International Journal of Science Education
Vol. 29, No. 9, 2 July 2007, pp. 1163–1187

RESEARCH REPORT

High School Students' Informal Reasoning on a Socio-scientific Issue: Qualitative and quantitative analyses

Ying-Tien Wu[a] and Chin-Chung Tsai[b]*
[a]National Taiwan Normal University, Taiwan; [b]National Taiwan University of Science and Technology, Taiwan

Recently, the significance of learners' informal reasoning on socio-scientific issues has received increasing attention among science educators. To gain deeper insights into this important issue, an integrated analytic framework was developed in this study. With this framework, 71 Grade 10 students' informal reasoning about nuclear energy usage was explored qualitatively and quantitatively. It was found that the students in this study tended to process reasoning from multiple perspectives, and most of them were prone to make evidence-based decisions. However, less than 40% of the participants were able to construct rebuttals against counter-arguments. It was also revealed that students' abundant usage of supportive arguments did not guarantee for their counter-argument construction as well as rebuttal construction, but their usage of counter-arguments might act as precursors to their construction of rebuttals. In addition, learners' usage of multiple reasoning modes might help them propose more arguments and, in particular, generate more counter-arguments, which may act as precursors to their rebuttal construction. This study also showed evidence that students' scientific knowledge that might be mainly acquired from school science instruction could be viewed as important foundation for better informal reasoning and decision-making on socio-scientific issues.

Introduction

Formal Reasoning and Informal Reasoning

Educators, particularly those in science education, have regarded learners' reasoning ability as one of the important perspectives for examining students' learning (Eylon & Linn, 1988). Reasoning can be defined as the process of constructing and

*Corresponding author. Graduate School of Technological and Vocational Education, National Taiwan University of Science and Technology, #43, Sec. 4, Keelung Rd., Taipei, 106, Taiwan. Email: cctsai@mail.ntust.edu.tw

ISSN 0950-0693 (print)/ISSN 1464-5289 (online)/07/091163–25

DOI: 10.1080/09500690601083375

evaluating arguments (Shaw, 1996). For many years, derived from a philosophical and psychological tradition of logicism, research on reasoning has been centered on the deductive reasoning paradigm in which learners are asked to evaluate logical arguments or generate valid conclusions from given premises (Evans, 2002).

In the tradition of science education, scientific reasoning often refers to deductive reasoning characterized by rules of logic and mathematics. In these reasoning tasks, learners are presented with well-defined problems, and they are told to assume the premises of problems are true and to draw or approve only conclusions that necessarily follow (Evans & Thompson, 2004). Besides, reasoners are required to avoid taking their background knowledge and personal beliefs into account, and they should try to solve the problems only by utilizing the information provided in the premises (Evans, 2002; Evans & Thompson, 2004).

Based on the assumption that logic provides the basis for rational human thought, two theories have been proposed to illustrate the mechanism of human reasoning: mental model theory (Johnson-Laird, 1983), claiming that people reason by constructing mental models; and mental logic theory (Braine & O'Brien, 1995), advocating that there is a mental logic available for people to apply when they reasoning and some large part of this logic is universal. However, it has been argued that although the results of science may be presented in the format of formal reasoning and logic, the results themselves originate through informal reasoning (Tweney, 1991). Educators also proposed that many of the reasoning tasks in the classroom are informal in nature (e.g., Perkins, 1985; Means & Voss, 1996). Thus, informal reasoning skill may be of considerable importance, and the significance of informal reasoning has been increasingly highlighted by educational researchers (e.g., Kuhn, 1993; Sadler, 2004).

As the literal meaning, formal reasoning and informal reasoning seem to be two opposite forms of reasoning. In fact, informal reasoning shares some commonalities with formal reasoning, but there are some essential distinctions between these two forms of reasoning. As aforementioned, the problems of formal reasoning are well-defined and the premises in these problems are always explicit and clear. However, unlike formal reasoning or scientific reasoning, the problems of informal reasoning are not well-defined, but ill-structured ones. In general, informal reasoning involves the generation and evaluation of position in response to complex issues that lack clear-cut solutions (Sadler, 2004). The premises may not be explicitly stated in informal reasoning tasks. As a result, the conclusions of the arguments in informal reasoning may not be demarcated. Therefore, informal reasoning is often used in situations where reasons exist both supporting and against the conclusion, such as making decisions about what to believe or what actions to take (Shaw, 1996). Nevertheless, as formal reasoning, informal reasoning is also recognized as a rational process of constructing and evaluating arguments (Kuhn, 1993). In recent years, to provide accounts of informal reasoning, both the advocates of mental model theory and mental logic theory have tried to modify their theories to account for numerous pragmatic influences that appear in reasoning tasks, including informal reasoning tasks (Evans & Thompson, 2004).

Dual-process Theory for Interpreting the Mechanism of Informal Reasoning

More recently, psychological researchers have also propose dual-process theories that posit the existence of two distinct cognitive systems, one essentially pragmatic and the other capable of deduction and hypothetical thought (e.g., Evans, 2002, 2003; Sloman, 1996). These two distinct systems are often described as Implicit and Explicit or, in the neutral terms, System 1 and System 2 (Evans, 2002). Sometimes, they are also termed Associative System and Rule-based System (Sloman, 1996). Some important distinctions between these two cognitive systems are summarized in Table 1. As shown in Table 1, the utilization of System 1 is unconscious, pragmatic, and contextualized, while the operation of System 2 is conscious and involves logical and abstract thinking. In addition, System 1 processes are rapid, parallel, and automatic in nature; while System 2 thinking is slow and sequential in nature and makes use of the central working system.

According to the characteristics attributed to the two cognitive systems, the process of informal reasoning may be illustrated as Figure 1. When an individual learner has to make a decision or judgment on an ill-structured problem, he or she has to utilize their informal reasoning abilities. First, on the basis of past experiences (including prior knowledge and personal beliefs instantaneously retrieved from long-term memory), System 1 will help him or her immediately develop an initial mental model about this problem. An individual learner might (and frequently does) make an intuitive decision accordingly. However, he or she can also, then, utilize System 2 to conduct hypothetical thinking, in which the initial mental model will be revised and new mental models will be constructed until a conclusion is reached. That is, a learner may use System 1 to make an intuitive decision, or he or she will further employ System 2 to elaborate his/her thinking and then make a decision.

