focus goes beyond the purpose of developing conceptual and procedural knowledge of science to the nurturing of activist commitments amongst learners. Between these two ends of the continuum, a mix of educational issues is involved in the teaching and learning of scientific concepts that can contribute towards the development of critical thinking. When critical thinking occurs, the focus moves towards the 'hot end'. In the current field of French education, the educational stakes are high and it is asserted that SAQs can develop high-level thinking, decision-making and critical thinking with a focus on promoting an engaged citizenship.

At the 'cold end', knowledge mobilised in the classroom is single-disciplinary science. At the 'hot end', it is discussed on an interdisciplinary basis in science and humanities. Between the two ends, it is interdisciplinary science.

We assert that the study of SAQs forces education to transcend disciplinary divisions, particularly between 'hard' science and human science. When examining (techno-)sciences, we have realised that many characteristics go beyond the boundaries of the disciplinary divisions and these divisions are as much the result of a social construction as of epistemological specificities. With a French SAQ approach, we argue for real interdisciplinarity where science and humanities are integrated in order to account for the complexity of the reality linked to SAQs. This interdisciplinary approach is also advocated by Hodson (2011). Recently Eastwood et al. (2011) have described and analysed an ambitious 4-year interdisciplinary university programme. Here the interdisciplinary approach goes beyond the single social impact, or the impact of values, or even the impact of culture. The approach requires hybridisation of knowledge between the humanities and natural sciences and may often include nonacademic knowledge.

We assert that values may be explicit or implicit in the teaching of SSIs. At the 'cold end', only epistemic values may be mobilised (validity, reliability, accuracy). At the 'hot end', philosophical principles underlying the values are explained and discussed. Between the two ends, the social values in science (Longino 2002) are identified and acknowledged. In fact in the French field of SAQs, values must be clarified, whether they are scientific or social. Such a focus is aimed at helping students to identify the values of different stakeholders, as well as their own, in their decision-making.

Beyond science learning, the challenge may be to develop scientific citizenship and even political citizenship so that teaching about SAQs may lead to the combination of both science education and political education – and thus the development of scientific, and even political, literacy.

Levinson (2010) has identified a number of democratic participation frameworks that can be used in the teaching of SSIs. For example, within the *deficit framework*, he observes that:

– Students construct their socially relevant scientific knowledge with the help of the teacher – the hierarchy is scientist–teacher–student.
– Science is the corpus of knowledge; where there are uncertainties and tentative knowledge, this resides in expert authority – 'hard' science diffuses out into applied science.
– Students and laypeople are unlikely to have the requisite knowledge and understanding to engage in controversial issues.
– In addition to science content, they can be taught about the methods of science and controversies both within the scientific and socio-scientific domains – consequently, authority of knowledge resides within science and the teacher as science's representative.
– Once citizens become aware of the technical complexity, there will be an enhancement of trust and confidence in expert decision-making.
– Ethical and political aspects and value differences have only a marginal role.

Whereas in the *deliberative framework:*

– 'Jurors' are informed of technical information by scientists and hear evidence from a range of non-professional experts from interest groups.
– Rhetoric, argument and testimony are the main forms of presentation.
– Techno-science is uncertain and constrained by value positions – understanding of knowledge claims, critical thinking skills and underpinning empathy are likely to be prerequisites.
– Information about science is likely to come from expert scientist(s) rather than from the teacher.

While in the *science education as praxis framework:*

- Knowledge is distributed and emerges through praxis; knowledge is both situated and emergent – through legitimate participation, participants become inducted into more sophisticated and shared techniques of problem solving.
- Scientific knowledge is contestable and open to participant reflexivity;
- All participants, scientists and nonscientists, subject their views to communal questioning and reflection.

In the *science education for democracy through conflict and dissent framework:*

- Knowledge is distributed and emerges through praxis.
- The emphasis is on political literacy, identifying and analysing the sources of social injustice and both using and producing knowledge to address techno-scientific issues related to injustice.
- The emphasis is on campaigning and activism through scientific citizenship for social and political change.

