Science
Education

Developing and Using an S^{3}R Model to Analyze Reasoning in Web-Based Cross-National Exchanges on Sustainability

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ABSTRACT: Within the increasing body of research that examines students' reasoning on socioscientific issues, we consider in particular student reasoning concerning acute, open-ended questions that bring out the complexities and uncertainties embedded in ill-structured problems. In this paper, we propose a socioscientific sustainability reasoning (S^{3}R) model to analyze students' reasoning exchanges on environmental socially acute questions (ESAQs). The paper describes the development of an epistemological analysis of how sustainability perspectives can be integrated into socioscientific reasoning, which emphasizes the need for S^{3}R to be both grounded in context and collective. We argue the complexity of ESAQs requires a consideration of multiple dimensions that form the basis of our S^{3}R analysis model: problematization, interactions, knowledge, uncertainties, values, and governance. For each dimension, in the model we have identified indicators of four levels of complexity. We investigated the usefulness of the model in identifying improvements in reasoning that flow from cross-national web-based exchanges between groups of French and Australian students, concerning a local and a global ESAQ. The S^{3}R model successfully captured the nature of reasoning about socioscientific sustainability issues, with the collective negotiation of multiple forms of knowledge as a key characteristic

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in improving reasoning levels. The paper provides examples of collaborative argumentation in collective texts (wikis) to illustrate the various levels of reasoning in each dimension, and diagrammatic representation of the evolution of collective reflections. We observe that a staged process of construction and confrontation, involving groups representing to some extent different cultural and contextual stances, is powerful in eliciting reasoned argument of enhanced quality. *Sci Ed* **98:**517–542, 2014

INTRODUCTION

A major aim of science curricula in the 21st century is to develop students' scientific literacy. The importance of social and ethical aspects of socioscientific reasoning (SSR) and decision making is recognized by the scientific community, the members of which are inevitably bound up with these debates in research and development (Tytler & Symington, 2006). Reasoning about the application of science in the postmodern risk society involves negotiating science knowledge and evidence alongside other forms of knowledge and beliefs, such as societal, economic, and political knowledge, and values. Thus, the focus of school science is to prepare students to become adults who are interested in and can engage in science discourse, are able to identify questions and draw evidence-based conclusions, are skeptical and questioning, and are able to make informed decisions about the environment and socioscientific issues (SSIs) to do with their lives (Rennie, 2006).

The notion of SSIs has been introduced as a way of describing how social dilemmas impinge on scientific fields (Gayford, 2002; Kolstø, 2001; Sadler, 2004). SSIs "are controversial social issues with conceptual and/or procedural links to science" (Sadler, 2011, p. 4). Teaching about SSIs raises the question of the interdependence of the cognitive, affective, and judgmental (axiological) components of education and training (Sadler & Zeidler, 2004). There is an increasing corpus of research that examines, in particular, the complexity of knowledges associated with student reasoning on SSIs (e.g., Bravo-Torija & Jiménez-Aleixandre, 2012).

The field of "Questions Socialement Vives"— in English, "socially acute questions" (SAQs)—represents a French orientation for the teaching of SSIs. It emphasizes the degree of "acuteness" of complex open-ended questions that bring out the uncertainties embedded in ill-structured problems relating to SSIs (Legardez & Simonneaux, 2006). SAQs reflect social representations and value systems that many in society believe are important to discuss. SAQs are at the heart of the challenge of teaching and learning about current events in an uncertain world, especially those related to issues surrounding the environment and sustainability. They express an appeal for a democratization of expert processes of risk assessment linked to socioscientific innovations.

Scientific literacy aims associated with sustainability issues challenge technicist notions of sustainability solutions where science and technology are considered the sole sources of knowledge for making appropriate decisions. In common with the science–technology–society–environment model (Hodson, 2003), reasoning about SAQs has the potential to support the development of scientific and political literacy.

Environmental SAQs are complex by nature, with components of the socio-eco-systems extending across scales of space, time, and social institutions (Morin, Simonneaux, Tytler, & Simonneaux, 2012). This complexity is central to a model of reasoning about sustainability SAQs we have been developing. In this paper, we refine our previous work on the model and investigate its usefulness in identifying improvements in reasoning that flow from cross-national exchanges on sustainability questions.

A MODEL TO DESCRIBE SOCIOSCIENTIFIC SUSTAINABILITY REASONING (S^3R)

An increasing number of science educators have devoted their attention to enhancing students' understanding of the multidimensional aspects of SSIs (Chang & Rundgren, 2010; Saoudi & Simonneaux, 2007; Wu & Tsai, 2007; Zeidler, Sadler, Simmon, & Howes, 2005; Zohar & Nemet, 2002). Given the status of SSIs as open-ended, ill-structured, debatable problems, Sadler and Zeidler (2004) have posited informal reasoning as the process through which individuals negotiate, arrive at conclusions, and attempt to resolve SSIs. Sadler, Barab, and Scott (2007) proposed a construct, SSR, to capture the practices in which citizens can be expected to engage across multiple SSIs, to understand students' practices relative to invariant features of SSIs. They highlight four practices for decision making in the context of SSIs: "(1) Recognizing the inherent complexity of the SSI, (2) examining issues from multiple perspectives, (3) appreciating that SSIs are subject to ongoing inquiry, and (4) exhibiting skepticism when presented potentially biased information."

Analyzing the contribution of social sciences to education for sustainable development, Audigier (2011) emphasizes consideration of the plurality of spatial, temporal, and social scales. Public attitudes to environmental socially acute questions (ESAQs) are inevitably locally framed in cultural values and expectations, or in local variations in their repercussions. The impact of and responses to changes to rainfall patterns due to climate change, for instance, will be seen differently in arid countries compared to countries with plentiful water resources. In comparing students' SSR on local issues (the reintroduction of bears in the Pyrenees in France, the presence of wolves in the Mercantour) and a global issue (global warming), we found (Simonneaux & Simonneaux, 2009) that the greater the proximity between the question considered and the students—a local issue in which they are implicated because of their sociocultural origins—the lower the level of scientific learning (critical analysis of their ideas, knowledge appropriation, socioepistemological thinking about the knowledge involved). Overt expressions of affect were found to subvert students' reasoning, blind them, and build resistance. However, sometimes mobilizing the affect encouraged critical analysis and scientific counterargument as they defended sociocultural positions (see also Jiménez-Aleixandre, 2006). In these apparently contradictory results, we find the fundamental imprinting of values on learning.

We suggested a need to extend the SSR model of Sadler et al. (2007) to include two further dimensions: consideration of knowledges provided by different producers and exploration of governance modalities involving participation of a concerned public. Indeed, there is not a single, valid, and rational answer to an SAQ (Levinson, 2010; Oulton, Dillon, & Grace, 2004), and decisions are not reserved for experts but concern all citizens (consumers, voters, legislators, etc.). This echoes the "hybrid forums" approach of Callon, Lascoumes, and Barthe (2001): "forums" because they are open spaces where groups can come together to discuss options that engage the collective, "hybrid" because these involved groups are heterogeneous, consisting of scientists, politicians, technicians, and laypersons who are concerned. Callon et al. argue such forums can contribute to the recognition of the complexity identifying the interests involved, the connections between the issues under discussion, and the options. This process of collective expertise enables the rational integration of plural knowledge in decision making.