Scientific Literacy and Informal Reasoning on Socio-scientific Issues

For science educators, achieving scientific literacy may become a well-recognized educational goal worldwide. Scientific literacy stands for what the general public ought to know about science, and is often synonymous with "public understanding

Table 1. Important distinctions between the two cognitive systems in dual-process theories

System 1: Implicit or Associative System	System 2: Explicit or Rule-based System
Unconscious	Conscious
Automatic	Controllable
Evolved early	Evolved late
Pragmatic and contextualized	Logical and abstract
High processing capacity, parallel	Constrained by working memory, sequential
Driven by learning and innate modules	Permits hypothetical thinking
Shared with other animals	Uniquely human

Note: Cited from Evans (2002, p. 983).

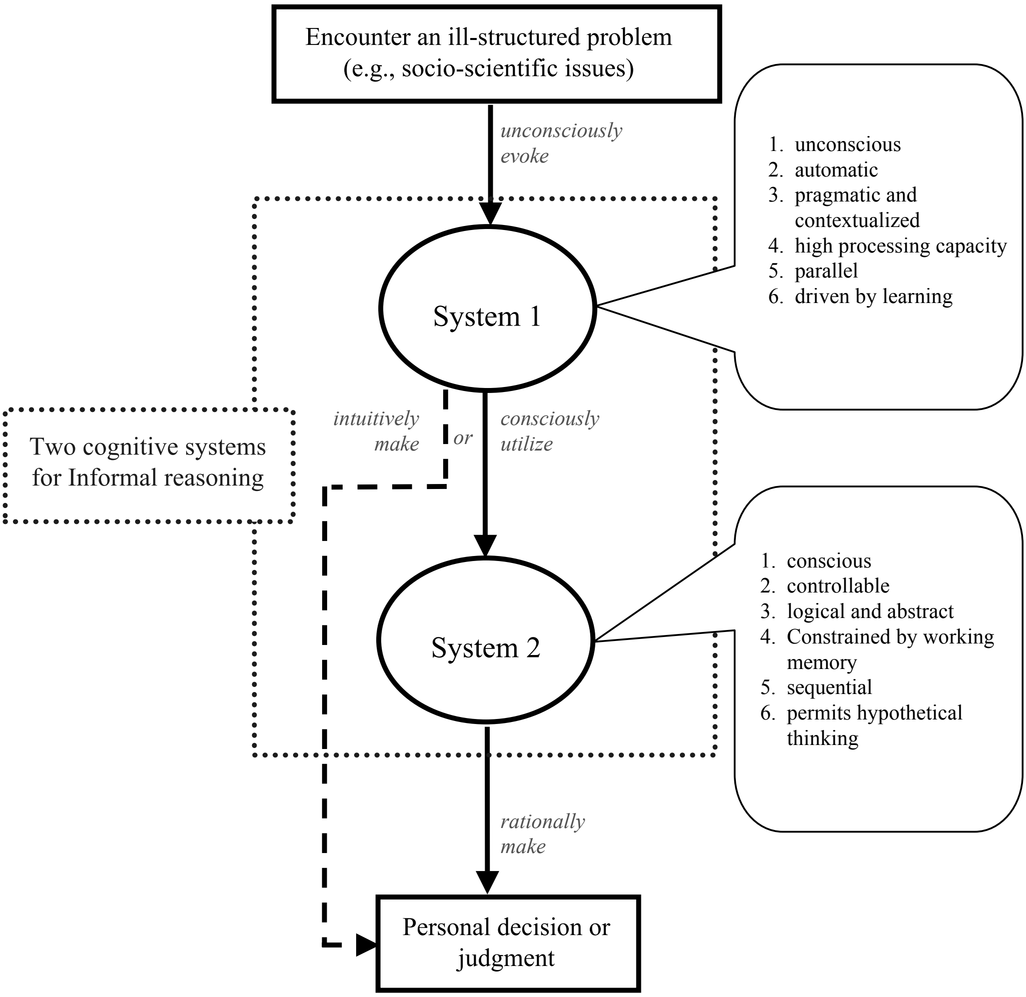

Figure 1. The process of informal reasoning in dual-process theories

of science", which includes scientific knowledge and knowledge about the nature of science (Kolsto, 2001; Laugksch, 2000). Although the definition of scientific literacy is controversial, students' ability to deal with socio-scientific issues thoughtfully has been recognized as one of the important components of scientific literacy (Sadler, 2004).

With the rapid development of science and technology, students, as the citizens in democratic society, may have more and more opportunities to encounter a variety of socio-scientific issues, and they and their parents may need to make some decisions or positions toward these issues. "Socio-scientific issues" are social dilemmas with conceptual or technological associations with science. In these issues, science and society represent interdependent entities, and both the social and scientific factors play the central roles (Sadler, 2004). In general, dealing with a socio-scientific issue often involves argumentation and decision-making on this issue. As socio-scientific issues are typically contentious, open-ended, ill-structured problems, the negotiation and resolution of such complex problems can be generally characterized by the process of informal reasoning (Sadler, 2004; Sadler & Zeidler, 2005).

To promote scientific literacy, learners' informal reasoning on socio-scientific issues has been highlighted (e.g., Bell & Lederman, 2003; Hogan, 2002; Sadler, 2004, 2005; Sadler & Zeidler, 2005; Yang, 2004). Contemporary reforms in science education have emphasized students' ability to make their decisions on socio-scientific issues (e.g., American Association for the Advancement of Science, 1990, 1993; National Research Council, 1996), and preparing learners' ability to deal with these issues has been also recognized as an important goal for science education (Kolsto, 2001). Moreover, many educators have also advocated that, to promote the practice of thinking skills, classroom activities must be placed in meaningful contexts (e.g., Glaser, 1984; Yang, 2004). Clearly, the argumentation and decision-making on socio-scientific issues can provide students with meaningful contexts for practicing their informal reasoning or thinking skill and applying what they have learned in science classrooms to solve real-world problems they have encountered in daily life. Hence, researchers have recognized the judgment of socio-scientific issues as a suitable way for the practice of informal reasoning (Kuhn, 1993; Means & Voss, 1996).

