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RESEARCH REPORT

High School Students' Informal Reasoning Regarding a Socio-scientific Issue, with Relation to Scientific Epistemological Beliefs and Cognitive Structures

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This study investigated the relationship among 68 high school students' scientific epistemological beliefs (SEBs), cognitive structures regarding nuclear power usage, and their informal reasoning regarding this issue. Moreover, the ability of students' SEBs as well as their cognitive structures for predicting their informal reasoning regarding this issue was also examined. The participants' SEBs were assessed with a quantitative instrument; their cognitive structures were assessed through tape-recorded interviews and were further analyzed with the 'flow map method'; their reasoning regarding nuclear power usage was assessed with an open-ended questionnaire; and, then, their responses were analyzed both qualitatively and quantitatively. It was revealed that students' beliefs about the justification of scientific knowledge (an aspect of the beliefs on the nature of knowing science) were significantly correlated with their reasoning quality; the extent and the richness of students' cognitive structures as well as their usage of the information processing mode, 'comparing,' were positively correlated with their reasoning quality. A series of regression analyses further confirmed that students' use of the information processing mode, 'comparing,' was the most significant factor for predicting reasoning quality, while their beliefs regarding the justification of scientific knowledge was the other important predictor.

Keywords: *Reasoning; Argumentation; Qualitative research; Quantitative research; High school; Socio-scientific issue; Scientific epistemological beliefs; Cognitive structures*

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Introduction

'What science should be learned?' has always been one of the most important issues that science educators have been trying to pin down (Bybee & DeBoer, 1994). However, the goals for science instruction may vary over time (Koballa, 1984). With the tremendous advancements in science and technology, the goals for contemporary science education have been redefined (Cajas, 2001). In particular, for a long time, some social dilemmas with conceptual or technological associations with science, such as global warming, genetic engineering, and nuclear power usage, have arose and have been highlighted by science educators (e.g., Bell & Lederman, 2003; Sadler, 2004; Yang, 2004). Consequently, improving learners' ability in dealing with these dilemmas (often termed 'socio-scientific issues'—SSIs) has been regarded as one of the important goals for modern science education (e.g., Kolsto, 2001; Sadler, 2004). Recently, learners' reasoning and decision-making on SSIs have also been included as the important components of scientific literacy (e.g., American Association for the Advancement of Science, 1989, 1993).

The Nature of Informal Reasoning on SSI

Learners' reasoning regarding an SSI has been generally recognized as the process of informal reasoning, a form of reasoning different from formal reasoning (Sadler, 2004; Sadler & Zeidler, 2005). For science educators, reasoning (or scientific reasoning) often refers to formal reasoning characterized by rules of logic and mathematics. In fact, as formal reasoning, informal reasoning is also recognized as a rational process of constructing and evaluating arguments (Kuhn, 1993). Unlike formal reasoning or scientific reasoning, the problems of informal reasoning are not well defined, but ill-structured ones (Sadler, 2004). In particular, 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. In general, informal reasoning is often used in situations in which reasons exist both supporting and against the conclusion, such as making decisions about what to believe or what actions to be taken (Shaw, 1996). Clearly, to deal with SSIs, students' informal reasoning ability plays an important role (Sadler, 2004).

Compared with research regarding scientific reasoning, learners' informal reasoning regarding SSIs is relatively a new one in science education research. In the past, numerous studies have focused on exploring learners' scientific reasoning (Lawson, 2004), while relatively less research has been conducted to investigate students' reasoning on SSIs (e.g., Bell & Lederman, 2003; Chang & Chiu, 2008; Hogan, 2002; Sadler, 2005; Sadler & Zeidler, 2005; Yang, 2004). Until today, still not much is known about the nature of learners' informal reasoning regarding SSIs. In particular, the mechanism of students' informal reasoning on an SSI (i.e., the process of learners' informal reasoning on SSIs) has been rarely addressed in the relevant studies. A careful and deeper exploration on students' informal reasoning regarding an SSI should be crucial. Therefore, by reviewing relevant literature, the current study aimed to firstly illustrate the possible mechanism of a learner's informal reasoning on an SSI.

The dual-process theories proposed by psychological researchers for explaining human's thinking and some recent findings in psychology may provide some insights for the possible mechanism of an individual's informal reasoning on an SSI (e.g., Evans, 2002, 2003; Sloman, 1996). Recently, psychological researchers have proposed 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). Some important distinctions between these two cognitive systems are: 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. Besides, some recent findings in psychology may also improve our understanding of the process of learners' informal reasoning on an SSI. For example, Evans (1996) has suggested that people decide first and think afterward in order to justify choices that are unconsciously determined. Evans and Curtis-Holmes (2005) further argued that a central phenomenon in dual-process accounts of reasoning is that of 'belief bias,' the tendency to evaluate the validity of an argument on the basis of whether or not it agrees with the conclusion, rather than on whether or not it follows logically from the premises. Nevertheless, System 2 reasoning can override pragmatic influence and lead to normative correct solutions (Evans, 2002).

According to the dual-process theories and the perspectives proposed by educational psychologists, it seems that, when encountering an SSI, an individual will unconsciously evoke System 1 reasoning and the usage of System 1 will trigger him/her to make an initial decision first. Then, he/she may utilize System 2 reasoning to justify his/her initial decision. Moreover, it has also been proposed that experts can make the 'right' decisions quickly because they have complex models that allow them to see underlying causes (e.g., Randel, Pugh, & Reed, 1996), indicating that differences between expert and novice on their informal reasoning regarding an SSI may exist. When encountering an SSI, experts' complex mental models regarding an SSI can help them intuitively make the 'right' decisions and justify their decisions quickly and efficiently. The same as experts, novices (such as high school students) also make intuitive decisions; however, unlike experts' quick justification on their decisions, they will spend more time in conducting logical and abstract thinking (i.e., conduct System 2 reasoning) to justify their initial decisions. Even novices may not use System 2 reasoning and only make intuitive decisions as their final decisions.