As the inherent uncertainties of ESAQs are deep, they reach the limits of traditional approaches that look toward universal solutions based on research of regularity in phenomena. Consistent with these perspectives, Funtowicz and Ravetz (1993) have proposed an alternative methodology to tackle these environmental issues. "*Post-normal-science*" (PNS) focuses on aspects of problem solving that tend to be neglected in traditional accounts

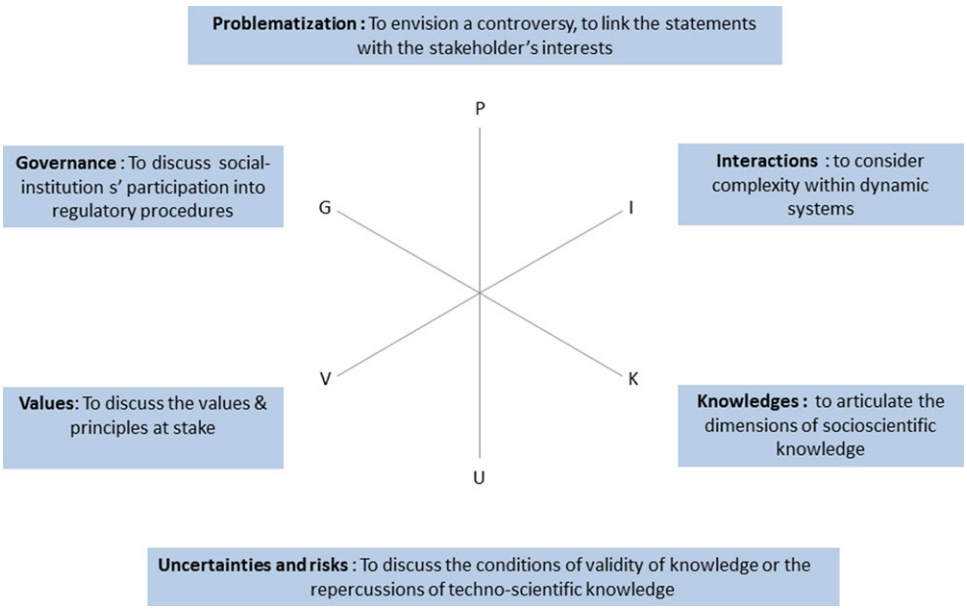

Figure 1. A socioscientific sustainability reasoning (S^3R) analysis model.

of scientific practices: uncertainties and value loading. From an epistemological point of view, PNS articulates the approaches of experimental and social sciences to evaluate both the conditions of production of scientific knowledge and their relevance in the context of their use. PNS highlights the importance of taking account of the plurality of stakes and of legitimate perspectives on environmental policy issues. The need to link inherent uncertainties associated with SSIs with diversity in stakeholders' ways of considering the SSI was also recognized by Sadler, Klosterman, and Topcu (2011) when they reconceptualized the perspective dimension of the SSR model of Sadler et al. (2007). In the latest form of their model, this perspective dimension assesses the extent to which students could discuss the perspectives and interests of multiple stakeholders.

Hence, our research assumes that socioscientific and sustainability reasoning needs to be both grounded in context and collective. In any action being carried out by stakeholders who have their own expectations, perspectives, and interests, collective decision making involves negotiation across the balance of interests and power. A systemic approach involving interactions between elements of the socio-eco-systems must be combined with an analysis of the process of transition from individual to collective actors, such as in Carlot's (2005) emphasis on the importance of awareness of the values of individuals and groups underpinning purposeful actions.

Flowing from these epistemological analyses of how sustainability perspectives can be integrated into SSR, we have previously argued (Morin & Simonneaux, 2011) that recognition of complexity requires integration of diverse cognitive operations across six distinct dimensions. These dimensions are shown in Figure 1. The aim of the current paper is to extend and validate this model, based on empirical data generated during a structured reasoning process.

For each dimension, we are developing indicators of four levels of complexity as follows:

- *Problematization*: Are the disparate aspects (environmental, social, and economic) of the situation tackled from different perspectives? The graduation deals with the awareness of complexity in the construction of the problem.
- *Interactions*: Are the dynamics of socio-eco-systems envisaged over different social, temporal, or spatial scales? The graduation deals with the awareness of complexity of interactions within dynamic systems.
- *Knowledge*: How are different knowledges mobilized? The graduation deals with the articulation of academic and other forms of knowledge.
- *Uncertainties*: Are the conditions of validity of knowledges and the technoscientific risks grasped? The graduation deals with the expression of epistemological doubt and the contextual nature of knowledge claims.
- *Values*: Is there an awareness of the values involved in the issue? The graduation deals with the explication and clarification of value positions.
- *Governance*: Are the relationships between private and collective interests considered across a variety of social institutions (family groups, peer groups, professional groups, associations, public institutions, nations)? The graduation deals with the extent of consideration for regulatory processes that enable citizen participation in balancing interests.

The first grid was elaborated in 2010 during previous research concerning individual discourses of 18 French, preservice students on an ESAQ concerning the use of pesticide in agriculture. We used this previous grid to track evolution of individual discourses before (pretest) and after (posttest) a debate. The confrontation of this theoretical grid with empirical data allowed our team to establish clarity with respect to the distinctive nature of each dimension and to assess its capacity to generate reliable judgments using the four levels in each dimension. The analysis process involved three of us blind coding the discourse, and iterative comparisons of our analysis to clarify each descriptor until the blind test provided similar results. The final grid of this previous research has been published in 2011 (Morin & Simonneaux, 2011). During this study, we observed different levels of reasoning, mainly at Levels 1 and 2 within the pretest and at Levels 2 and 3 in the posttest. Thus, more data were required to establish more precisely the descriptors of difference between Level 3 and 4.

The orientation toward collective action is a key element of S^3R. During subsequent research, we examined collective rather than individual reasoning. Involving participants in collaborative work and negotiations of collective text can provide more sophisticated discourse and enhance the depth of reasoning, enabling us to progressively refine the descriptors for Levels 3 and 4 in our model. At the moment, we have collected and analyzed 24 collective productions of 113 students. In this paper, we focus on the analysis of eight groups involved in cross-national reasoning interactions.

RESEARCH QUESTIONS

In considering SSIs on the ground, the knowledges that need to be brought to bear are inevitably contextual and contingent, being steeped in local understandings and values, and often involving scientific principles either not yet resolved, or difficult to apply to complex systems. In this research, therefore, we worked with groups of French and Australian preservice teachers of science, at the University Claude Bernard of Lyon, France, and at Deakin University in Melbourne, Australia, to explore how their reasoning on socioscientific sustainability issues differed according to local perspectives, and how the diversity of perspectives might be used to generate quality reasoning from which some consensus might

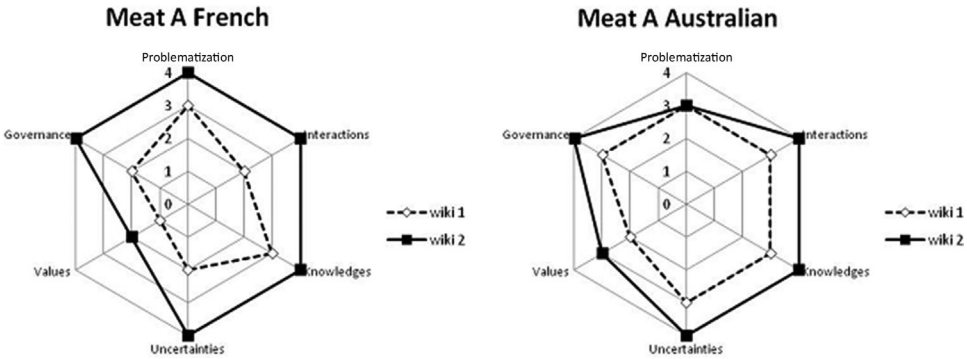

Figure 2. Growth of reasoning from Wikis 1 to 2, Meat A French and Australian groups.