Previous Studies regarding Informal Reasoning on Socio-scientific Issues

During the past two decades, some qualitative studies have been conducted to represent students' informal reasoning on socio-scientific issues, as summarized in Table 2. For example, Sadler and Zeidler (2005) have recognized that college students demonstrated three patterns of informal reasoning on six genetic engineering scenarios, including rationalistic, emotive, and intuitive forms. Rationalistic informal reasoning described reason-based considerations; emotive informal

Table 2. Summary of the representations of informal reasoning in previous studies

Type of representation of informal reasoning	Study	Main results
Decision-making modes	Sadler & Zeidler (2005)	Three *patterns of informal reasoning*: rationalistic, emotive, and intuitive
Reasoning modes	Yang & Anderson (2003)	Two *reasoning modes*: scientific-oriented reasoning, and social-oriented reasoning
	Patronis et al. (1999)	Four *modes of arguments*: social, ecological, economic, and practical
Reasoning quality	Sadler & Zeidler (2004, 2005)	Four *components of flowed reasoning*: intra-scenarion coherence, inter-scenarion non-contradiction, counterposition construction, and rebuttal construction

reasoning described care-based considerations; and intuitive informal reasoning described considerations based on immediate reactions to the context of a scenario (Sadler & Zeidler, 2005). According to the information used during the problem task involving nuclear energy, Yang and Anderson (2003) also identified two reasoning modes—scientific-oriented reasoning (i.e., reason with scientific-oriented information) and social-oriented reasoning (i.e., reason with social-oriented information). In their system network for students' arguments on a socio-scientific issue, Patronis, Potari, and Spiliotopoulou (1999) also summarized students' qualitative arguments into four aspects: social, ecological, economic, and practical. That is, learners may generate arguments on a socio-scientific issue from social, ecological, economic, or practical considerations. In addition, to evaluate university students' informal reasoning quality in six genetic engineering scenarios, Sadler and Zeidler (2004, 2005) utilized the four criteria: intra-scenarion coherence, inter-scenarion non-contradiction, counterposition construction, and rebuttal construction. According to Sadler and Zeidler (2004), intra-scenarion coherence assesses whether the rationale supports the stated position; inter-scenarion non-contradiction evaluates whether the positions and rationales from each of the related scenarios are non-contradictory with one another; counterposition construction assesses whether the participant can construct and explain a counterposition; and rebuttal construction evaluates whether the participant can construct a coherent rebuttal. If an individual is able to form a coherent position, a counterposition, and a rebuttal, then he or she displays flowed reasoning.

Besides, researchers were also interested in exploring the factors influencing learners' informal reasoning on socio-scientific issues. Therefore, some relevant studies have investigated the relationships between students' informal reasoning on socio-scientific issues and their conceptual understanding as well as their beliefs about the nature of science. The results derived from these studies showed that an individual's conceptual understanding has significant influence on his or her informal reasoning (Hogan, 2002; Sadler, 2005; Sadler & Zeidler, 2004). Moreover, students' informal reasoning on socio-scientific issues is related to certain aspects of beliefs about nature of science, such as social embeddedness of science and tentativeness (Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackeet, & Simmons, 2002), but learners' differences in views on nature of science may not lead to different decision-making on a socio-scientific issue (Bell & Lederman, 2003).

The Rationales and Purposes of this Study

As aforementioned, almost all the previous studies regarding informal reasoning on socio-scientific issues were conducted qualitatively (e.g., Bell & Lederman, 2003; Hogan, 2002; Sadler, 2005; Sadler & Zeidler, 2004, 2005; Yang, 2004; Yang & Anderson, 2003). Recently, researchers in psychology have also proposed some quantitative measures for representing learners' informal reasoning, such as "number of sound arguments", "number of reasons", and "counter-arguments" (e.g., Means & Voss, 1996). The utilization of these quantitative measures may be able to provide science education researchers with multiple aspects in representing students' informal reasoning on socio-scientific issues. Moreover, educational researchers have argued the commonalities between quantitative and qualitative research, and have advocated mixed-methods research as a new research paradigm (e.g., Johnson & Onwuegbuzie, 2004). To gain deeper insights into students' informal reasoning on socio-scientific issues, an analytic framework integrating the aforementioned qualitative aspects (i.e., the modes, the patterns, and the quality of informal reasoning on socio-scientific issues) and quantitative measures may be of great usefulness. However, an integrated framework for representing learners' informal reasoning on socio-scientific issues is still not available. To address this important issue, the current study was one of the initial attempts to develop an integrated framework for analyzing students' argumentation and decision-making on socio-scientific issues with both qualitative indicators and quantitative measures. With this analytic framework, a group of high school students' informal reasoning on a socio-scientific issue was explored. The relationships between students' qualitative indicators and quantitative measures for their reasoning and decision-making on this issue were also investigated.

Method

Participants

The participants of this study were 71 Grade 10 students, coming from two classes of an urban high school in Taiwan (including 45 male and 26 female students). For the energy shortage problem, there is a fierce debate on whether or not a fourth nuclear power should be built in Taiwan. Therefore, the issue of nuclear power usage is suitable to be utilized as the socio-scientific issue for exploring learners' informal reasoning in this study. Before the conduct of this study, the participants had already learned about the basic principles of nuclear power in their fundamental physical courses, and they also learned about the advantages and disadvantages of different methods for generating electric power (e.g., thermal power, waterpower, solar energy, and nuclear power) in their earth sciences course.

Developing the Analytic Framework

To obtain more potential insights on learners' informal reasoning, including argumentation and decision-making on a socio-scientific issue (i.e., nuclear power usage), an integrated framework for representing learners' informal reasoning was developed in this study. This framework was developed by summarizing the analysis methods used in previous studies (i.e., Means & Voss, 1996; Patronis et al., 1999; Sadler and Zeidler, 2004, 2005; Yang & Anderson, 2003).

As shown in Figure 2, with qualitative analyses, learners' informal reasoning would, first, be represented by several qualitative indicators. Then, some quantitative