The process of learners' informal reasoning may be further illustrated as in Figure 1. As revealed in Figure 1, when an individual learner has to make a decision or judgment on an ill-structured problem, there are two stages of his/her informal reasoning: *the preliminary stage* and *the deliberation stage*. In the first stage (i.e., the preliminary stage), on the basis of his/her past experiences (including prior knowledge and personal beliefs instantaneously retrieved from long-term memory), System 1 will trigger an individual learner immediately to make an initial decision accordingly. It should be noticed that an individual learner might (and frequently does) only experience the preliminary stage. In other words, he/she may only make an intuitive decision at the end. However, it is also possible that he/she, then, proceeds to reason in the deliberation stage. In this stage, System 2 will help him/her form some evaluative criteria, justify his/her initial decision accordingly, and, then, make his/her final decision until a conclusion is reached. That is, in the preliminary stage, a learner may use System 1 to make an intuitive decision, which may also be his/her final decision, or he/she will further employ System 2 to elaborate his/her thinking and then make a final decision in the deliberation stage.

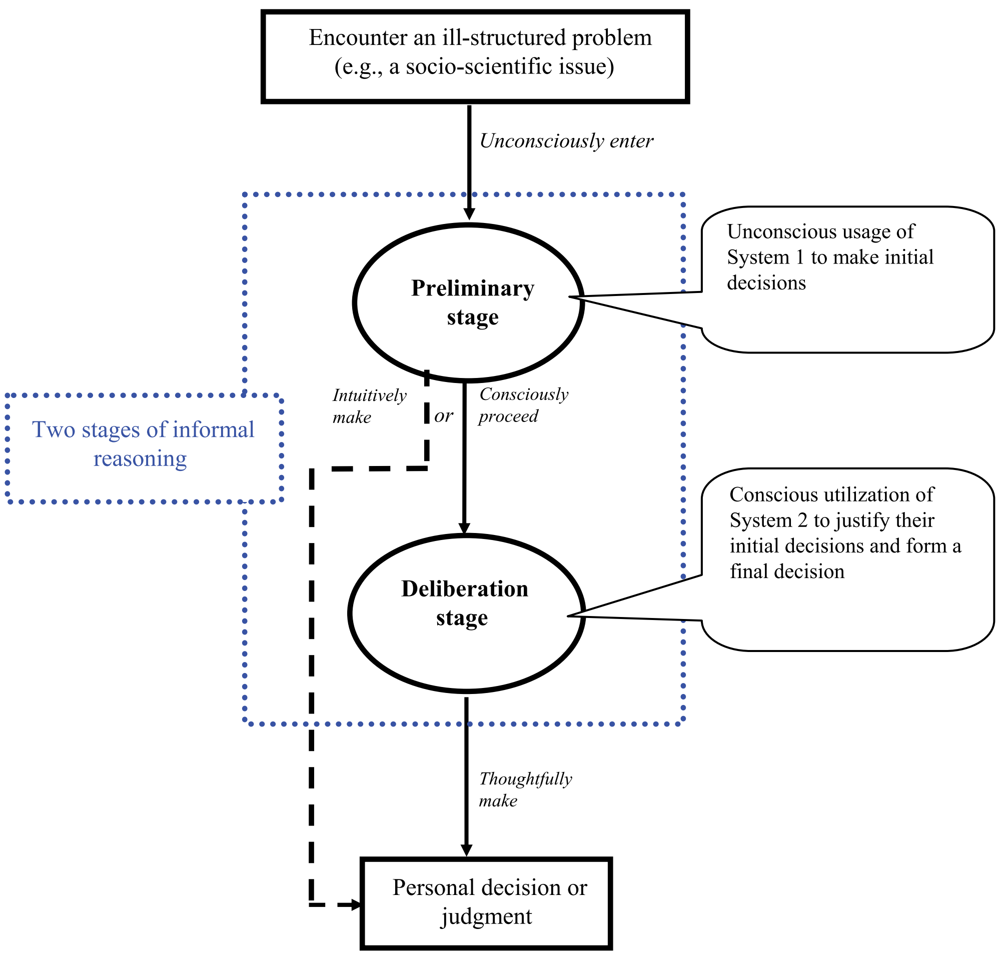

Figure 1. The process of learners' informal reasoning (modified from Wu and Tsai, 2007, p. 1166)

Student Epistemological Views Toward Science, Conceptual Understanding, and Informal Reasoning on SSI

Learners' application of what they have learned in novel contexts (i.e., the transfer of learning) is always an important issue for educators (e.g., Haskell, 2001). For a long time, learners' conceptual understanding and their proper epistemological views toward science and scientific knowledge have been recognized as two important science learning outcomes (Yore, 2003). To solve the socio-scientific dilemma they encountered, learners may have to apply what they have learned in science classrooms, including their acquired knowledge regarding this issue and their epistemological views toward science and scientific knowledge, to reason and then to make personal decisions regarding this issue. Therefore, how students' conceptual understanding regarding an SSI, as well as their epistemological views toward science and scientific knowledge, contributes to their informal reasoning on an SSI should be one of the important issues for science education researchers.