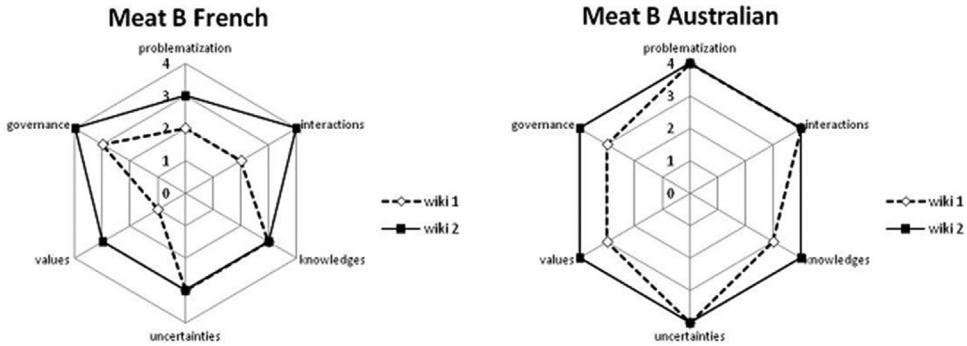

Figure 3. Growth of reasoning from Wikis 1 to 2, Meat B French and Australian groups.

be reached across the groups. Do French citizens view water issues, or meat consumption issues, in similar ways to Australian citizens? French and Australian preservice teachers of science were involved in an online forum and production of a position on two SAQs to explore these issues. Our research questions (RQ) were as follows:

RQ1: How might we characterize the nature and level of reasoning about socioscientific sustainability issues?
RQ2: What are the factors facilitating collaborative construction of perspectives and the development of S^3R on an environmental SAQ?

To respond to RQ1, the generation of socioscientific and sustainability model was a back and forth iterative process between elaboration/extension of the S^3R grid derived from previous work, theoretical discussions within our team coming from analyses of literature on SSIs, and refinement by submission of our model to the proof of empirical data.

We examined collective reasoning of participants working in groups separately during a first phase, and after argumentation exchanges between the cross-national groups, in a second phase to examine how the reasoning of the groups progressed, and tease out the factors affecting this (RQ2). We compared improvements of reasoning of groups working together in the two different countries (Figures 2–5) and in the same university (Figure 6).

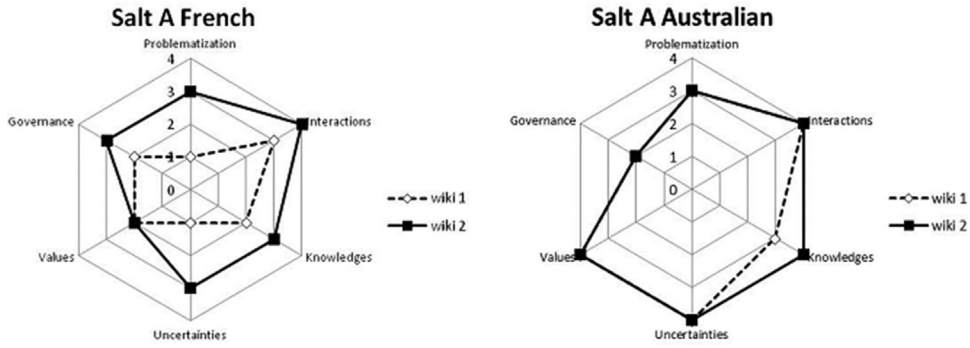

Figure 4. Growth of reasoning from Wikis 1 to 2, Salt A French and Australian groups.

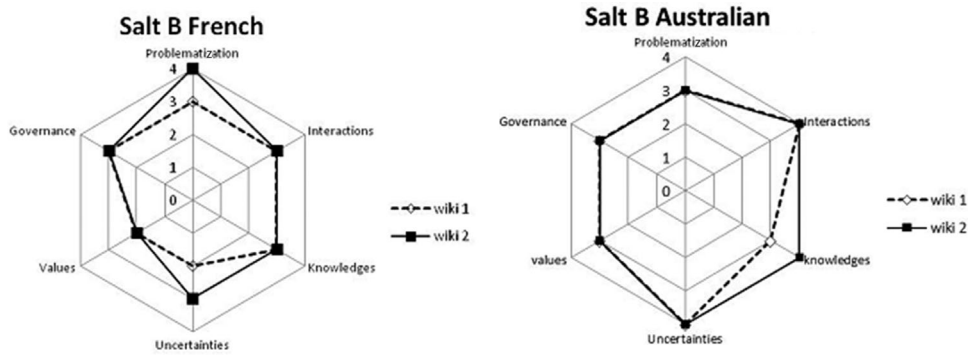

Figure 5. Growth of reasoning from Wikis 1 to 2, Salt B French and Australian groups.

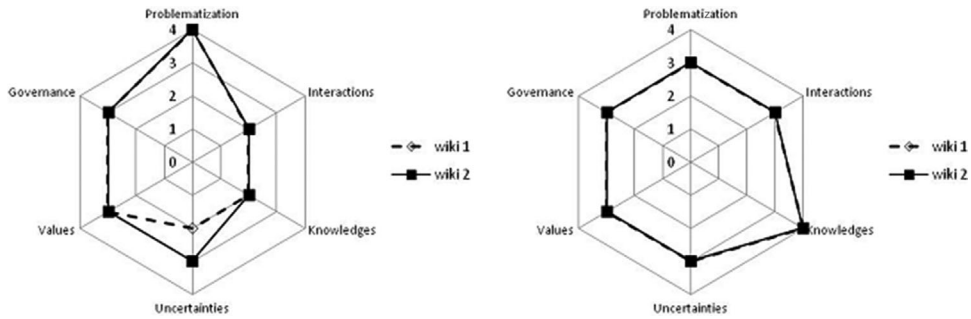

Figure 6. Growth of reasoning from Wikis 1 to 2, Meat, French groups exchanging together.

METHOD

Flowing from our previous results, the basic premise of this study is that consideration of diversity of perspective can enhance the socioscientific sustainability reasoning of each participant. Hence, the research design involved the orchestration of collective activities including confrontation of productions between different groups. The intervention took place during March–June 2012, with French students from the University of Lyon in their fourth year of a teacher education degree in biology and Australian students undertaking their third year of a teacher education degree specializing in science and environmental education. Each cohort was divided into four groups, each looking at one of two

socioscientific sustainability issues. These two issues were designed such that one issue was particularly pertinent to Australia and the second was global in nature. The issues involved are as follows:

- The construction of desalination plants to produce fresh water. This issue was particularly pertinent and "local" for the Australian students since desalination had become a political topic associated with sustained drought.
- The changes in global meat consumption, with regard to population projections in 2050, which we judged to be an issue of global scale, and similar in exposure for the French and Australian students.

We have chosen these two issues because of their potential to offer a diversity of approaches from French and Australian participants. We assumed a diversity of perspectives might be favored with the seawater desalination issue since knowledge of local contexts and community positions, the local media coverage, and the potential life experiences of students are different for the two countries. The consumption of meat was held to be an issue that could affect each student since it deals with conviviality and links to wealth. This issue involves everyone in their behavior as consumers. We assumed that a diversity of perspectives on this issue would relate to individual rather than group contexts.

Design of the Intervention

The sequence of events was as follows:

1. A media file was prepared for each of the two issues and uploaded onto the project Web site. Each media file followed a similar structure:
   Each file, consisting of four pages, was designed to provide stimulus information without closing the controversy or claiming to be exhaustive. The intention is to present a diversity of issues and arguments to stimulate additional literature searches. The first page presents the SAQ in a few sentences accompanied by a picture illustrating the questions. This is summarized in a one sentence-oriented choice of individual or collective actions: Meat, Should you eat it or not? Is desalination the solution? This is supplemented by four boxes giving values concerning consumption, production, and population growth. The second page sets out opposing positions and demonstrates the vitality of social controversy with images of events or parts of slogans. The third and fourth pages are organized on a model of frequently asked questions. They open lines of scientific and sociological thought by providing testimony, results of controversial surveys and research (e.g., about Melbourne's water supply and drought risk, the financial cost of desalination, potential for technological advances, the dangers of overconsumption of meat, and the effects of different types of farms on local agricultural systems and on a global scale) and highlight ethical values involved such as respect for animal welfare.
2. Each issue was explored by two Australian and two French groups working separately in a first phase, and discussing together and then redrafting their production in a second phase. Groups dealing with the meat consumption issue are called "Meat" and those dealing with seawater desalination are called "Salt" (see Table 1). The Meat A French group confronted productions and exchanged argument with the Meat A Australian group, the Meat B French group was the partner of the Meat B Australian group, and so on with Salt groups.