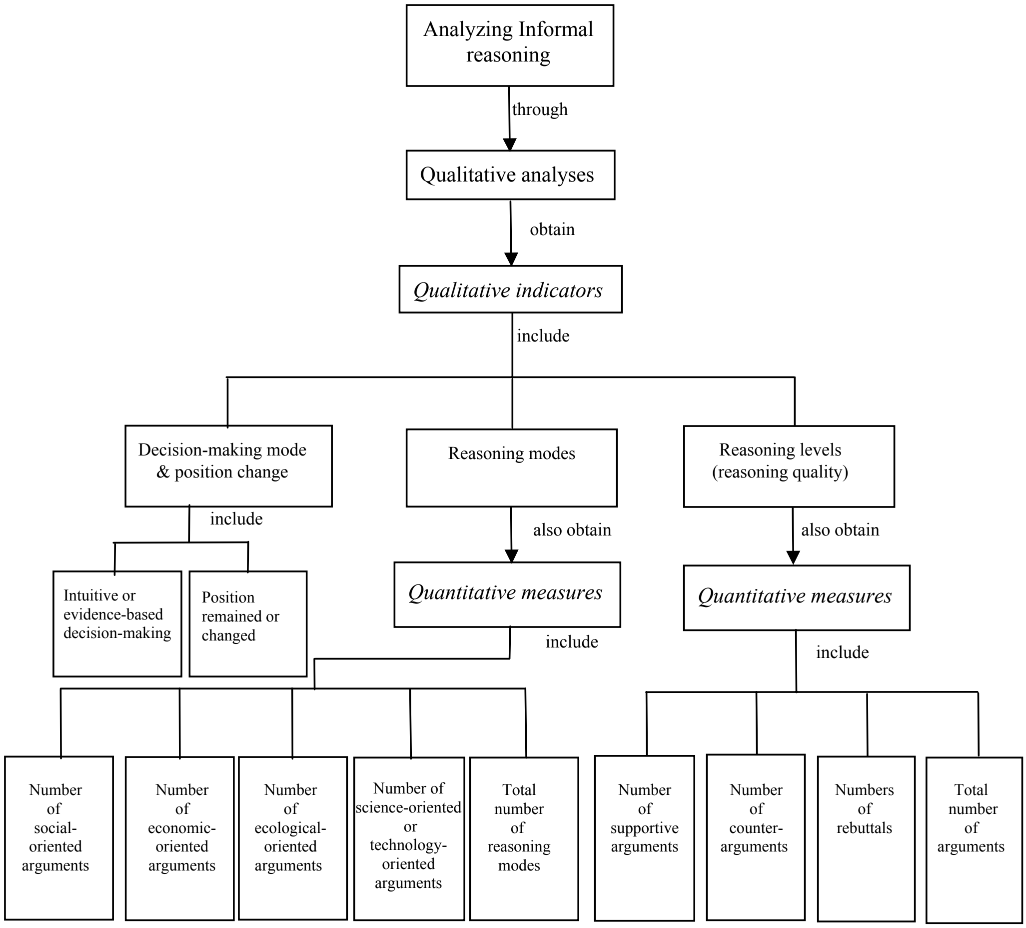

Figure 2. An integrated framework for analyzing learners' informal reasoning

measures would, accordingly, be acquired for representing learners' informal reasoning. A detailed description of these indicators and measures is as follows:

1. *Qualitative indicators*. Three qualitative indicators are used for assessing students' argumentation and decision-making on socio-scientific issues:
   (a) *Decision-making mode*. Assessing students' orientations for decision-making. This indicator is modified from the three patterns of informal reasoning in Sadler and Zeidler (2005) (i.e., rationalistic, emotive, and intuitive forms) to explore learners' modes of decision-making. In this study, students' decision-making modes are divided into two categories, intuitive and evidence-based. Learners may be more oriented to make their decisions intuitively, or, on the other hand, they may make evidence-based decisions on a socio-scientific issue.

(b) *Reasoning mode.* By summarizing the analysis methods in Patronis et al. (1999) and Yang and Anderson (2003), this indicator evaluates the perspectives from which learners make their arguments on a socio-scientific issue. Learners may generate their arguments from different aspects, such as "social-oriented", "ecological-oriented, "economic-oriented", and "science-oriented or technology-oriented" perspectives. Social-oriented reasoning describes the considerations based on the welfare of society or human sympathy. Examples of social-oriented reasoning are "I agree with the building of nuclear power plant because it benefits most of the people in Taiwan" and "I disagree with the building of nuclear power plant because no one wants to live near a nuclear power plant". Ecological-oriented reasoning refers to ecology-based considerations. An example of ecological-oriented reasoning is "The building of nuclear power plant in Taiwan may threaten the survival of coral; therefore, I disagree with it". Economic-oriented reasoning describes considerations based on the perspective of economical development. An example of economic-oriented reasoning is "The shortage of electric power in Taiwan is a serious problem, and may have significant influence the economic development in Taiwan; therefore, I agree with the building of nuclear power plant". Science-oriented or technology-oriented reasoning describes considerations based on the strength or the limitation of science or technology. An example of this reasoning mode is "The science and technology today can not guarantee the safety of nuclear power plant; hence, I disagree with the building of nuclear power plant".

(c) *Reasoning level (quality)*. By modifying the analysis methods in Sadler and Zeidler (2004, 2005), this indicator assesses students' abilities and skills to generate arguments for three different purposes. In their study with six scenarios about genetic engineering, Sadler and Zeidler (2004) have identified four criteria—intra-scenarion coherence, inter-scenarion non-contradiction, counterposition construction, and rebuttal construction of flowed reasoning—and then evaluated students' informal reasoning quality. In their study, the inter-scenarion non-contradiction among these scenarios could be evaluated because more than two scenarios are utilized to assess students' informal reasoning quality. However, only one scenario about nuclear power plant was utilized in the current study. Hence, only three components of flowed reasoning proposed in Sadler and Zeidler (2004), including supportive argument construction, counterposition construction, and rebuttal construction, were utilized to assess the quality of informal reasoning in this study. Kuhn (1993) has argued that rebuttals are critical because they complete the structure of argument, integrating argument, and counter-argument. Therefore, in this study, students' reasoning level would be categorized as "lower-level" if they only made simple claims (supportive arguments) or counter-arguments, while their reasoning level would be categorized as "higher-level" if they generated not only simple claims (supportive arguments) and counterarguments, but also rebuttals.

2. *Quantitative measures*. After qualitative analyses, the following quantitative measures would be also obtained for representing students' informal reasoning on socio-scientific issues:
   (a) *Number of social-oriented arguments*. The amount of social-oriented arguments constructed by an individual learner. The more social-oriented arguments an individual learner generate, the more he/she is oriented to reason from social-oriented aspects.
   (b) *Number of ecological-oriented arguments*. The sum of ecological-oriented arguments expressed by an individual learner. The more ecological-oriented arguments an individual learner proposes, the more he/she tends to reason with ecological-oriented care.
   (c) *Number of economic-oriented arguments*. The amount of economic-oriented arguments constructed by an individual learner. The more economic-oriented arguments an individual learner generates, the more he/she is oriented to think with economic considerations.
   (d) *Number of science-oriented or technology-oriented arguments*. The sum of science-oriented and technology-oriented arguments shown by an individual learner. Students may learn relevant scientific knowledge regarding a socio-scientific issue in their science classrooms. Undoubtedly, the construction of science-oriented or technology-oriented arguments is particularly related to their ability to apply what they have learnt in science classrooms. The more science-oriented or technology-oriented arguments an individual learner proposes, the more he/she is prone to reason from science-oriented or technology-oriented perspectives as well as he/she is more able to apply what they have learnt in science classrooms.
   (e) *Total number of reasoning modes*. The total number of reasoning modes an individual utilized in his/her informal reasoning. As mentioned above, totally, four reasoning modes would be categorized in this study. The more the total number of reasoning modes an individual learner utilizes, the more he/she is oriented to reasoning from multiple perspectives. For example, when reasoning on a socio-scientific issue, if an individual proposed one socio-oriented argument and two economic-oriented arguments, he/she would be viewed as utilizing two reasoning modes.
   (f) *Number of supportive arguments*. The amount of supportive arguments a learner constructs. The more the supportive arguments a learner proposes, the more he/she is able to provide supportive evidences for his/her position.
   (g) *Number of counterarguments*. The amount of counterarguments a learner proposes. This measure assesses the ability of a learner to reason from the counterposition.