In the past, not a few studies have addressed the aforementioned important issue. Some of them have been conducted to examine the possible relationship between students' epistemological views toward science and scientific knowledge and their informal reasoning on SSIs, but diverse findings have been revealed in these studies (e.g., Bell & Lederman, 2003; Sadler, Chambers, & Zeidler, 2004; Zeidler, Sadler, Applebaum, & Callahan, 2009; Zeidler, Walker, Ackett, & Simmons, 2002). For example, the results of Sadler et al. (2004) revealed that high school students' informal reasoning was related to certain aspects of beliefs about the nature of science (NOS), such as social embeddedness of science. In addition, Zeidler et al. (2002) found that 9th–12th graders' views of NOS were related to their decision-making on an SSI, while, in Bell and Lederman (2003), no differences were found between the decisions of university faculties of various NOS views. Besides, other previous studies have explored the possible relationship between students' conceptual understanding and informal reasoning regarding an SSI and have revealed that an individual's conceptual understanding has significant influence on his or her informal reasoning (Hogan, 2002; Sadler, 2005; Sadler & Zeidler, 2004). However, most of these relevant studies were conducted qualitatively (e.g., Bell & Lederman, 2003; Sadler et al., 2004; Zeidler et al., 2002). Besides, it should also be noticed that each of them was merely conducted either to explore the relationship between students' conceptual understanding and their informal reasoning regarding an SSI or to investigate the relationship between students' epistemological views toward science and scientific knowledge and their informal reasoning regarding SSI. One may be interested in exploring whether students' conceptual understanding regarding an SSI or their scientific epistemological views toward science and scientific knowledge will be the more dominant factor contributing to their informal reasoning regarding this issue. To address this issue, quantitative studies will be helpful. Researchers in psychology have proposed some quantitative measures for representing learners' informal reasoning in daily life (e.g., Means & Voss, 1996). It seems that, with similar quantitative analyses conducted by psychological researchers, the aforementioned issue can be addressed. In other words, with quantitative analyses, the relationship between students' conceptual understanding and their informal reasoning regarding SSI as well as the relationship between students' epistemological views toward science and their informal reasoning regarding SSI can be re-examined. Also, the power of learner's conceptual understanding regarding an SSI as well as their epistemological views toward science for predicting their informal reasoning regarding this issue can be assessed. More importantly, whether students' conceptual understanding or their epistemological views toward science and scientific knowledge is the dominant factor contributing to students' informal reasoning regarding an SSI can also be confirmed. Therefore, with qualitative and quantitative analyses, this study was conducted to address the aforementioned important issues.

As aforementioned, some pioneering research has been conducted to examine the possible relationship between students' epistemological views toward science and scientific knowledge and their informal reasoning on SSIs. These studies majorly focused on the relationship between student 'beliefs about NOS' and their informal reasoning on SSI (e.g., Bell & Lederman, 2003; Sadler et al., 2004; Zeidler et al., 2002). However, research aiming to examine the relationship between learners' scientific epistemological beliefs (SEBs) and their informal reasoning on an SSI is still not available. In science education, two constructs, that is, 'beliefs about NOS' and 'SEBs,' have been most commonly proposed to refer to learners' epistemological views toward science and scientific knowledge. The term 'NOS' most commonly refers to the assumptions, values, and characteristics of scientific knowledge (Lederman, 1992; Ryan & Aikenhead, 1992; Tsai & Liu, 2005), while, from the perspective of Hofer and Pintrich (1997), 'SEBs' refer to beliefs about the nature of scientific knowledge and beliefs about the nature of knowing science. It should be noticed that Hofer and Pintrich's (1997) categories for the epistemological beliefs are kind of a personal epistemology proposed by educational psychology and, as such, though related, are different from epistemological categories as considered by the philosophy of science. In fact, both 'SEBs,' addressing beliefs about scientific knowledge and knowing science, and 'beliefs about NOS,' exploring views toward the NOS, address some common issues, such as the beliefs on the nature of scientific knowledge; nevertheless, there are also some distinctions between some issues they addressed. For example, 'NOS' addresses social and culture aspects of scientific knowledge, while 'SEBs' are more concerned with beliefs about the nature of knowing science, such as the beliefs on the justification of scientific knowledge. In other words, 'SEBs' deal with some specific range of beliefs that are likely concerned with learners' reasoning and decision-making regarding a socio-scientific dilemma (i.e., the beliefs on the justification of scientific knowledge). Therefore, the exploration of the relationship between learners' SEBs and their informal reasoning regarding an SSI may provide us with deeper insights into the role students' epistemological beliefs toward science and scientific knowledge play in their dealing with SSIs. However, almost no research has been conducted to explore the relationship between learners' SEBs and their informal reasoning on an SSI. To address the aforementioned issue, in this study, students' SEBs, rather than their beliefs on NOS, were assessed quantitatively, and, with statistical analyses, the relationship between students' SEBs and their informal reasoning regarding an SSI was examined.

Moreover, in the relevant studies examining the relationship between students' conceptual understanding and their informal reasoning regarding an SSI, learners' conceptual understanding was mostly assessed by traditional assessment method, such as multiple-choice questions (e.g., Sadler, 2005; Sadler & Zeidler, 2004). For a long time, science educators have advocated the use of multiple ways to assess students' learning outcomes (e.g., Mintzes, Wandersee, & Novak, 2001). It seems that alternative assessment for students' conceptual understanding will be helpful to reconfirm the relationship between students' conceptual understanding and their informal reasoning on SSIs. In the past, educators and cognitive scientists have tried to represent pre-acquired knowledge in terms of 'cognitive structure' (Pines, 1985; West, Fensham, & Garrard, 1985). A cognitive structure is a hypothetical construct, showing the extent of concepts and their relationships in a learner's long-term memory (Shavelson, 1974). Through probing learners' cognitive structures, science educators can understand what learners have already acquired (Tsai & Huang, 2002). Therefore, the measurement of learners' cognitive structures has been viewed as one of the important indicators for assessing learners' conceptual understanding (e.g., Shavelson, Carey, & Web, 1990; Tsai, 2001; Wu & Tsai, 2005a). In this study, with the exploration of their cognitive structure regarding an SSI, the participants' conceptual understanding regarding an SSI was assessed, and, then, with statistical analyses, the relationship between students' conceptual understanding and their informal reasoning regarding an SSI was also re-examined.