TABLE 1
Constitution of Groups

Meat Groups Dealing With Meat Consumption Issue				Salt Groups Dealing With Seawater Desalination Issue			
French–Australian Partners A		French–Australian Partners B		French–Australian Partners A		French–Australian Partners B	
Meat A French Group	Meat A Australian Group	Meat B French Group	Meat B Australian Group	Salt A French Group	Salt A Australian Group	Salt B French Group	Salt B Australian Group
Five students	Seven students	Five students	Five students	Five students	Six students	Five students	Six students

The groups formed and discussed the issue, and how they would organize themselves to construct the wiki in response to the questions: "Which action do you advocate as a group? Why and under which conditions?" In the Australian case, this was face to face. In the French case, for local timetable reasons, it was through an online forum.

3. For each group, an online forum involved discussion separately for the French and Australians, in the groups' first language, leading to the construction of a first wiki by each group, again in their first language. This collective production is called "wiki 1." According to the estimation of students, the duration of online activities was equivalent to 3 hours time. On average, the wiki contained 2435 words.
4. The French wikis were translated into "rough English," and the wikis of the French and Australian groups were opened to each other to consider. Both groups were recommended to use "Google Translate" and "Wordreference" to help with understanding the arguments in the wikis. The substantive student reasoning in the wikis was in their own language. In the exchanges, we did help at times with translation but the quality of translation in the wikis was high, checked by the team that is effectively bilingual, so that judgments about reasoning are made drawing on first language text.
5. A second forum was opened for international exchanges in which each partner group questioned the other and attempted to come to a common understanding. This took place in mixed English and French as the French students practiced their English and presented comments both in English and French. Again Google Translate was used as a backup.
6. Reconstruction of the wikis following this international exchange. Each group modified the first wiki and elaborated a second one that is called "wiki 2." According to the estimation of students, the duration of this second phase of activities was equivalent to 3 hours time.
7. Individual reflections were generated by the students concerning the process and their personal positions compared to the group.

Our aim in the analyses presented in this article is to trace the quality of reasoning around the issues expressed in the wikis and to examine the role of the cross-national exchange in development in reasoning in the wikis.

Data Collection and Analysis

The data generated in the study included the following:

- a record of the online forum discussions,

- recording of the initial face-to-face discussions of the Australian groups,
- a time-sequenced record of the building of both the first and second wikis,
- a record of the international forums in which French and Australian students discussed their respective wikis,
- reflective commentaries by students on their experience of the process including what they felt they got out of the experience, and
- informal fieldnotes of the Australian classes.

In this paper, we are using only the data generated in the wiki developments, supplemented by some aspects of students' individual reflections.

Analysis to Identify Quality of Reasoning. The analysis of the quality of reasoning and its growth between the two wikis for each group was carried out in an iterative process of refining and applying the S^3R reasoning model. The analysis of the wikis involved the extension and refinement of the S^3R model shown in Figure 1 to generate four positions for each dimension, representing increasing sophistication on that dimension. This involved an iterative analysis process with multiple discussions and comparisons within the research team, checking until a degree of agreed coherence was reached. The refinements involved both modifying the key features describing each dimension and progressively improving the clarity of the level descriptors, ensuring (a) they represented a coherent progression, (b) they could be used to identify distinctive, nonoverlapping features of the reasoning, and (c) that each level across the six dimensions represented a relatively coherent position on knowledge production and application. The full model, with these levels, is shown in the Results section (Table 2).

The level descriptors form relative coherent epistemological positions, which act as indicators of growth in epistemological sophistication needed to reason about SAQs at a deep level. The dimensions of these epistemological positions can be seen, then, as the components of an education aimed at a scientific literacy capable of serving individuals in their interactions with science and personal and public policy. The highest level of reasoning connects and integrates different knowledges including technoscientific, personal, and political, which has implication for how we think about scientific literacy. We will discuss this issue further in the final sections of the paper.

The model is applied to each wiki as a whole and not to individual elements. The development of the model involved discussion and testing between members of the team at different stages in the process. The translation of the model from French to English, for instance, provided the opportunity to clarify meanings across both languages, and this led to further insight into the key features of each dimension. The final coding was accomplished mainly by one of the research team, but samples went through a process of dual coding, and the descriptors and their application were further discussed until reliable agreement was reached. Thus, each wiki was able to be scored on each dimension, with a Level between 1 and 4. In any wiki, various levels of depth for a same dimension of reasoning were observed depending on the different themes students collectively tackled. To encode the entire wiki, we assigned the maximum level observed in each dimension.

Analysis to Identify Factors Affecting the Quality of Reasoning in the Wikis. Following the development of the model with levels, represented in Table 2, and the coding of each of the wikis, a process of analysis occurred whereby aspects of the reasoning were linked with aspects of the cross-national interactions. These analyses involved (a) comparisons of the patterns of reasoning in the Salt and Meat wikis for the French and Australian groups,

TABLE 2
Levels of the Dimensions of the S^{3}R Analysis Model

		Level 1: There is one right answer. The task is to identify the right form of knowledge.	Level 2: Recognition of multiple positions, values, knowledges without seeing need for integration. Juxtaposes, lists, describes.	Level 3: Identification of many elements and recognition of a need for integration of knowledges, aspects, values, and participation of different stakeholders. Coherence, however, is built around one aspect only.	Level 4: Knowledge is complex, plural, contingent, uncertain, and conditional on context. Multiple positions can be justified depending on values. Interests need to be managed in a democratic negotiate process. Socio-eco-systems are dynamic and interactive.
The graduation deals with the awareness of complexity in the construction of the problem	**P: Problematization:** Are the disparate aspects (environmental, social, economical) of the situation tackled from different perspectives?	Tackles the issue and its context from only one aspect and one perspective.	Considers the issue from different perspectives about one aspect, or from only one perspective on different aspects.	Considers different aspects of the issue from different perspectives.	Identifies the nature of controversy around the variety of perspectives, and link this to competing stakeholder interests.
The graduation deals with the awareness of complexity within dynamic systems	**I: Interactions:** Are the dynamics of eco-socio-systems envisaged over different social, temporal, or spatial scales?	Does not consider any distinct scale (social, temporal, spatial) in relation to the issue, which is seen as either very general or limited to familiar, everyday life.	Examines aspects (economic, social, environmental) at different scales, beyond generalities or beyond familiar everyday life contexts.	Describes interactions over space and time in the ecosystem, or between different social groups, without considering the interactions between the socio- and eco-systems.	Describes interactions across different social, temporal, and spatial levels, integrating the eco-socio-systems, relevant to sustainability.
The graduation deals with the articulation of academic and other forms of knowledge	**K: Knowledges:** How are different knowledges mobilized?	Considers only academic or non academic knowledge (vernacular, vocational, from media . . .).	Juxtaposes several different knowledge elements (either academic or nonacademic).	Links socioscientific knowledges but with coherence limited to one perspective on the problem.	Links socioscientific knowledges, acknowledging the possibility of coherence of divergent perspectives.

(*Continued*)

TABLE 2
Continued

		Level 1: There is one right answer. The task is to identify the right form of knowledge.	Level 2: Recognition of multiple positions, values, knowledges without seeing need for integration. Juxtaposes, lists, describes.	Level 3: Identification of many elements and recognition of a need for integration of knowledges, aspects, values, and participation of different stakeholders. Coherence, however, is built around one aspect only.	Level 4: Knowledge is complex, plural, contingent, uncertain, and conditional on context. Multiple positions can be justified depending on values. Interests need to be managed in a democratic negotiate process. Socio-eco-systems are dynamic and interactive.
The graduation deals with the expression of epistemological doubt and the contextual nature of knowledge claims	**U: Uncertainties and risks:** Are the conditions of validity of knowledge and the technoscientific risks grasped?	Does not perceive any lack of information. The assertions are presented as truths.	Recognizes that competing claims about the issue draw upon multiple sources of information.	Envisages the need to coordinate multiple sources of information to evaluate competing claims about risk or competing solutions.	Explicates the need for knowledge claims to be interpreted in a particular context to reduce the uncertainties or to estimate the risks.
The graduation deals with the explication and clarification of value positions	**V: Values:** Is there an awareness of the values involved in the issue?	Shows no awareness of the value or the beliefs underlying the selected arguments.	Identifies the values underlying the selected arguments.	Explicates the values central to the conflict.	Articulates a personal value position that acknowledges the range of values or principles at issue.
The graduation deals with the potential for regulatory processes that enable citizen participation in balancing interest	**G: Governance:** Are the relationships between private and collective interest considered for a variety of social institution (family groups, peer groups, professional groups, associations, public institutions, nations)?	Does not consider the need to take account of different stakeholder concerns.	Envisages solutions imposed on stakeholders.	Envisages active participation of different stakeholders in an open regulatory process.	Critically analyses possible regulatory procedures between social institutions.