(h) *Number of rebuttals.* The amount of rebuttals a learner generates. The amount of the rebuttals a learner proposes. The more the rebuttals a learner constructs, the more he/she is able to justify for his position.

(i) *Total number of arguments.* The total amount of the three kinds of arguments above (i.e., supportive arguments, counter-arguments, and rebuttals). This measure evaluates an individual learner' ability to make arguments regarding a socio-scientific issue.

Data Collection and Analysis

With the framework above, this study then explored a group of high school students' informal reasoning regarding nuclear energy usage. To this end, an open-ended questionnaire was developed and used to collect research data about students' informal reasoning on nuclear energy usage. There were three phases when collecting the data. First, students were asked to write down whether they agreed with building nuclear power plants in Taiwan (i.e., their initial position about building nuclear power plants), and how their decisions were made (intuitively or evidence-based). Then, a summary report about both the advantages and disadvantages of nuclear energy usage from multiple perspectives, such as safety, economic, ecological perspectives, was given to each student to read. Finally, the students were asked to respond to the following questions and wrote down their answers:

1. Do you agree with the building of the fourth nuclear power plant in Taiwan? Why? (Assessing students' possible position change on the building of the fourth nuclear power in Taiwan.)
2. If you want to convince your friend with your position, what arguments you will propose to convince him/her? (Evaluating students' ability to generate supportive arguments for their positions.)
3. If someone holds an opposite position with you on this issue, what arguments he/she may have? (Assessing students' ability for counterargument construction.)
4. According to the arguments you have proposed in question 3, can you write down your opposing ideas to justify your position? (Evaluating students' ability for rebuttal construction.)

The participants were asked to complete the open-ended questionnaire in 50 min.

After data collection, the participants' informal reasoning on nuclear energy usage was analyzed by means of the framework developed in this study. There are two stages of data analyses in this study: initial analysis stage, and follow-up analysis stage. In the initial analysis stage, through a series of qualitative analyses, students' decision-making modes and their reasoning mode of each argument in their responses were categorized. The validity of each argument for its purpose (i.e., supportive arguments, counter-arguments, and rebuttals) was also evaluated. To assess the reliability of qualitative analyses in this study, two researchers were asked to analyze 16 students' responses, and their inter-coder agreements for these analyses were assessed. In this study, all the inter-coder agreements of these analyses were greater than 0.8. The discrepancies were discussed, and final agreements were achieved. Thus, the qualitative analyses of this study were viewed as sufficiently reliable. After a series of qualitative analyses, several qualitative indicators and quantitative measures, as already mentioned, were also generated for representing students' informal reasoning and decision-making on nuclear energy usage. In addition, gender differences on qualitative indicators and quantitative measures were also examined in this stage. In the second stage (i.e., follow-up analysis stage), some t-test analyses were conducted to explore the differences between students of different decision-making modes (as well as different reasoning levels) on their informal reasoning. Also, the correlations between these quantitative measures were examined in this stage.

Results

Results derived from Initial Analyses

With the aforementioned qualitative indicators, participants' informal reasoning regarding nuclear power usage was qualitatively analyzed. Then, some quantitative measures were also derived from the results of a series of qualitative analyses.

Students' decision-making modes and position change. As revealed in Table 3, most of the participants (72%) were found to make evidence-based decisions. No significant difference was found between male and female students on their decision-making modes ($\chi^2 = 0.86$, $p > .05$). Table 3 also shows that about 24% of the participants changed their decisions after reading the summary report about nuclear energy usage. The male and female students did not show significant difference on whether they change their decisions after reading the report ($\chi^2 = 1.05$, $p > .05$).

This study then further explored whether students who made evidence-based decisions in this study were significantly more oriented to change their positions after reading the report than intuitive thinkers. The results in Table 4 show that, compared with the intuitive thinkers, the students who made evidence-based decisions in this study were significantly more oriented to change their positions after reading the report ($\chi^2 = 5.49$, $p < .05$). It seemed that, compared with intuitive thinkers in this study, evidence-based thinkers were more oriented to reconsider

Table 3. Students' decision-making modes and position change

		All (n)	Male (n)	Female (n)	Gender comparison (χ^2)
Decision-making modes	Evidence-based	51	32	19	0.86 (not significant)
	Intuitive	20	13	7	
Position change	No	54	36	18	1.05 (not significant)
	Yes	17	9	8	

Table 4. Students' position change between different decision-making mode groups

	Decision-making mode	
	Evidence-based (n)	Intuitive (n)
Position remained	35	19
Position change	16	1
χ^2	5.49*	

Note: *$p < .05$.

their initial positions on a socio-scientific issue when relevant information was available, and they might change their positions accordingly. On the other hand, intuitive thinkers, compared with evidence-based thinkers, were more prone to remain original position even after encountering more other relevant information regarding a socio-scientific issue.

Students' usage of different reasoning modes. The results presented in Table 5 show that the participants in this study, on average, proposed 1.13 "ecological-oriented" arguments, 1.04 "economic-oriented" arguments, 0.76 "science-oriented or technology-oriented" arguments, and 0.21 "social-oriented" arguments. The students utilized, on average, more than two argumentation modes (mean = 2.27), suggesting that learners in this study tended to reason from multiple perspectives. The results concurred with those by Sadler and Zeidler (2005) and Yang and Anderson (2003) that learners were oriented to reason from multiple perspectives. However, the students proposed relatively less "science or technology-oriented" arguments. It might be due to their insufficient abilities to make the connections between what they had learned in science classrooms and the socio-scientific issues they encountered in daily life. Furthermore, as shown in Table 5, the male and the female students did not show significant gender difference on their usage of the aforementioned four reasoning modes and the number of their reasoning modes ($p > .05$).

Table 5. Students' usage of different reasoning modes

	All		Male students		Female students		Gender difference
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	t value
Social-oriented	0.21	0.48	1.56	0.37	0.31	0.62	−1.31 (not significant)
Economic-oriented	1.04	0.62	1.00	0.67	1.12	0.52	−0.81 (not significant)
Ecological-oriented	1.13	0.91	1.18	0.98	1.04	0.77	0.66 (not significant)
Science-oriented or technology-oriented	0.76	1.09	0.80	1.06	0.69	1.16	0.39 (not significant)
Total number of reasoning modes	2.27	0.77	2.22	0.79	2.34	0.75	−0.66 (not significant)

Students' construction of arguments for different purposes and their reasoning levels. The current study investigated students' construction of arguments for different purposes (i.e., supportive-argument construction, counter-argument construction, and rebuttal construction). The results in Table 6 show that the students, on average, proposed more than one supportive argument (mean = 1.58) and one counter-argument (mean = 1.08), while they generated less than one rebuttal (mean = 0.45). It was relatively difficult for the participants to generate rebuttal arguments. Moreover, Table 6 also reveals that the male students and the female students in this study did not show any significant difference on their construction of arguments for different purposes (i.e., supportive argument, counter-argument, and rebuttal) and the total number of arguments.