Taking all of these views into account, we should not consider the continuums presented in Fig. 3.1 as if they coexisted; instead, these provide a visual summary of trends towards a more engaged education. It is interesting to put them into perspective with the four levels of sophistication for an issue-based education as described by Hodson (2010):

- Level 1: appreciating the societal impact of scientific and technological change and recognising that science and technology are, to a significant extent, culturally determined
- Level 2: recognising that decisions about scientific and technological development are taken in pursuit of particular interests and that benefits accruing to some may be at the expense of others; recognising that scientific and technological development are inextricably linked with the distribution of wealth and power
- Level 3: developing one's own views and establishing one's underlying value positions
- Level 4: preparing for and taking action on socio-scientific and environmental issues

3.2 Epistemological Stances

The diversity of functions that the actors in the education system attribute to science reveals their epistemological stances, and Simonneaux (2011) has established four categories, based on previous work in epistemology and in the sociology of science, which can be used to describe them. These are:

- The *scientistic* stance, which is inspired by Ernest Renan (1890). Here, science is considered to be essential to progress, and disciplinary and academic construction is the basis of this posture. The confidence placed in the scientific approach contributes to the sacralisation of science, where the researcher is the essential actor. The disciplinary content, and the way science is divided up, constitutes the basis of all learning from a hierarchical viewpoint. This view is widespread in schools and academic institutions, where learning is delivered by the teacher and disciplinary expert downwards to the student. The teaching of the agronomic and economic principles of the Green Revolution took on this stance. The Green Revolution refers to a strategy designed to transform agriculture in developing countries, which is based mainly on the principle of developing intensive farming methods and the use of high-yielding varieties of cereal grains. In the scientistic posture, new scientific knowledge in the field of plant breeding has led to technological innovation and progress.

– *Utilitarianism* constitutes a second stance. It can be defined as referring to the utilitarianism of John Stuart Mill. In this case, knowledge takes on meaning through the actions that it helps to produce. Here the operational dimension is paramount and the value of knowledge lies in the power to act on reality. Knowledge is considered from a production angle and is viewed as a resource. The institutions in which this knowledge is transmitted (a business, the market, a vocational training centre) have a function connected to production. The expert, engineer or administrator, who makes the right decisions, is the emblematic figure of this stance which fosters innovation. The teaching of precision agriculture is an illustration of this stance. Precision farming aims to optimise the management of a plot of land from an agronomic point of view (e.g. by adapting cultivation methods as closely as possible to the nitrogen requirements of the plant), from an environmental point of view (e.g. by limiting the leaching of excess nitrogen) and from an economic point of view (e.g. by increasing competitiveness through better management of nitrogen fertilisers).
– *Scepticism* constitutes a third stance, which can be linked to the works of Habermas (1987), Beck (1986) and Bourdieu et al. (1968). Events, with a more or less catastrophic impact in relation to the techno-sciences, have shaken our confidence in scientific progress and the gap between scientists and society is widening. The sciences produce breakthroughs but also controversies and risks. The scientists' questions and doubts are no longer confined to research but fuel public debate and are relayed by the media and citizens' associations. A person assuming this stance believes that scientific research is guided by political and economic choices. The educational intentions underlying this stance mean that the teacher will aim to promote citizenship training and critical thinking. Teaching on the potential environmental risks of producing insect-resistant GMOs illustrates this epistemological stance.
– *Relativism*, the fourth stance, finds its reference in the work of Feyerabend (1979), who considers that science cannot proclaim itself to be a superior form of knowledge because no universally validated method can be attributed to the sciences. It thus becomes difficult, or even impossible, to distinguish a scientific approach from any other belief or myth. Teaching the anthroposophist principles of biodynamics (a method used in organic farming) is a relativist stance. Anthroposophy is a school of thought and a form of spirituality founded in the early twentieth century by Rudolf Steiner. According to him, it is a spiritual science, an attempt at studying, experiencing and describing spiritual phenomena

with the same precision and clarity with which science both studies and describes the physical world. The use of the term 'science' in connection with this approach has been disputed by proponents of the scientific method.

The characteristics of these four stances are summarised in Table 3.1.

We argue that these epistemological stances impact the construction of didactic strategies in education about SAQs and will be explained in the next section.

3.3 Didactic Strategies

Didactic strategies reflect the stakes chosen by the school or by the teachers. Simonneaux (2011) identified four possible didactic strategies:

- A *doctrinal* strategy that aims to develop the acceptance of the ideas presented in the high authority of the teacher, who leaves little room for interaction with students.
- A *problematising* strategy that focuses on students' cognitive activity – here, students take an active part in the construction of an *issue* and develop a line of reasoning rather than finding *the* solution.
- A *critical* strategy aims to develop a critical sense – here, the educational purpose is to teach students how to argue and to assess expertise and different stances on complex issues which carry both uncertainties and risks.
- A *pragmatic* strategy is based on involving the students in an activity – here, the challenge is to stimulate student *action.*

Of course, several strategies can be used within the same teaching situation. Generally, there will be a dominant strategy, for instance critical and problematising strategies, which can bolster a dominant pragmatic strategy.