(b) interrogation of details of the first wikis in the Salt groups, for which the SAQ had strong contextual aspects, to ascertain the features of the issue that impacted on student reasoning, and (c) interrogation of the changes in wikis following the cross-national exchange, and linking these changes to arguments made in the companion wiki and to the nature of the exchanges in the international forum.

Students' reflective comments were also analyzed for evidence of perceptions of the value of the exchanges, and for commentaries on practical aspects of the process that were held to affect the quality of the reasoning.

RESULTS CONCERNING THE DEVELOPMENT OF THE REASONING MODEL S^3R

One of the key outcomes of this research is the generation of the S^3R model represented by Figure 1 and Table 2. The examination of collective productions and the improvement of groups' reasoning between wikis 1 and 2 provided empirical data that enabled us to refine and test the model. This model is a response to RQ1, concerning how we might validly characterize reasoning about ESAQs. In the preceding section, we have presented its genesis, drawing on internal aspects and links to previous literature. We further examine its generativity as an analytic tool—can it be used to identify valid distinctions in reasoning that contribute to comparative analyses of the reasoning across groups, across time, and across topics?

The columns in the grid represent an increasing sophistication in how knowledge and values are conceived of. The four positions at the top of the grid claim a coherence to the sequencing of reasoning. Level 1 represents a naïve position in which knowledge and values are thought certain and unproblematic. Level 4 recognizes the complex, plural, and contextual nature of knowledges, and the need to manage interests in a democratic negotiating process.

The following quotes will illustrate the application of the framework to judgments about the quality of reasoning represented by the wikis. We selected extracts corresponding to the most representative examples illustrating transitions between levels.

Problematization Dimension. P2 (Problematization Level 2: Salt A Australian group, first wiki) considers the issue from different points of view, but about the environmental aspect only.

> *Quote 1*: One of the main controversies surrounding desalination plants is the potential damage to the surrounding environment. In the case of the Wonthaggi plant, there have been numerous protests and negative opinions about the environmental impacts the building, and running of the plant will result in.

Later in the wiki, however, further aspects of the desalination issue, relating to economics and public costs, were raised. The level of reasoning in the wiki on this dimension was thus judged to be P3.

P3 (Problematization Level 3: Salt A Australian group, first wiki):

> *Quote 2*: The construction of the Wonthaggi desalination plant will provide the community with both positive and negative long-term economic implications. The total costs of creating the desalination plant ... have blown out to 4.8 billion in taxpayers' money. Additionally, Drill suggests that Victorian taxpayers can expect to pay around 24 billion dollars over a period of 28 years in water bills to cover the cost of running the plant.

Interactions Dimension. At I2 (Interaction Level 2: Meat B French group, first wiki), social, economic, and environmental aspects of ESAQs are addressed at different scales, but the interactions between the elements of the socioecosystems are not teased out:

> *Quote 3*: In the developing world, consumption of proteins from plant and animal is better balanced; in developed countries, meat consumption is excessive. On average, a French person eats 92.5 kg of meat per year, or more than 250 g per day.

These interactions are described in an integrative approach in I4.
I4 (Interaction Level 4: Meat B French group, second wiki):

> *Quote 4*: What would be the impact of a total shutdown of production of meat? . . . Environmental problems: certainly there would be a decrease in the amount of greenhouse gas emissions, but intensive cultivation of vegetables and cereals (to compensate for the meat) would be dramatically detrimental to the environment with heavy use of water, soil and groundwater pollution, etc. . . . . . Sociocultural problems: the amount of meat consumption depends on the cultures, religions, habits . . . Some people would be then more disadvantaged by the removal of meat that others have already the habit to eat other products (insects, seeds, vegetables . . .).

Knowledges Dimension. K2 (Knowledges Level 2: Salt A French group, first wiki) is characterized by an accumulation of information.

> *Quote 5*: Disrupting abiotic factors of the different ecosystems where it is rejected, the brine can cause serious consequences on biodiversity. In addition, the construction of a desalination plant and its operation thereafter require a lot of energy . . . .

At K3 (Knowledges Level 3: Salt A Australian group, first wiki), mobilized knowledges are articulated achieving a level of consistency within the group:

> *Quote 6*: While there are a large number of advantages in having a desalination plant, one of biggest advantage of desalination is that it provides a guaranteed source of water without the reliance on the amount of rainfall. The quality of the drinking water is safe for human consumption, with boron levels lower than 0.5 mg/l, this is below the recommended level of 4 mg/l by the Australian drinking water guidelines. The plant will be able to provide 150 billion liters of water per year for Victorians, with a possibility to supply up to 200 billion liters. . . . It also will create more than a thousand jobs both in its construction phase and after its construction is completed. This will also help businesses around the area of Wonthaggi as there would be increase in spending at local shops due to the construction workers using nearby services. . . .

When different perspectives are considered, various coherences are taken into account and we coded the wiki at level K4.
K4 (Knowledges Level 4: Meat A Australian group, second wiki):

> *Quote 7*: Some farmers are beginning to integrate new technologies and computer based management into their farms. However, these new developments are often costly and many farmers are reluctant to change, especially if they have been farming the same way for several generations. Governments and local communities need to unite to support farmers that are choosing to shift to sustainable methods of farming. This shift could be encouraged through offering subsidies or free training programs and products to farmers that are prepared to opt for the more environmentally friendly pasture based approach to farming.

Uncertainties Dimension. At U3 (Uncertainties Level 3: Salt A French group, second wiki), a plurality of speech is considered to reduce uncertainty about the risks and implications of choice.

> *Quote 8* (about the solution of rainwater tanks): Note that this kind of technology is possible only on a small scale (for example to water gardens, or for toilet drain . . .). It is more a backup system and a daily behavior than a real solution to the problem of water.

At U4 (Uncertainties Level 4: Salt A Australian group, first wiki), estimation of risks is done through the weighting of speech and consideration of contextual elements of the situation.

> *Quote 9*: The plant at Wonthaggi has been of great contention with the Government supporting and funding the entire venture to save water for our future, where as in contrast locals are unsure of the long lasting implications it may leave. Kleinman (2007) reported that the Wonthaggi town hall was standing room only when 500 locals rallied against the plant. Amongst the concerns was the effect the plant would have on land and house value in the area, the impact on the burgeoning Bass Coast tourism industry and the lack of guaranteed employment for locals at the plant. However, on the top of the list was the impact on marine environmental and concerns about the financial burden that would be placed upon the Australian taxpayer.

Values Dimension. At V2 (Values Dimensions Level 2: Salt A French group, first wiki), the values underlying the selected arguments are identified. In the following, excerpt students opt for an anthropocentric approach giving not only to environment the value of a legitimately exploitable resource but also exhaustible and that therefore it should be preserved in the long term:

> *Quote 10*: We must above all preserve resources . . . On the other hand, can we really live as a human being without impacting our environment? The issue is to reduce the impact, in this context, the recovery of rainwater seems a good start.

In the following excerpt, the value underlying the students' argument is safety, in this case by maintaining the water supply. But students go beyond the exposure of this value, and we coded this extract at Level V3 because it also develops the value of confidence in technological progress as central to their view of the controversy.