The Purposes of This Study

In sum, this study aimed to provide deeper insights into learners' informal reasoning on an SSI. To this end, this study was conducted with a group of high school students, and 'nuclear power usage' was used as the SSI for students to reason in this study. In this study, firstly students' informal reasoning regarding nuclear power usage and their cognitive structures regarding nuclear power usage were analyzed with qualitative analyses; then, further quantitative analyses regarding these two variables were also conducted. The participants' SEBs were assessed with a quantitative instrument. With aforementioned qualitative and quantitative analyses, statistical analyses regarding these variables could be further conducted in this study to provide distinct insights into learners' informal reasoning regarding SSIs from qualitative studies. This study aimed to examine the following major research questions:

(1) What are the relationships (if any) between high school students' SEBs and their informal reasoning regarding nuclear power usage?
(2) What are the relationships (if any) between high school students' cognitive structures regarding nuclear power usage and their informal reasoning regarding this issue?

(3) Among the variables regarding students' SEBs and their cognitive structures about nuclear power usage, what are significant predictors for students' informal reasoning regarding this issue? Among these significant predictors for students' informal reasoning regarding this issue, which one was the most significant predictor?

Method

Participants and the Socio-Scientific Issue

In this study, two out of eight 10th grade classes in a private high school in middle Taiwan were randomly selected, and all the students in these two classes were invited as the participants of this study. The participants of this study were 68 tenth graders (15–16 years old), including 46 males and 22 females. Compared with other high school students in Taiwan, the students in this high school were average achievers. When entering this high school, students were randomly assigned to classes.

In this study, 'nuclear power usage' was used as the SSI for the participants to reason. For the energy shortage problem, there is always a fierce debate on whether the fourth nuclear power should be built in recent years in Taiwan. Before the conduct of this study, these participants had already learned about nuclear energy usage in their physical and earth science classes. Therefore, the issue of nuclear power usage is suitable to be utilized as the SSI for exploring learners' informal reasoning in this study.

General Research Design

This study aimed to explore the possible relationship between students' SEBs (as well as their cognitive structures) and informal reasoning on an SSI. To this end, a correlational research approach was utilized in this study.

Both questionnaire-based and tape-recorded interview data were collected. The participants' SEBs were assessed first; then, in the next day, their cognitive structures regarding nuclear power usage were probed; also, their informal reasoning on nuclear power usage was explored about an hour later (50 minutes). The students' SEBs were assessed by a questionnaire, while the data regarding the students' cognitive structures on nuclear power and nuclear power usage were collected by tape-recorded interviews. In addition, an open-ended questionnaire, revised from Wu and Tsai (2007), was utilized to gather the data about the participants' informal reasoning on nuclear power usage.

Instruments, Data Collection, and Data Analyses

There are three major variables involved in this study: students' SEBs, students' cognitive structure regarding nuclear power usage, and students' informal reasoning on nuclear power usage. A detailed description about the instruments used in this study, as well as the data collection and data analyses of these three variables, is as follows:

Assessing students' scientific epistemological beliefs. In this study, the self-reported questionnaire developed by Conley, Pintrich, Vekiri, and Harrison (2004), consisting of Likert-type rating scales, was utilized to gather data regarding students' SEBs. The instrument developed by Conley et al. (2004) consists of four dimensions: source, certainty, development, and justification. The source and justification dimensions reflect beliefs about the nature of knowing science, while the certainty and development dimensions reflect beliefs about the nature of scientific knowledge (Conley et al., 2004). The questionnaire consists of a total of 26 items, presented with bipolar strongly agree/strongly disagree statements on a five-point Likert scale (1 on the Likert scale is strongly disagree, while 5 on the Likert scale is strongly agree). A detailed description of the four scales and sample items from each scale is presented below:

(1) *Source*: assessing students' beliefs about scientific knowledge residing in external authorities. A sample item is 'Everybody has to believe what scientists say.'
(2) *Certainty*: evaluating learners' beliefs in the right answer in scientific knowledge. A sample item is 'All questions in science have one right answer.'
(3) *Development*: assessing students' beliefs about scientific knowledge as an evolving and changing subject. A sample item is 'The ideas in science books sometimes change.'
(4) *Justification*: examining learners' views on the role of experiments in science and how an individual learner justifies scientific knowledge. A sample item is 'In science, there can be more than one way for scientists to test their ideas.'

Students' responses on the source and certainty scales should be reversed; so that for each of the scales, higher scores reflected more sophisticated beliefs.

In Conley et al. (2004), the α-reliability of the aforementioned four scales were 0.82, 0.79, 0.66, and 0.76, respectively. A series of confirmatory factor analyses were further conducted in Conley et al. (2004) and confirmed the adequate reliability and validity of this instrument for assessing learners' epistemological beliefs in science. Therefore, the instrument was administrated in this study to assess the participants' SEBs. Before being used in this study, the instrument was translated into Chinese. In this study, the reliability (alpha) coefficients for these scales in the Chinese version of the instrument, respectively, were 0.76, 0.70, 0.83, and 0.76, and the overall alpha was 0.85. Therefore, the Chinese version of the instrument used in this study was deemed to be sufficiently reliable for assessing students' SEBs.

Exploring students' cognitive structures regarding nuclear power usage. In recent years, the measurement of learners' cognitive structures has been viewed as another important indicator in assessing learners' conceptual understanding (Shavelson et al., 1990; Tsai, 2001). Based upon the review conducted by Tsai and Huang (2002), the 'flow map method,' described in details later, may be the most useful method to represent learners' cognitive structures. Therefore, 'flow map method' was used to explore students' cognitive structures about nuclear power usage in this study.

To probe learners' cognitive structures about nuclear power usage, students' narratives were obtained through tape-recorded interviews, and the following non-directive questions were asked by an independent researcher:

(1) Can you tell me what you know about nuclear power or nuclear power usage?
(2) Could you tell me more about the ideas you have mentioned?
(3) Could you tell me the relationships between the ideas you have mentioned?

Then, all the tape-recorded narratives were transcribed into the format of 'flow maps.'