In this study, the students who were capable of constructing not only simple claims (supportive arguments) and counter-arguments, but also rebuttals, were viewed as attaining a "higher" reasoning level, while those who only made simple claims (supportive arguments) or counter-arguments were regarded as achieving a "lower" reasoning level. It was found in the current study that only 27 students (38%) were categorized as "higher reasoning level" (27 students), while 44 students (62%) were as "lower reasoning level". In other words, more than one-half of the participants in this study had difficulty in generating rebuttals to against counter-position arguments. Moreover, still no gender difference was found on the participants' reasoning levels in this study ($\chi^2 = 0.28$, $p > .05$).

Results of Follow-up Analyses

Students' usage of reasoning modes between evidence-based and intuitive decision-making groups. According to Table 7, the students of different decision-making modes (i.e., evidence-based and intuitive) did not show any significant difference on their usage of the four different reasoning modes as well as the total number of reasoning modes ($p > .05$).

Table 6. Students' usage of arguments for different purposes

	All		Male students		Female students		Gender difference
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	t value
Supportive-argument construction	1.58	0.65	1.67	0.67	1.42	0.58	1.54 (not significant)
Counter-argument construction	1.08	0.58	1.04	0.60	1.15	0.54	1.61 (not significant)
Rebuttal construction	0.45	0.67	0.38	0.61	0.58	0.76	–1.21 (not significant)
Total number of arguments	3.11	1.38	3.09	1.29	3.15	1.54	–0.19 (not significant)

Table 7. Students' usage of reasoning modes between different decision-making mode groups

	Social-oriented		Economic-oriented		Ecological-oriented		Science-oriented or technology-oriented		Total number of reasoning modes	
	Mean, standard deviation	*t* value	Mean, standard deviation	*t* value	Mean, standard deviation	*t* value	Mean, standard deviation	*t* value	Mean, standard deviation	*t* value
Evidence-based	0.22, 0.50	0.12 (not significant)	1.06, 0.65	0.36 (not significant)	1.18, 0.93	–0.13 (not significant)	0.84, 1.05	1.02 (not significant)	2.31, 0.76	0.80 (not significant)
Intuitive	0.20, 0.41		1.00, 0.56		1.15, 0.88		0.55, 1.19		2.15, 0.81	

Students' construction of arguments for different purposes between different decision-making mode groups. Also, Table 8 reveals that these students of different decision-making mode groups did not reveal any significant difference on the numbers of the arguments constructed for different purposes (i.e., supportive arguments, counterarguments, and rebuttals) and the total number of the arguments ($p > .05$).

Students' usage of reasoning modes between different reasoning level groups. The results presented in Table 9 reveal that, when reasoning on nuclear energy usage, the students of higher reasoning level (i.e., those were able to construct rebuttals) generated significantly more ecological-oriented arguments ($t = 6.18$, $p < .05$) as well as science-oriented or technology-oriented arguments ($t = 2.62$, $p < .05$). This implied that the students of higher reasoning level were more prone to reason from ecological-oriented perspectives as well as science-oriented or technology-oriented considerations than their counterparts. Moreover, these students of higher reasoning level also significantly utilized more reasoning modes when they were reasoning ($t = 4.59$, $p < .05$). That is, they were more oriented to reason from multiple perspectives than their counterparts.

Students' construction of arguments for different purposes between different reasoning level groups. Table 10 reveals that students of different reasoning level did not show significant difference on their usage of supportive arguments ($p > .05$). However, those students of high reasoning level significantly outperformed their counterparts, no matter in their usage of counter-arguments ($t = 4.21$, $p < .01$) and the total number of arguments ($t = 6.19$, $p < .01$). This observation indicates that learners of higher reasoning level (i.e., those able to propose rebuttals) can generate not only more arguments, but also more counter-arguments than their counterparts.[1]

Correlations between students' usage of arguments for different purposes. Table 11 shows that students' construction of supportive arguments was not significantly correlated with their construction of counter-arguments as well as rebuttals ($p > .05$). Nevertheless, their usage of rebuttals was significantly correlated with their usage of counter-arguments ($r = 0.60$, $p < .01$). This implied that students' abundant usage of supportive arguments did not guarantee for their counterargument construction and rebuttal construction, but their usage of counter-arguments might act as precursors to their construction of rebuttals.

Moreover, the results presented in Table 11 also revealed that learners' number of reasoning modes was significantly correlated with their total number of arguments ($r = 0.69$, $p < .01$), indicating that the more the reasoning modes a learner utilizes, the more arguments he/her will propose. That is, learners' utilization of multiple reasoning modes may help them propose more arguments. In addition, the participants' usage of rebuttals was also significantly correlated with their number of

Table 8. Students' construction of arguments for different purpose between different decision-making mode groups

	Supportive-argument construction		Counter-argument construction		Rebuttal construction		Total number of arguments	
	Mean, standard deviation	t value	Mean, standard deviation	t value	Mean, standard deviation	t value	Mean, standard deviation	t value
Evidence-based	1.61, 0.63	0.63 (not significant)	1.16, 0.58	1.70 (not significant)	0.45, 0.64	0.01 (not significant)	3.12, 1.29	1.15 (not significant)
Intuitive	1.50, 0.69		0.90, 0.55		0.45, 0.76		2.70, 1.59	

Table 9. Students' usage of reasoning modes across different reasoning level groups

	Social-oriented		Economic-oriented		Ecological-oriented		Science-oriented or technology-oriented		Total number of reasoning modes	
	Mean, standard deviation	*t* value	Mean, standard deviation	*t* value	Mean, standard deviation	*t* value	Mean, standard deviation	*t* value	Mean, standard deviation	*t* value
Higher level group	2.60, 0.53	0.64	1.07, 0.55	0.54	1.81, 0.92	6.18**	1.22, 1.34	2.62*	2.73, 0.72	4.59**
Lower level group	1.82, 0.46		1.02, 0.66		0.70, 0.59		0.48, 0.79		1.95, 0.61	

Note: $^{*}p < .05$, $^{**}p < .01$.