V3 (Values Dimensions 3: Salt B Australian group, first wiki):

> *Quote 11*: Throughout the ages, civilization has learnt from their mistakes growing from them, formulating new ideas and adapting them to make it better. . . . Humans are great in that they are constantly learning, constantly growing and improving. Taking into consideration the last 30 years in respect to desalination, the amount of energy being expensed has fallen precipitously. . . . Australia's plant will be one the greenest in the world by using renewable energy to offset 100 per cent of its operational power and its world leading energy recovery device to reduce power consumption. As a result, it is designed to reflect the community's needs environmental requirements and global technology.

Governance Dimension. When taking into account the different scales of the social groups taking part in the regulation procedures, the Level R3 corresponds to the need for an active participation of different stakeholders in an open regulatory process.

G3 (Governance Dimension Level 3: Meat B French group, first wiki):

> *Quote 12*: If the livestock industry must find ways to curb its contribution to global warming and to various pollutions, we, as individuals, can participate in this process by regulating our own consumption of animal proteins.

At G4 (Governance Dimension Level 4: Meat B French group, second wiki, and Meat B Australian group, second wiki), the regulatory procedures are discussed as shown in the two following excerpts:

> *Quote 13*: In order to overcome the increased meat consumption, financial measures can be implemented. The first solution is an increase in the price of meat. . . . The second one advocates the contrary, a change in the cost of other products that provide protein. In this case, if the State provides financial assistance in the form of subsidies to farms insects or to soybeans production. This solution implies political work of great magnitude.

> *Quote 14*: The meat industry provides so many economical benefits to different parts of the world and to completely wipe it out would send areas into an increasing economic downfall. It is for that reason that other ways to lessen the impact in which the meat industry has on the environment need to be developed and educated among global communities.

RESULTS CONCERNING IMPROVEMENTS OF REASONING IN THE WIKIS

Through the process described above, of analysis of reasoning in each wiki, and refinement of the framework, each of the 16 wikis (wikis 1 and 2 of each of the four French and four Australian groups) was given a quality of reasoning score on each of the six dimensions. The key questions related to whether there were differences in reasoning on the two issues related to cultural factors, and whether there was an improvement in reasoning following the cross-national exchanges. Were the students challenged to improve their reasoning, being exposed to different perspectives on these issues? The results are shown in Figures 2–5. Each hexagonal diagram represents, for the French and Australian groups, the levels of reasoning for each of the six dimensions, in the first wiki (dotted line) and second wiki (full line). To help understand the nature of improvement reasoning of the students, we summarize the main features of the wikis for each matched pair of groups.

The first wiki of the French team about meat consumption is mainly a list of foods that can provide alternative protein intake necessary for good health. Students gave priority to the scientific approach by focusing on dietary aspects. This wiki evolved with the Franco-Australian exchanges in the direction of greater consideration of human aspects: The arguments are still based on scientific and universal value knowledges but also incorporate features of the local situation (e.g., the socioeconomic implications of the transition to organic farming and the cultural dimension of the act of eating).

In the first Australian wiki, several aspects of the SAQ are considered. It presents an alternative search of food but this list does not constitute the bulk of the wiki. This first draft is primarily oriented toward possible changes in agricultural practices and the economic system of meat distribution. The second Australian wiki shows a deepening of the reflections following discussions with the French: Thus, the health risks of overconsumption of meat are cited, the list of alternative foods is no longer limited to other meats, but is extended to foods of plant origin, the environmental impact is not limited to pollution but also considers the depletion of resources (e.g., water consumption related to meat production is taken into account), and a discussion of biotechnology (breeding, production of muscle cells in vitro) is developed.

Two interesting trends appear in the collective construction of reasoning—(i) The contribution of shared experience: In the first wiki, each team tended to consider the SAQ in their particular context, but extended their understandings to other contexts after the international forum, thus enriching their reasoning. (ii) The interest in developing arguments was driven by the different positions, leading to a common position in both groups: The quality of the conclusions in the second wiki tends to highlight the importance of consciousness raising, information, and consumer empowerment. Such awareness from future teachers of their educational role beyond the transmission of academic knowledge is in our view a significant element of professional growth.

In the Meat B groups, the first collective text of French students describes environmental and physiological concerns of meat consumption alternatives. It starts with a presentation of average meat consumption data (in France), of dietary recommendations of daily protein intake, and of detrimental effects of meat production on the environment. After comparing disparate processes of meat production in terms of water consumption and energy transfer, the students develop an argument considering insect consumption, linked to a reflection about cultural acceptance. In the second version of the wiki, after the international exchanges, the social aspect and the interactions between the stakeholders become important. The reflections were also directed toward financial aspects associated with the viability of local agriculture such as prices and subsidies.

The Australian Meat B group tackles the situation as a social controversy and considers a diversity of viewpoints of stakeholders. They discuss health issues in some detail, with evidence, as well as local and global economic aspects. They integrate environmental, social, and ecological aspects of the issue. Their answer to their question: "How can we get the global voice to help put a stop to unsustainable high production farms and move toward smaller scale farms where the production of meat is part of a sustainable cycle?" is the basis for an argument for citizen education to foster a "slow food movement." The modifications in their second wiki are a widening of the reflection beyond the Australian scale, a consideration of the alternative of insect consumption and the way to overcome cultural reluctance, and a deepening of the reflections on the ecological consequences of excessive red meat consumption. They also take animal welfare and social consequences of the raising of meat prices into account. They ended their text with the issue of public education.

The first wiki of the Salt A French group presents technological alternatives to seawater desalination. Students consider above all the detrimental environmental effects of this process. Even though they start by speaking about the drought in Australia, their inquiry remains a general investigation, independent of the geographical context. They seek ways to reduce environmental effects, through alternative water supplies (the use of rainwater and the recovering of water from spray or mist), by making people aware of their consumption of fresh water and by providing the desalination plant with brackish water and renewable energy. The second wiki's organization demonstrates a clarification of the reasoning. It shows the consideration of the local situation, by presenting the benefits of seawater desalination both on water supply and economic development of the area, and by considering other aspects like the impact of the plant on tourism activity.

The first wiki of Salt A Australian group is organized around eight paragraphs (in the following order: background, the ecology and the environment, advantages of desalination, conclusion, economy, effect on the community, Australia vs. global perspective, and counterargument) written by different subgroups. This distribution of tasks leads to some repetitions particularly about the formulation of the issue. The wiki is well documented, with many sources being referenced. Some controversial aspects are clearly identified, with

students establishing matters of contention, for instance, the bill Victorian taxpayers would have to pay to finance the running of the plant, the impact of the destruction of the coastline on the thriving tourism industry. The main point highlighted was the ecological impact of dumping salt concentrate back into the sea.

The second wiki of this group is reorganized with a clearer structure and more aspects covered. They deal in detail with technological concerns, carried out a deeper exploration of an environmental issue (effect on the marine habitat), and dealt in some precision with the validity of using different types of watertanks. Nevertheless, a great part of the modification deals with the use of nuclear energy for powering the plants.

In its first production, the Salt B French group considered the seawater desalination process as a response to water vulnerability on a global scale. Like the other French group they do not focus on the Victorian situation and this wiki would have been the same whatever the geographical context. In the second wiki, students completed their text with information about the Australian situation, including water restrictions and awareness campaigns. Focusing on Victoria's controversy, they describe in a new paragraph the dramatic situation of drought and the electoral context that affected this political choice, and then oppose data provided by the promotion campaign of the Victoria government with counterarguments from the Greens party. Nevertheless, their conclusion still remains a compilation of the individual viewpoints with no change.

The first text of the Australian Salt B group is structured around the local concerns, the sequence of events, and the context of the policy decision-making process. It is already at a high reasoning level. After the exchanges with the French team, this Australian group added a complementary paragraph counterarguing the use of icebergs as a water supply, with many references about the practicality and the cost of such an option, but without any more modifications to the former text.