Figure 2 shows a student's flow map about nuclear power. Basically, the flow map is constructed by entering the statements in sequence uttered by an individual learner. The sequence of discourse is examined, and recurrent ideas represented by recurring word elements in each statement (presenting a connecting node to prior idea) are linked by connecting arrows. For example, the student's narrative mapped in Figure 2 shows a sequential pattern beginning with the nuclear power plants in Taiwan to the basic rationale of nuclear power. The student also stated the waste materials produced by nuclear power plants. Moreover, recurrent arrows are inserted that link revisited ideas to the earliest step where the related idea first occurred. Statement 2, for example, 'The fourth nuclear power plant is built now in Taiwan,' includes one major revisited idea 'nuclear power plant.' Therefore, Statement 2 has one recurrent arrow drawn back to Statement 1 (i.e., 'There are three nuclear power plants in Taiwan'). Then, each student's recall information analyzed through the flow map method could provide the following two quantitative variables representing his/her cognitive structure (Tsai, 2001):

(1) *Extent*: the total number of ideas in the learner's flow map, for example, five in Figure 2.
(2) *Richness*: the total number of recurrent linkages in the learner's flow map, for example, three in Figure 2.

In addition, to acquire a deeper understanding about an individual student's information processing strategies, the information processing modes shown in the flow maps were also investigated through a series of content analysis. Each of the student's statements, shown in the flow maps, was categorized into one of the following four levels of information processing modes (from low to high) (Tsai, 2001; Wu & Tsai, 2005b):

(1) *Defining*: providing a definition of a concept or a scientific term, for example, 'nuclear power is a form of energy produced by an atomic reaction.'
(2) *Describing*: depicting a phenomenon or a fact, e.g., 'there are three nuclear power plants in Taiwan.'
(3) *Comparing*: stating the relationships between (or among) subjects, things, or methods, for example, 'compared with thermal power, nuclear power can generate electric power more effectively.'

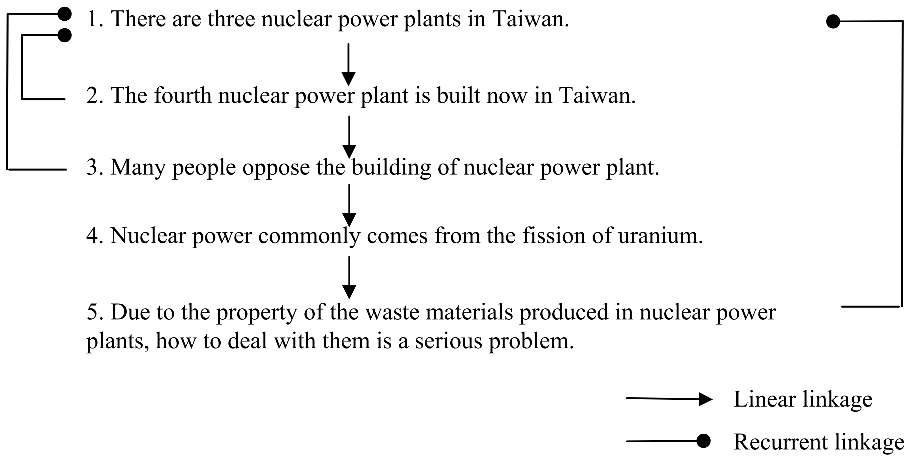

Figure 2. A student's flow map about nuclear power

(4) *Inferring or explaining*: describing what will happen under certain conditions or offering an account to justify the causality of two facts or events, for example, 'due to the dangerous property of the waste materials produced by nuclear power plants, how to deal with them is a serious problem.'

For example, Statement 1 in Figure 2, 'there are three nuclear power plants in Taiwan,' was coded as the 'describing' category. Then, the frequencies of the four information processing modes used by the learner were counted. In this study, the two information processing modes, 'defining' and 'describing' were viewed as lower-level modes of information processing, while the other two information processing modes (i.e., 'comparing' and 'inferring or explaining') were viewed as higher-level modes of information processing. Students who frequently used higher-order modes of information processing (i.e., 'comparing' and 'inferring or explaining') were viewed as having better strategies for organizing information during recall.

After students' interviews, narratives were transcribed into flow maps, the reliability of flow map diagramming was determined by asking a second independent researcher to draw a subset of students' narratives. In this study, the independent researcher was asked to transcribe a total of 10 students' narratives into flow maps. The inter-coder agreement for sequential linkages of diagramming flow map was 0.92. Moreover, the inter-coder agreement of recurrent linkages was 0.90 (for the details of calculation of the reliability coefficient, please refer to Anderson & Demetrius, 1993; Tsai & Huang, 2001). In general, it is considered sufficient for narrative analysis if the reliability is greater than 0.80. Based on this evidence, this method was deemed to be sufficiently reliable for the purpose of this study. Similarly, the inter-coder reliability for the content analysis of information processing modes was also obtained in this study. The percentage of two researchers that coded the students' ideas into the same category of information processing modes was

94%. Therefore, the content analysis of information processing modes in this study was viewed as adequately reliable.