We argue for precognition, that is to say, developing a pedagogy which engages students into a knowledge inquiry, instead of retrocognition, where the traditional pedagogy is based on stabilised scientific 'works' and conceptual development that uses conventional teaching methods (Ladage and Chevallard 2010). As a consequence, we argue for a strategy that develops a critical rationality beyond a techno-scientist rationality and we believe that there are at least two key issues in the didactics of SAQs that should encourage critical analysis from the perspective of scientific citizenship: they are ethical reflection and epistemological questioning.

Several pedagogical strategies may be used to develop critical rationality. They include debate, role play, simulation of a citizens' conference, epistemological disturbance, an identification of a contextualised problem situation, analysis of media coverage, analysis of local projects, online cross-cultural cooperative work on local and global issues and the development of serious games. We have used all these types of pedagogical strategy and analysed them using various theoretical frameworks (Habermas 1987; Boltanski and Thévenot 1991; Moscovici 1976; Beck 1986; Douglas 1992; Simonneaux et al. 2012; Simonneaux 2001; Simonneaux and Chouchane 2011; Morin et al. 2011; Vidal and Simonneaux 2010).

Table 3.1 Characteristics of epistemological stances

	Scientism	Utilitarianism	Scepticism	Relativism
Relationship to the sciences	Sacralisation	Relevance of science is linked to its effects on the world	Science produces knowledge, controversies and risks	All types of thought deserve attention and can be uttered
Goals attributed to sciences	Progress, rationality	Advice, help with decision-making, innovation, development	Understanding the world but scientific reflexivity necessary	An understanding of the world amongst others
Authors	Renan	John Stuart Mill	Habermas, Beck, Bourdieu	Feyerabend
Institutions	Schools, education authorities	Business, market, vocational training centres	Citizens' associations, media	
Chosen communication model	Hierarchical and academic teaching	Innovation model, expertise	Civic debate, scientific café	All types
Examples of application in the field of agriculture	Green Revolution	Precision agriculture	Environmental and sanitary repercussions of GMOs	Biodynamics

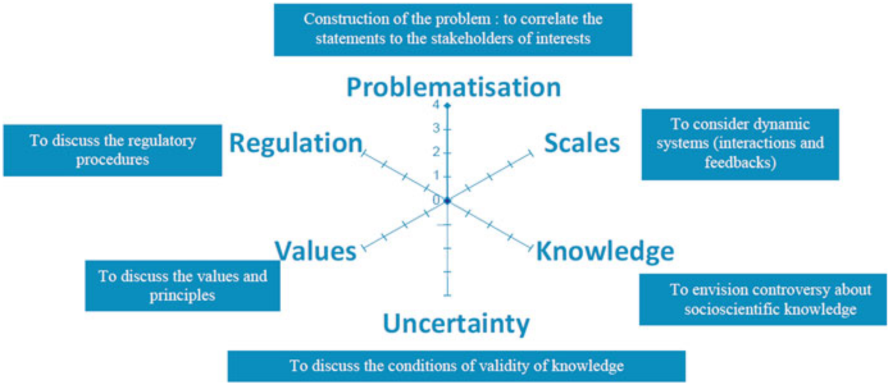

Fig. 3.2 Six dimensions of the SSR set within the perspective of sustainability

Within this perspective of procognition, we have tried to develop students' socio-scientific reasoning (SSR). We assert that context and identity have a great impact on SSR. Various studies have contributed to a characterisation of SSR, including *The Quality Gradient of Argument* (Grace 2009), *Informal Reasoning* (Sadler and Zeidler 2005), *The Development of Reflective Judgement* (Zeidler et al. 2009), *Socio-Scientific Reasoning* (Sadler et al. 2007) and *SSR and Sustainability* (Saoudi 2009; Morin and Simonneaux 2011).

At this point, the question we must ask is: are there patterns of reasoning broadly applicable to all or to most SSIs/SAQs? Sadler et al. (2007) developed a model of socio-scientific reasoning as a means of understanding student practices relative to the invariant features of SSIs that could assess these practices. They hypothesised that after negotiating specific SSIs, students would have the knowledge and skills to respond to the implications of the invariant features of diverse SSIs. But their results (Sadler et al. 2011) and ours (Simonneaux and Simonneaux 2009) do not confirm this hypothesis. We think that context and identity dimensions impact on SSR differently, depending on the issues under debate.