Table 10. Students' construction of arguments for different purpose between different reasoning level groups

	Supportive-argument construction		Counter-argument construction		Total number of arguments	
	Mean, standard deviation	*t* value	Mean, standard deviation	*t* value	Mean, standard deviation	*t* value
Higher level group	1.69, 0.74	1.20	1.42, 0.58	4.21**	4.00, 1.41	6.19**
Lower level group	1.50, 0.59		0.86, 0.46		2.34, 0.83	

Note: $^{*}p < .05$, $^{**}p < .01$.

reasoning modes ($r = 0.56$, $p < .01$). In other words, when reasoning on a socio-scientific issue, the more reasoning modes he/she will utilize, the more he/she will be able to construct rebuttals.

Table 11 also reveals that students' rebuttal construction was highly correlated with their usage of science-oriented or technology-oriented arguments ($r = 0.60$, $p < .01$), reconfirming the result in Table 9 that students of higher reasoning level generated significantly more science-oriented or technology-oriented arguments than their counterparts. In other words, the result above highlights the significance of scientific knowledge on learners' informal reasoning, as proposed by Kolsto (2001), that students' scientific knowledge obtained from school science instruction can serve as important foundation for better informal reasoning and decision-making on controversial issues.

Discussion and Educational Implications

Contemporary reforms in science education have highlighted students' ability to make their decisions on socio-scientific issues (e.g., American Association for the Advancement of Science, 1990, 1993; National Research Council, 1996). Driver, Newton, and Osborne (2000) also suggested that instructors should give the role of argument a high priority in science classrooms. As suggested by Driver et al., informal reasoning, which has been recognized as a rational process of constructing and evaluating arguments, should be highlighted by science instructors. However, the results of this study showed that almost one-quarter of participants were relatively oriented to make their decisions on nuclear power usage intuitively. As preparing students for rational thinkers is of great importance, how students make their decisions on socio-scientific issues should receive more attention among science educators. In addition, this study also showed that the students, who made evidence-based decisions, were significantly more oriented to change their positions after reading a summary report with relevant information. Further research should be conducted to explore the evaluative standards that learners utilize to judge the usefulness of the

Table 11. Correlations between students' usage of arguments for different purposes and their usage of different reasoning modes

	Usage of arguments for different purposes				Usage of reasoning modes				
	Supportive argument	Counter-argument	Rebuttals	Total number of arguments	Social-oriented	Economic-oriented	Ecological-oriented	Science-oriented or technology-oriented	Total number of reasoning modes
Supportive argument	–	0.17	0.12	0.60**	0.39**	0.15	0.29*	0.24*	0.43**
Counter-argument	0.17	–	0.60**	0.79**	0.14	0.23	0.31**	0.53**	0.52**
Rebuttals	0.12	0.60**	–	0.79**	0.19	0.02	0.37**	0.60**	0.56**
Total number of arguments	0.60**	0.79**	0.79**	–	0.33**	0.18	0.44**	0.63**	0.69**

Note: $^{*}p < .05$, $^{**}p < .01$.

incoming information, such as information in relevant reports when they are reasoning, and make decisions on socio-scientific issues.

Kolsto (2001) argued that students' knowledge acquired in science classroom can serve as tools for their informal reasoning and decision-making on controversial issues. However, it was found that the high school students in this study proposed relatively less "science-oriented or technology-oriented" arguments. It seems that they did not have sufficient abilities to make the connections between what they had learned in science classroom and the socio-scientific issues they encountered. The results above indicate that instructors should pay more attention to learners' ability to apply their learned scientific knowledge to solve real-world problems. In particular, in Internet-based science learning environments, learners may have more opportunities to acquire relevant scientific knowledge on the Internet and apply it for dealing with socio-scientific issues they encountered. Therefore, how they judge the web-based information they have searched and utilize relevant information to help them reason rationally and make thoughtful decisions on socio-scientific issues may become important issues for science education researchers. Previous studies have suggested that instructors should highlight how students assess the accuracy and usefulness of web-based materials in Internet-based learning environments (e.g., Tsai, 2004; Wu & Tsai, 2005). Indeed, there is certainly some sound scientific knowledge available on the Internet, and a lot of other materials that purport to be scientific knowledge which is dubious to say the least. Hence, the students should be encouraged to evaluate the merits of any so-called scientific knowledge that they find on the Internet. In addition, the research regarding how Internet can be utilized to help learners think rationally and make thoughtful decisions on socio-scientific issues is still not sufficient. Therefore, how learners utilize the Internet information resource as a useful tool for improving the quality of their informal reasoning on socio-scientific issues is essential for further investigation.

Osborne, Erduran, and Simon (2004) advocated that science instructors should try to improve learners' argumentation levels. Kuhn (1993) has argued that rebuttal construction is critical in learners' informal reasoning. Therefore, to improve learners' informal reasoning level, their abilities of constructing rebuttals are very important. The results in this study showed that the students of high reasoning level (i.e., those who were able to generate rebuttals) proposed significantly more counter-arguments than their counterparts. It seems that students' counter-argument construction may act as precursors to their rebuttal construction. In addition, in this study, those capable of proposing rebuttal arguments (i.e., higher-level reasoners) also significantly utilized more reasoning modes than their counterparts. It seemed that learners' utilization of multiple reasoning modes may be necessary in order to precede and promote the development of learners' informal reasoning skills (or levels), or vice versa. That is, learners' utilization of multiple reasoning modes and their informal reasoning skills may mutually reinforce one another. Therefore, to help learners achieve higher informal reasoning level, educators should not only guide them to reason from the counter-position (i.e., to construct counter-arguments), but also encourage them to reason from multiple perspectives. Thus, the quality of learners' decision-making on socio-scientific issues may be improved. To this end, explicit instruction regarding informal reasoning skill may also helpful for improving students' informal reasoning quality. Zohar and Nemet (2002) have tried to integrate explicit teaching of reasoning patterns into the teaching of human genetics, and have found the effectiveness of the instruction. Therefore, by utilizing flowed reasoning proposed by Sadler and Zeidler (2004), instructors may try to integrate the instruction for practicing rational reasoning by specific science content. Also, a reasoning framework, guiding learners to reasoning from multiple perspectives, can be integrated into the explicit instruction. For example, when learners practice informal reasoning on nuclear power usage, a reasoning framework, consisting of four perspectives—social-oriented, economic-oriented, ecological-oriented, and science-oriented or technology-oriented considerations—can be utilized to guide learners' argument construction and decision-making on nuclear power usage.