Evaluating students' informal reasoning regarding nuclear power usage. In a pilot study, Wu and Tsai (2007) have developed an open-ended questionnaire for assessing learners' informal reasoning on nuclear power usage. In this study, the open-ended questionnaire developed by Wu and Tsai (2007) was slightly modified and used to collect the data regarding students' informal reasoning on nuclear energy usage. In this study, the participants were asked to write down their answers about the following questions:

(1) If someone asks you what is your position toward the building of the fourth nuclear power plant in Taiwan, will you intuitively make a decision regarding this issue or will you think about it before making a decision on this issue? (*Assessing the participants' decision-making modes*)
(2) If somebody agrees with the building of the fourth nuclear power plant in Taiwan, what arguments or perspectives do you think he/she may hold? (*Assessing initial supportive argument, or counterargument, construction*)
(3) If somebody disagrees with the building of the fourth nuclear power plant in Taiwan, what arguments or perspectives do you think he/she may hold? (*Evaluating initial supportive argument, or counterargument, construction*)
(4) Do you agree with the building of the fourth nuclear power plant in Taiwan? (*Assessing students' personal position on the building of a nuclear power plant*)
(5) If you want to convince your friend with your position, what arguments will you propose to convince him/her? (*Evaluating students' ability to generate supportive arguments for their positions*)
(6) If someone holds an opposite position from you on this issue, what arguments may he/she have? (*Assessing the ability for counterargument construction*)
(7) According to the arguments you have mentioned in Question 6, can you write down your opposing ideas to justify your position? (*Evaluating the ability for rebuttal construction*)

To minimize possible errors derived from data collection, before the administration of the open-ended questionnaire, the participants were asked to make responses by following the instruction: (1) read one question once and in order, and (2) then write down their answers.

To obtain more potential insights on learners' informal reasoning, an integrated analyzed framework for analyzing students' informal reasoning on nuclear power usage was developed in Wu and Tsai (2007) by summarizing the analysis methods used in previous studies (i.e., Means & Voss, 1996; Patronis, Potari, & Spiliotopoulou, 1999; Sadler & Zeidler, 2004, 2005; Yang & Anderson, 2003). The framework included several qualitative indicators (i.e., decision-making modes, reasoning mode, reasoning quality) and quantitative measures (i.e., number of reasoning modes, number of supportive arguments, number of counterarguments, number of rebuttals, and total number of arguments) (Wu & Tsai, 2007). In this study, the aforementioned framework was also slightly modified and used to analyze the participants' informal reasoning on nuclear power usage. As shown in Figure 3, each participant's decision-making mode, use of different reasoning modes, and the quality of his/her reasoning were analyzed first. Then, the amounts of the arguments he/she constructed for different purposes and the amounts of different reasoning modes he/she used were acquired for representing his/her informal reasoning outcomes regarding nuclear power usage.

A detailed description of these indicators and measures in this study is as follows:

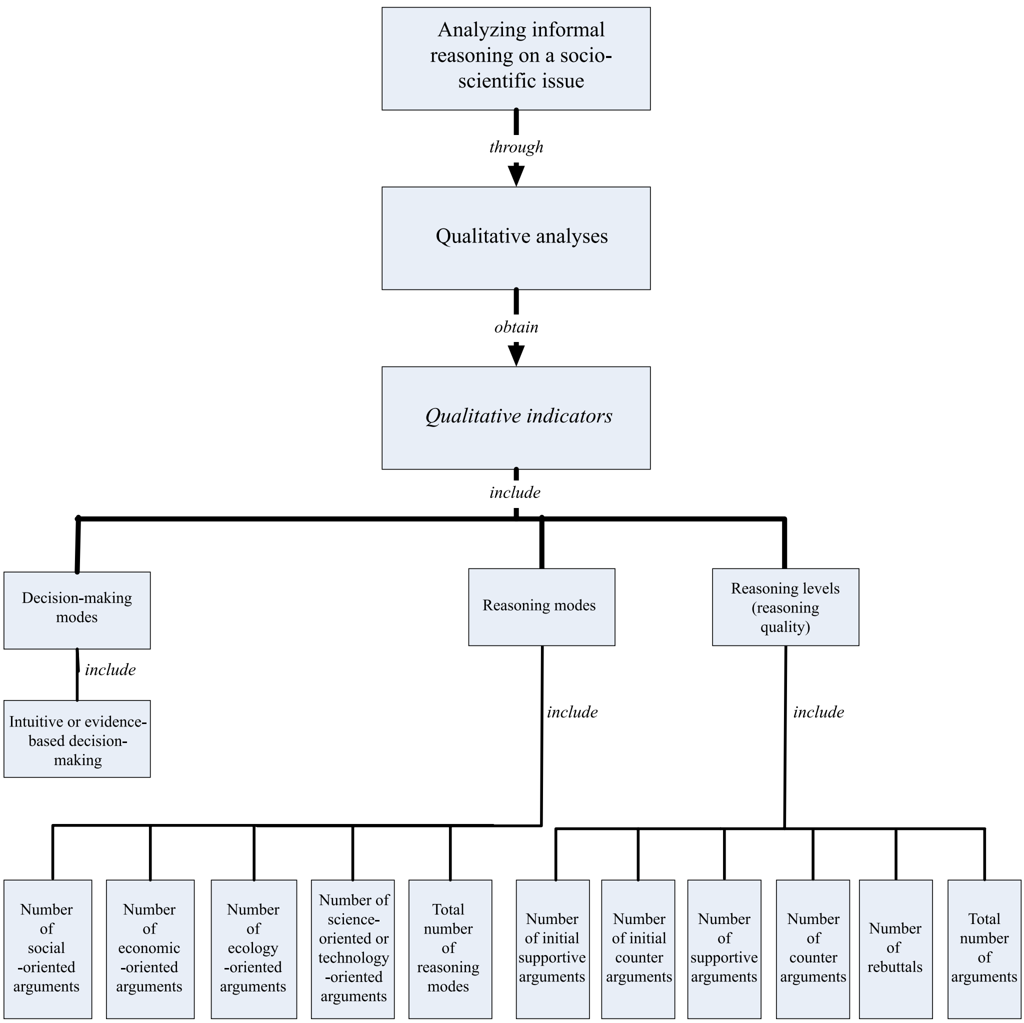

Figure 3. An integrated framework for analyzing students' informal reasoning on nuclear power usage (modified from Wu and Tsai, 2007, p. 1170)

(1) *Qualitative indicators*: Three qualitative indicators were used for assessing students' informal reasoning on nuclear power usage, including:
   (a) *Decision-making mode*: Assessing students' orientations for decision-making. In this study, students' decision-making modes were 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 an SSI.
   (b) *Reasoning quality*: By modifying the analysis methods in Sadler and Zeidler (2004, 2005), this indicator assessed students' abilities and skills to generate arguments for three different purposes, including supportive argument construction, counterposition construction, and rebuttal construction, and was 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 counterargument. Therefore, in this study, students' rebuttal construction was viewed as the indicator for their informal reasoning quality. If a student proposed more rebuttals, he/she was regarded as having better reasoning quality in this study.
   (c) *Reasoning mode*: Learners may generate their arguments from different aspects, such as 'social-oriented,' 'ecology-oriented,' 'economic-oriented,' and 'science- or technology-oriented' perspectives.