To support our viewpoint, it is important to note that our grid for the analysis of SSR within the perspective of sustainability (see Fig. 3.2) has been elaborated progressively and can be used to compare the SSR of different types of public, in different contexts and in different cultures. It can even be used to assess the evolution of SSR after an activity. In its latest (but still provisional) version, the grid is constructed in six dimensions (problematisation, scale, knowledge, uncertainty, value, regulation) and each one is divided into four levels and is explained as follows:

Within the problematisation dimension, points of view are identified as ranging from a person seeing only one point of view or everyone having the same point of view to persons who are capable of seeing that there are different points of view and are able to present these viewpoints from differing perspectives. The highest level of the problematisation dimension is the perception of a controversy about the stakes and being able of put forward perspectives through the various assertions that are reflected by each stakeholder's interest.

The levels of scale range from those people that see a limited effect – both spatial (local or perhaps generally or globally) and temporal (over a short period) – to those who see a complex effect of time and environment interacting in ways that involve a feedback system. The highest level of the scales' dimension is the conception of dynamic systems (integrating spatial interactions with diverse scales as well as temporal feedback).

In the knowledge dimension, viewpoints range from a point of view that is naïve, where knowledge is seen as unproblematic (it may be academic or not), to points of view which consider that multiple knowledge systems can contribute to the analysis of a socio-scientific problem. The highest level of the knowledge dimension is the integration of different types of knowledge (academic or not) in science and humanities, and the perception of controversy about socio-scientific knowledge.

In the uncertainty dimension, the viewpoints range from those who have no problem with the information and consider it to be the truth to those who hold an epistemic view of knowledge building and apply this to knowledge used in the resolution of socio-scientific issues. At the highest level is discussion of the conditions for validity of the reference knowledge that is an awareness of epistemological doubt.

In the values dimension, the range includes those who are unaware that arguments can be underpinned by different values to those who are aware of different value systems and the potential conflict between them. At the highest level is the perception of possible conflicts within these values.

The perspective of regulation ranges from a view that there is already a solution (based on law or ethics or accepted techno-scientifically) or one which does not consider the possibility of any other viewpoints and interactions to those who are aware that regulation must take into account all the stakeholders' positions. At the highest level is discussion of the regulation procedures between the categories of actors or the governance (the modalities of decision-making).

The impact of various didactic strategies on the SSR has been analysed in various studies. In our different studies, we noticed that students' commitment to reasoning was linked:

- With their rationality (scientific, social or techno-scientific) – the more they expressed techno-scientific rationality, the less they developed sophisticated reasoning
- With their personal conviction (environmental in the field of education for sustainability, ethical in the field of health)
- With their epistemological position (expressing doubt or 'blind' confidence in science)

4 Challenges for Future Post-normal Education

What knowledge will be relevant to future generations?

Is there a process of desacralisation of a more humanistic science?

Our research shows that there is a need to highlight successful practices, to provide more teacher professional development and to encourage more cross-curricular and school-based prioritisation of the value of SSIs as central to a contemporary curriculum (Prain 2012).

Whether coming from epistemological, sociological or anthropological areas, more and more voices are being raised to highlight the way in which social and economic factors interweave with scientific activity (Beck, Callon, Lakatos, Latour, Stengers). We acknowledge that this shift in perspective initially came from post-normal science (Funtowicz and Ravetz 1993) which legitimises post-normal education. It is significant to re-emphasise that this is where we situate SAQs.

We continue to advocate that critical reflexivity is essential to citizenship education. Similarly to Levinson (2010), we believe that it is the educational centrepiece of scientific literacy which can lead to political literacy (Levinson 2010). Such a purpose emphasises the need to move towards a 'critical-constructivist' pedagogical paradigm (Tutiaux-Guillon 2008). Here, the question of knowledge should be the central question for society and we cannot ignore its social and political dimensions. Once we can recognise how science works, we can consider other purposes and other forms of teaching science. Because we believe that teaching SAQs requires going beyond disciplinary divisions, we argue that the questioning of traditional didactic methods could provide a way of showing how to make the transition towards post-normal education.

In short, when implementing post-normal education, it is not sufficient just to learn and to understand. Instead, the central purpose is to encourage participation and action in the scientific activity. We realise that science has a limited and temporary validity which is marked by social interactions; therefore, we need to consider using a different model to develop understanding rather than the downward transmission that is normally practised. Instead we need to develop a model that gives priority to more active and participatory methods.

Overall the goal of a didactic for SAQ is to get the students to take an active part in the scientific process. This is a process which cannot be separated from the social process.

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