A cursory examination of the graphical displays in Figures 2–5 establishes the general improvement in reasoning for each group, from wiki 1 to wiki 2. There are a number of interesting features to these diagrams that point to contextual features of reasoning and also growth in reasoning related to the exchanges. The growth in reasoning from wiki 1 to wiki 2 was substantial in the case of meat, more so for the French team, and least substantial for the Australian salt group who were already reasoning at a high level in the first wiki. Thus, we can conclude at a general level that the international exchanges were productive in leading to improved reasoning and an increase in epistemological sophistication. There are a number of details in patterns, however, that vary. The variations include the following:

- the reasoning level in wiki 1 varies both within topics (Australian vs. French students) and across topics (Meat vs. Salt),
- the degree of growth varies and the dimensions along which this growth occurs. The final reasoning level for groups involved in discussion is not the same.
- improvement occurs even for the groups with initially higher reasoning levels. The fact of discussion seems to make a difference, beyond the level of argument being responded to. and
- opinions do not converge.

These variations will be examined in detail to tease out the factors that are operating to determine how the reasoning of the groups progresses (RQ2).

Results Concerning the Effect of Cross-National Exchange in the Forums

At a general level, the growth in reasoning between wikis 1 and 2 can be seen as evidence of the value of cross-national exchanges for reasoning about SAQs. In a previous iteration of this project, analysis of the international forums had shown the input of perspectives from the different countries had widened and deepened consideration of the issues by bringing to the table the perspectives of a wider range of stakeholders, knowledge of practicalities and political concerns, and different social ramifications (Morin et al., 2012). In the current analysis, we will draw on details of changes to the wikis linked to aspects of the companion wikis to explore the way the exchange served to enhance the reasoning. We identified in the second wiki themes corresponding to the changes that have been encoded at a higher level than in the first wiki, and we observe that these themes are those that have been discussed during the discussions in international forums. Here are some examples.

Values Are Discussed in the Meat A Groups. Australians, who did not consider resource depletion in their first wiki, take it into account in their second version in terms of responsibility: "It is the responsibility of the global community to protect and conserve our resources for future generations": whereas the French, very neutral in their first wiki, express their commitment to values (fairness, responsibility) in their second wiki: "Rationing of meat consumption or a tax are solutions that don't seem possible. Part of the solution therefore lies in the following points: – Better allocation of resources. – A policy of effective education to develop the awareness of food waste from an early age." We can link these changes to the following excerpts from the international forum:

> M (French, contribution no. 10): "One can talk about 'overpopulation' as long as there is a lack of something (a lack of food in this case). However, according to a FAO (Food and Agriculture Organization) study, currently there is enough food to feed the whole planet. That's why the issue may be rather political than demographic."

A discussion is then engaged and after a few exchanges, S (Australian, contribution no.. 17) raises the question of education:

> Population growth always seems to be raised as a problem, that if reduced will solve many issues. If there is enough food then the problem is in the distribution not the number of people. . . . I agree with K. that reducing the population is not an answer to reducing meat consumption. The answer involves educating people on the issues caused by excessive meat consumption, assisting farmers in improving husbandry, developing more sustainable farming techniques and finding alternatives rather than finding an 'answer' to the population growth.

The Exploration of Possible Regulations and Interactions Takes Place in the Meat B Groups. In the Quotes 12–14, we observe the introduction in the discussion of possible regulations in the wiki 2. The Quote 4 also shows that interactions are further explored by the French who consider social impacts (employment, consumer price) incentives to reduce meat consumption. The following excerpt from the international forums show that this deeper reasoning is linked to comparisons of related cultures:

> E. (French, contribution no. 14): "... Our subject talking about food, and when I heard that I immediately spit. Indeed, I'm really proud about my history, my culture, and our

> COOKING. Above all since UNESCO had raised the 'French gourmet meal' as intangible cultural heritage of mankind. . . . As you could imagine, meat particularly beef, take a big place in European culture. And the 'meat culture' is deeply established in our mind. . . . However I became conscious about the environmental impact of industrial process of meat production and when I want to eat meat, I preferred buy something which is locally produced (and preferentially organic) or with a quality label. But these methods give products more expensive, unless if it reduces its consumption . . . Do you think it could be a solution? Or priority should be given low price that everyone have access to this great source of protein?"

Similar analyses were conducted concerning the articulation of knowledge and uncertainties and the problematization of the controversy. These again illustrate the general principle of the forum impacting significantly on the wiki.

Through the analysis of the forum discussions and wikis, we observe that the dual process, involving groups representing to some extent different cultural and contextual stances, is powerful in eliciting reasoned argument of enhanced quality. In a previous, similar study involving groups of French students within only one university (Lyon), the forum exchange failed to result in improved quality of reasoning in the second wikis (Fig. 6), because there were not substantial differences between the points of view of the two French groups.

In contrast, during the French/Australian session, the teacher of the Australian students observed:

> The Australian students learnt to be appreciative about different perspectives as they became: open to new ideas; tolerant towards each other; engaged in their level of discussion; interested and curious about French Culture; critical about their local problems, and; aware of their own values.

It is difference that drives the quality of reasoning—the need to more sharply explicate and support a position or to accommodate a range of viewpoints in a more nuanced position following discussion. It has been argued that the fundamental purpose of reasoning is argumentative (Mercier & Sperber, 2011), in which case it makes sense that having positions to argue against or accommodate is an important indicator of reasoning. We contend that an important factor in raising the level of reasoning in this activity was the staged process of coming to a group position on the SAQ and then needing to reconcile this with a different position.

The reasoning in the forums and in the face-to-face Australian group discussions is currently being more thoroughly analyzed using an "interactive framework" developed in a previous iteration of the current project (Morin et al., 2012). This framework is based on a combination of the work of Habermas (1987) concerning the validity claims in argument, and that of Mercer (1995, 2000) concerning the orientation of talk, which can be disputational, cumulative, or exploratory. We identified the highest level of talk as *integrative exploration* where everyone participates in the exploration and negotiation of all the strands representing the options in the group. This analysis will be reported in a separate paper, which will also more rigorously examine links between the growth in quality of reasoning in the wikis to reasoning in the forum discussions.

The focus of the current paper is largely restricted to analysis of the wikis. Further evidence is found in student reflections on the value of the cross-national exchange: In their reflection, they commented on many aspects of the process of wiki development and the forum exchanges. Their views were often critically informed and thoughtful, and they shared an appreciation of the experience and what it had yielded in quality of thinking and as a powerfully educative strategy:

> Throughout this entire task it was extremely evident that our opposite locations in the world completely affect our views on the topic ... [it] shows us the value of education from multiple sources and this has enriched my understanding & the way in which I will teach my own classroom one day. (Australian student)

> The fact that we secondly took part in an international forum pointed out that our viewpoint is mainly built on what we know: our culture, country, climate, environment, habits. Exchanging with people from another area in the world is quite interesting to realize that solutions we wouldn't have thought about could be imagined. (French Student)

Results Concerning the Effect of Diversity Within Groups

Members of the Australian Meat A group made the point that there was already cultural and experiential diversity that led to diversity of opinion within the group.

> ... we are a group with diverse backgrounds. I am a qualified nutritionist with an environmental conscience. One girl in the group works at McDonalds ... Other people in our group have been vegetarians ... Two women are mothers of children who enjoy meat eating. They were concerned that their children obtain enough nutrients in their diets but also have to shop to a budget.

For this particular group, the cultural component was an important factor in their discussion. They commented, for example, that in developing countries, meat consumption relies pretty much on how wealthy you are to have access to eat meat. They argued that for these countries the dilemma of meat consumption turned more on an economical variable than on an ethical or moral one. They also commented that cultural beliefs and traditions affect their views on this topic. The cultural diversity embedded in each of the Australian groups was possibly an element that helped students to show a higher level of reasoning than the French groups. This aligns with previous data from the French research regarding groups that had people from different disciplines compared to monodiscipline groups. The values of cross-cultural approaches—which are in our studies cross-national and/or cross-disciplinary—consist of broadening and sharpening students' perspectives on the uncertainties and the complexity of ESAQs.