(2) *Quantitative measures*: After qualitative analyses, the following quantitative measures were also obtained for representing students' informal reasoning on nuclear power usage:
   (a) *Number of social-oriented arguments*: The amount of social-oriented arguments constructed by an individual learner. An example for social-oriented argument is 'I disagree with the building of the fourth nuclear power plant in Taiwan because nobody wants to live nearby a nuclear power plant or a nuclear waste storage.' The more social-oriented arguments an individual learner generated, the more he/she was oriented to reason from social-oriented aspects. (Obtained by analyzing an individual student's responses on Questions 5–7 of the questionnaire.)
   (b) *Number of ecology-oriented arguments*: The sum of ecology-oriented arguments expressed by an individual learner. An example for ecology-oriented argument is 'I disagree with the building of the fourth nuclear power plant in Taiwan because the coral reefs living nearby the nuclear power plant may be damaged.' The more ecology-oriented arguments an individual learner proposed, the more he/she tended to reason with ecology-oriented care. (Obtained by analyzing an individual student's responses on Questions 5–7 of the questionnaire.)
   (c) *Number of economic-oriented arguments*: The amount of economic-oriented arguments constructed by an individual learner. An example for economic-oriented argument is 'I agree with the building of the fourth nuclear power plant in Taiwan because it can provide sufficient electric power for the

development of industry in Taiwan.' The more economic-oriented arguments an individual learner generated, the more he/she was oriented to think with economic considerations. (Obtained by analyzing an individual student's responses on Questions 5–7 of the questionnaire.)

(d) *Number of science or technology-oriented arguments*: The sum of science-oriented and technology-oriented arguments shown by an individual learner. An example for economic-oriented argument is 'I agree with the building of the fourth nuclear power plant in Taiwan because the use of nuclear power is safe.' Students may learn relevant scientific knowledge regarding an SSI in their science classrooms. Undoubtedly, the construction of science or technology-oriented arguments is particularly related to their ability to apply what they have learnt in science classrooms. The more science- or technology-oriented arguments an individual learner proposed, the more he/she was prone to reason from science- or technology-oriented perspectives as well as he/she was more able to apply what they had learnt in science classrooms. (Obtained by analyzing an individual student's responses on Questions 5–7 of the questionnaire.)

(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 utilized, the more he/she was oriented to reason from multiple perspectives. For example, when reasoning on an SSI, if an individual proposed one socio-oriented argument and two economic-oriented arguments, he/she would be viewed as utilizing two reasoning modes. (Obtained by analyzing an individual student's responses on Questions 5–7 of the questionnaire.)

(f) *Number of initial supportive arguments*: The amount of supportive arguments a learner constructs before he/she makes personal a position on nuclear power usage. (Obtained by analyzing an individual student's responses on Questions 2 and 3 of the questionnaire.)

(g) *Number of initial counterarguments*: The amount of counterarguments a learner proposes before he/she makes personal a position on nuclear power usage. (Obtained by analyzing an individual student's responses on Questions 2 and 3 of the questionnaire.)

(h) *Number of supportive arguments*: The amount of supportive arguments a learner constructs. The more the supportive arguments a learner proposed, the more he/she was able to provide supportive evidences for his/her position. (Obtained by analyzing an individual student's responses on Question 5 of the questionnaire.)

(i) *Number of counterarguments*: The amount of counterarguments a learner proposes. This measure assessed the ability of a learner to reason from the counterposition. (Obtained by analyzing an individual student's responses on Question 6 of the questionnaire.)

(j) *Number of rebuttals*: The amount of rebuttals a learner generated. The more the rebuttals a learner constructed, the more he/she was able to justify for his position. (Obtained by analyzing an individual student's responses on Question 7 of the questionnaire.)

(k) *Total number of arguments*: The total amount of the three kinds of arguments above (i.e., supportive arguments, counterarguments, and rebuttals). This measure evaluated an individual learner's ability to make arguments regarding an SSI. (Obtained by analyzing an individual student's responses on Questions 5–7 of the questionnaire.)

To assess the reliability of the aforementioned analyses in this study, another researcher was asked to analyze 15 students' responses on the open-ended questionnaire independently, and their inter-coder agreements for these analyses were assessed. In this study, all the inter-coder agreements for the analyses were greater than 0.80, indicating that the qualitative analyses of students' informal reasoning in this study were sufficiently reliable. Besides, the discrepancies were discussed, and final agreements were achieved.

Results

Students' Informal Reasoning Outcomes

It was found that 55 participants (about 81%) in this study tended to make evidenced-based decisions toward nuclear power usage, while the other 13 students (about 19%) were oriented to make intuitive decisions toward this issue. That is, most of the participants were found to make evidence-based decisions.

The results in Table 1 showed that the students, on average, proposed more than one supportive argument (mean = 1.25) and one counterargument (mean = 1.18), while they generated less than one rebuttal (mean = 0.50). Moreover, they had, on average, a total of more than two arguments (mean = 2.85). It was also revealed in Table 1 that the participants in this study, on average, proposed 1.09 'science- or technology-oriented' arguments, 0.74 'economic-oriented' arguments, 0.81 'ecology-oriented' arguments, and 0.25 'social-oriented' arguments. In addition, they utilized, on average, more than two argumentation modes (mean = 2.21).