Recently, psychological researchers (e.g., Evans, 2002, 2003; Sloman, 1996) have proposed dual-process theories to interpret the mechanism of informal reasoning, and some relevant empirical studies have been conducted (e.g., Evans, 2003; Sloman, 1996). As already mentioned, the flowed reasoning involves supportive arguments construction, counter-arguments construction, and rebuttal construction. It seems plausible that the construction of supportive arguments and counter-arguments is related to the retrieval of relevant information from his/her long-term memory (or cognitive structure), and thus may be viewed as the productions of the utilization of System 1 in dual-process theories. In addition, the construction of rebuttal in flowed reasoning may involve hypothetic thinking, which is related to the operation of System 2 (see Table 1 and Figure 1). Therefore, the construction of rebuttal may be viewed as one of the productions of operating System 2. However, further studies are needed to examine these perspectives.

As learners' informal reasoning ability is important, science educators and researchers should pay more attention to this important issue. This study is an initial attempt to provide an integrated and systemic representation in learners' informal reasoning. However, the analytic framework in this study may need some slight modification according to the specific features of the socio-scientific issues being addressed. For example, when reasoning on genetic engineering, learners may not frequently reason with economic-oriented considerations, which is one of important aspects when reasoning on nuclear power usage. Consequently, when analyzing students' reasoning on genetic engineering, the analysis framework may need some modifications. To examine the usefulness of the framework proposed in this study, more following-up studies should be conducted to investigate learners' informal reasoning on other socio-scientific issues.

Furthermore, with the framework developed in this study, some further research can be undertaken to facilitate our understandings regarding the nature of learners' informal reasoning. For example, previous studies have investigated the relationships between students' informal reasoning on socio-scientific issues and their conceptual understandings as well as beliefs in the nature of science (e.g., Bell &

Lederman, 2003; Hogan, 2002; Sadler, 2004, 2005; Sadler et al., 2004; Yang, 2004; Zeidler et al., 2002). Based on the framework proposed in this study, a careful examination on how learners' beliefs about the nature of science affect their informal reasoning is also suggested.

Gender difference is always one of the important issues for science education researchers. The current study is also an initial attempt to investigate whether gender differences exist on learners' informal reasoning. The results revealed that the high school students in this study did not show any gender difference on their quantitative measures of informal reasoning. To understand whether gender differences on learners' informal reasoning exist at different school levels, further research is suggested to address this important issue with samples at other different school levels (such as elementary school or university).

Acknowledgement

Funding of this research work is supported by National Science Council, Taiwan, under grant number NSC 94-2511-S-009-003.

Notes

1. It should be noted that, for some items in Tables 5–10, there are very large standard deviations compared with the means (e.g., Table 5, first row entry on "Social-oriented", the mean of "female students" is 0.31 but the standard deviation of "female students" is 0.62). It seems that the non-significant differences on some measures in these tables are probably due to the characteristics of the sample in this study. Therefore, caution must be taken when interpreting this part of results, and more studies with different samples are suggested to examine the robustness of this part of results in this study.

References

American Association for the Advancement of Science. (1990). *Science for all Americans.* New York: Oxford University Press.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Bell, R. L., & Lederman, N. G. (2003). Understandings of the nature of science and decision making on science and technology based issues. *Science Education, 87,* 352–377.

Braine, M. D. S., & O'Brien, D. P. (1995). Predicting intermediate and multiple conclusions in propositional logic inference problems: Further evidence for a mental logic. *Journal of Experimental Psychology: General, 3,* 263–292

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 23,* 689–698.

Evans, J. St. B. T. (2002). Logic and human reasoning: An assessment of the deduction paradigm. *Psychological Bulletin, 128,* 978–996.

Evans, J. St. B. T. (2003). In two minds: Dual-process accounts of reasoning. *Trends in Cognitive Sciences, 7,* 454–459.

Evans, J. St. B. T., & Thompson, V. A. (2004). Informal reasoning: Theory and method. *Canadian Journal of Experimental Psychology, 58,* 69–74.

Eylon, B., & Linn, M. C. (1988). Learning and Instruction: An examination of four research perspectives in science education. *Review of Educational Research, 58,* 251–301.

Glaser, R. (1984). Education and thinking. *American Psychologist, 39,* 93–104.

Hogan, K. (2002). Small groups' ecological reasoning while making an environmental management decision. *Journal of Research in Science Teaching, 39,* 341–368.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher, 33*(7), 14–26.

Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference and consciousness.* Cambridge, UK/Cambridge, MA: Cambridge University Press.

Kolsto, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education, 85,* 291–310.

Kuhn, D. (1993). Connecting scientific and informal reasoning. *Merrill-Palmer Quarterly, 39,* 74–103.

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education, 84,* 71–94.

Means, M. L., & Voss, J. F. (1996). Who reasons well? Two studies of informal reasoning among children of different grade, ability, and knowledge levels. *Cognition and Instruction, 14,* 139–178.

National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argument in school science. *Journal of Research in Science Teaching, 41,* 994–1024.

Patronis, T., Potari, D., & Spiliotopoulou, V. (1999). Students' argumentation in decision-making on a socio-scientific issue: Implications for teaching. *International Journal of Science Education, 21,* 745–754.

Perkins, D. N. (1985). Post-primary education has little impact upon informal reasoning. *Journal of Educational Psychology, 77,* 562–571.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching, 41,* 513–536.

Sadler, T. D. (2005). Evolutionary theory as a guide to socioscientific decision-making. *Journal of Biological Education, 39,* 68–72.

Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education, 26,* 387–409.

Sadler, T. D., & Zeidler, D. L. (2004). The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetic knowledge to genetic engineering issues. *Science Education, 88,* 683–706.

Sadler, T. D., & Zeidler, D. L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching, 42,* 112–138.

Shaw, V. F. (1996). The cognitive processes in informal reasoning. *Thinking and Reasoning, 2,* 51–80.

Sloman, S. A. (1996). The empirical case for two systems of reasoning. *Psychological Bulletin, 119,* 3–22.

Tsai, C.-C. (2004). Information commitments in Web-based learning environments. *Innovations in Education and Teaching International, 41,* 105–112.

Tweney, R. D. (1991). Informal reasoning in science. In J. F. Voss, D. N. Perkins, & J. W. Segal (Eds.), *Informal reasoning and education* (pp. 3–16). Hillsdale, NJ: Erlbaum.

Yang, F. Y. (2004). Exploring high school students' use of theory and evidence in an everyday context: The role of scientific thinking in environmental science decision-making. *International Journal of Science Education, 26,* 1345–1364.

Yang, F. Y., & Anderson, O. R. (2003). Senior high school students' preference and reasoning modes about nuclear energy use. *International Journal of Science Education, 25,* 221–244.

Wu, Y.-T., & Tsai, C.-C. (2005). Information commitments: Evaluative standards and information searching strategies in Web-based learning environments. *Journal of Computer Assisted Learning, 21,* 374–385.

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education, 86,* 343–367.

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39,* 35–62.