DISCUSSION AND IMPLICATIONS

In this study, we built on a process developed through previous research whereby tertiary-level students from Australia and France engaged with online cross-national exchanges to reason about socioscientific sustainability issues. The intervention and analysis proved productive in a number of respects.

First, we developed an S^3R framework that successfully captures the nature of reasoning about socioscientific sustainability issues in producing a wiki. Given the interest in reasoning about SAQs and about sustainability, in particular, this framework is significant in drawing together a range of research analyses of dimensions of reasoning and establishing a defensible scale on each of these. The framework underlines the key characteristics of high-level reasoning on SAQs as involving the interaction of a plurality of knowledges and interests, as being open and provisional rather than closed and convergent, and as being deeply contextual. The progression in levels of reasoning across the framework columns is inherently epistemological in nature and has much in common with the work of Perry (1999) who constructed an epistemological progression for undergraduate students, which

broadly followed a path from absolutist, through relativist to more considered positions recognizing the choices that need to be made in establishing reliable knowledge.

The collective negotiation of multiple forms of knowledge as central to S^3R is a key characteristic of the framework. Beyond science learning, the challenge may be to develop not only scientific but also political literacy as preparation for informed citizenship through teaching about ESAQs. Levinson (2010) has identified a number of democratic participation frameworks that can be used in the teaching of SAQs. Of these, we consider that we are in the "science education as praxis" framework, in which

- knowledge is distributed and emerges through praxis. It is both situated and emergent and through legitimate participation, individuals become inducted into more sophisticated and shared techniques of problem solving;
- scientific knowledge is contestable and open to participant reflexivity, and
- all participants subject their views to communal questioning and reflection.

Research within the sociocultural perspective has contributed important knowledge about how individuals develop their moral ability by participating in sociocultural activities. Öhman and Östman (2007) have suggested "an approach that allows for an in situ analysis of how individuals' prior experiences take part in the processes of moral meaning-making, which also takes sociocultural activity into consideration" (p. 151). Moral judgements are different according to the issues under discussion, reflecting sociocultural and professional factors. Öhman and Östman recall that

> research on moral development and education has been dominated by approaches that tend to view the individual as an isolated moral agent making decisive moral decisions through conscious cognitive processes. The moral development of the individual is assumed to follow a universal trajectory towards a specific moral ideal. Especially influential is Kohlberg's stage model on moral development (see, for instance, Kohlberg, 1981), which in turn is based on the classical theories of cognitive development by Piaget (1929/1989). (pp. 151–152)

However, we follow these authors in their argument for the importance for moral development of the interaction between the individual and the social and cultural environment. This alternative position, or complementary one, belongs to the sociocultural field, which views moral positions and actions as constructed in relation to individuals' experiences and interactions, and according to the context.

Second, we observed in all groups an improvement in S^3R reasoning between wikis 1 and 2, whatever the starting level of reasoning. This is an encouraging finding. It would have been possible for the international exchange to have resulted in a solidifying of opinion behind entrenched positions, but this did not happen. The expansion of the scores represents a broadening of view to acknowledge multiple positions and a more complex accounting of the problem. Thus, we have cause to be optimistic that this improved reasoning is aligned with movement toward expanded global understandings.

Third, through tracking reasoning during the cross-national exchanges, we were able to show the relationship between these online exchanges and improvements in reasoning in the wikis. High-level discussion in which new perspectives were canvassed and different cultural positions clarified led to increased reasoning on the associated dimension.

Fourth and finally, we were able to identify diversity of perspectives as a key factor driving the quality of reasoning, particularly including variation due to cultural differences, and to the degree of familiarity of the local context framing the issue. With respect to the latter factor, we hypothesized that exchanging with remote students about local ESAQs

(here desalination plants) could promote reflection and improve reasoning. Such was the case on the local ESAQ, but also on the global ESAQ (meat consumption). Even issues that are common globally have intensely local contexts for individuals. With respect to cultural differences, our intent is not to objectify the differences between the cultures of students from different countries. Rather, we consider the collective dimension as a process of interculturality (Pretceille, 2010), by considering the dynamic of emergence of mutual understandings. This occurred through reasoning both within and across groups, which varied in their cultural and experiential diversity. Thus, we do not assume that "cross-national" equates to "cross-cultural," but rather used the cross-national design to maximize the possibility of difference, along with coalescence around particular local perspectives.

Assessing SSR

Sadler et al. (2011) argue that SSI-based education will not be recognized as having a place within science education unless it becomes possible to proceed with a "standard" assessment of what the students learn, as is the case in international comparative studies. Yet learning within an SSI framework depends not only on the situations enacted but also on the nature of the SSIs studied and the social representations associated with them, in a given context at a given time. Furthermore, the educational goals are multiple (learning underlying scientific concepts, the nature of science, higher order thinking including argumentation, risk assessment, evidence assessment, etc., decision making, critical thinking, sociopolitical activism). Sadler et al., within the Curriculum and Assessment Tools for Socio-scientific Inquiry (CATSI) project, were not able to observe in the assessment of SSR any correlations that proved the consistency of students' performance for each SSR aspect across context. They proposed "SSR as a single construct with interrelated sub-constructs (i.e., aspects). The results produced in the CATSI project did not support this interpretation. The aspects did not show significant relationships" (p. 72). They suggest optimizing SSR assessment using a broader range of issue contexts and refining the aspects rubrics. Our framework is consistent with this direction. We would argue, however, that while there is a pattern of reasoning broadly applicable to all or most SSIs, as is the case with much of what we learn, transferring reasoning at the same level of detail is problematic.

Implications for Future Work: Ways Forward

The practical aspects of the process, particularly the organization of socioepistemological disturbance between groups is presented in a previous article (Morin et al., 2013). We would advocate that this approach, which brings together different perspectives on SAQs, is a valuable stimulus for higher level reasoning about SSIs, which should be adapted to school science in pursuit of scientific literacy. This is becoming increasingly possible with enhanced information and communication technology capability in schools. We argue that such practice, across the secondary school years, should be an important component of education for scientific literacy. The cross-cultural exchanges open up differences that stimulate reasoning. This does not only apply to cross-national exchange but also to any cultural differences or difference of opinion based on other factors that the group is exposed to and must respond to. In a further paper, we will explore the nature of reasoning in the discussion surrounding the wiki development to more firmly establish a link between quality of reasoning in the process of discussion and quality expressed in the wiki product. Context also is a significant factor in quality of reasoning.

This research answered a number of questions but raised more concerning both the framing of the reasoning and factors affecting that, and practical issues around managing

and potentially extending the cross-national exchange aspects. Further research is needed in the following areas:

1. Further refinement and validation of the interactive framework based on Habermas and Mercer is needed to analyze more closely the nature of productive reasoning in groups and the features that support quality reasoning. Exploration of the application of the framework to face-to-face interactions would be potentially valuable for teachers encouraging quality reasoning in group discussions.
2. There is a need to tease out more definitively the relative effects of context and group diversity in determining the quality of reasoning.
3. Further research is needed on the effect of variations in the approach to match contexts, for instance, exploring variation in the sequencing of face-to-face and online discussion, and the nature of the sequencing of discussion forums and wiki development.
4. The French–Australian exchanges worked partly through the efforts of the bilingual French researchers and the French students' knowledge of English and the Australian researchers' familiarity with French. However, if this approach is to be exported to more varied situations and inevitably less shared-in-common languages, we need to develop effective ways of negotiating and supporting exchanges across languages.
5. This research has opened up the possibility of productive cross-national exchanges around SAQs at secondary or even primary school level, as a potentially powerful means of encouraging focused discussion and reasoning toward a richer version of scientific literacy. Education for sustainability is important at the international level and the approach exemplified in this study offers a way forward for engaging students in reasoning consistent with the complexity of sustainability issues. Research into the organization of such exchanges between school classes would be a valuable step in this direction.

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