Students' Scientific Epistemological Beliefs

Table 2 presents students' average scores and standard deviations on the scales of a questionnaire for assessing SEBs. According to Table 2, students scored highest on the 'development' scale (an average of 4.24 per item), followed by 'justification' scale (an average of 3.98 per item), 'certainty' scale (an average of 3.81 per item), and 'source' (an average of 3.61 per item). Although students scored relatively lower in the 'source' scale (an average of 4.49 per item), the average score was still higher than the absolute mean of the 1–5 Likert scale (i.e., 3). The results indicated that the

Table 1. Students' argument construction for different purposes and usage of different reasoning modes (n = 68)

	Mean	*SD*	Range
Argument construction before making personal positions			
Initial supportive argument	1.26	0.58	1–3
Initial counterargument	1.41	0.65	1–3
Argument construction for different purposes			
Supportive argument	1.25	0.56	1–3
Counterargument	1.18	0.49	0–3
Rebuttal	0.50	0.66	0–4
Total number of arguments	2.85	1.12	0–7
Usage of different reasoning modes			
Number of science-oriented or technology-oriented arguments	1.09	1.05	0–5
Number of economic-oriented arguments	0.74	0.59	0–3
Number of ecology-oriented arguments	0.81	0.70	0–3
Number of social-oriented arguments	0.25	0.47	0–2
Total number of reasoning modes	2.21	0.61	1–3

Table 2. Students' scores on the scales of questionnaire for assessing scientific epistemological beliefs (n = 68)

Scale	Mean	*SD*	Range
Source	3.61	0.64	2–5
Certainty	3.81	0.53	2.5–5
Development	4.24	0.49	3–5
Justification	3.98	0.41	2.89–5

students in this study, in general, displayed relatively sophisticated epistemological beliefs toward science.

Students' Cognitive Structure Regarding Nuclear Power Usage

Table 3 presents the data about the participants' cognitive structure outcomes gathered from the interviews. It was revealed that the 'extent' of the students' cognitive structures regarding nuclear power was, on average, 2.85, and the 'richness' of their cognitive structures regarding nuclear power was 1.34. In addition, Table 3 also shows the students' frequencies of using different information processing modes. It was found that these students were more prone to use the information processing mode 'describing' (mean = 1.82) than the information processing mode 'inferring or explaining' (mean = 0.63) and 'comparing' (mean = 0.41). It should be noticed that, as shown in Table 3, none of the participants used the information processing mode, 'defining,' indicating that none of them mentioned any statement for the definition regarding nuclear power during interviews.

Table 3. Students' cognitive structure outcomes and information processing modes regarding nuclear power (n = 68)

	Mean	*SD*	Range
Extent	2.85	1.60	1–7
Richness	1.34	1.57	0–6
Defining	0	—	—
Describing	1.82	1.09	0–5
Comparing	0.41	0.63	0–2
Inferring or explaining	0.63	0.91	0–4

Students' Belief Bias Revealed in Informal Reasoning on Nuclear Power Usage

Evans and Curtis-Holmes (2005) have argued that a central phenomenon in dual-process accounts of reasoning is that of 'belief bias,' the tendency to evaluate the validity of an argument according to whether it agrees with the conclusion or not, rather than on whether or not it follows logically from the premises. This study also attempted to examine the aforementioned perspective. In this study, before they wrote down their personal positions toward nuclear power usage, the participants were asked to write down the arguments for supporting the both positions toward nuclear power usage (i.e., Questions 2 and 3 in the open-ended questionnaire for evaluating students' informal reasoning regarding nuclear power usage). Then, the participants were asked to write down their personal positions on building a nuclear power plant. According to a participant's response on his/her personal position on building a nuclear power plant, his/her initial supportive argument construction and initial counterargument construction were further analyzed. For example, if a participant agreed with building a nuclear power plant. Then, his/her responses on Question 2 in the open-ended questionnaire (i.e., 'If somebody agrees with the building of the fourth nuclear power plant in Taiwan, what arguments or perspectives do you think he/she may hold?') were viewed as the outcomes of his/her initial supportive argument construction, while his/her responses on the Question 3 in the open-ended questionnaire (i.e., 'If somebody disagrees with the building of the fourth nuclear power plant in Taiwan, what arguments or perspectives do you think he/she may hold?') were regarded as the outcomes of his/her initial counterargument construction.

To examine the existence of learners' 'belief bias' in their reasoning regarding an SSI, t-test analyses between students' argument construction (including both supportive argument construction and counterargument construction) before and after making their personal decisions on nuclear power usage were conducted in this study. Table 4 revealed that no significant difference was found between students' supportive argument construction before and after making their personal decisions on nuclear power usage. However, the students significantly proposed more counterarguments before making personal decisions than they did after making personal decisions ($p < 0.05$). It seems that, after making their personal decisions on an SSI, learners may tend to ignore some counterarguments they have known.

Table 4. Comparisons of students' argument construction before and after making their personal decisions on nuclear power usage

	Supportive argument		Counterargument	
	Mean (*SD*)	*t*	Mean (*SD*)	*t*
Before making personal decisions	1.26 (0.58)	0.16	1.41 (0.65)	2.99**
After making personal decisions	1.25 (0.56)		1.18 (0.49)	

**$p < 0.01$.

The Relationship between Students' SEBs and their Informal Reasoning Outcomes

In this study, *t*-test analyses were conducted to examine the differences in students' SEBs between the two different decision groups. Table 5 revealed that the students of evidence-based and intuitive decision groups did not show any significant difference on their scores on the four scales of questionnaire for assessing SEBs ($p > 0.05$).

This study also examined the correlation between the students' SEBs and their informal reasoning outcomes regarding an SSI. The results derived from the Pearson's correlation analyses were revealed in Table 6. It shows that the students' scores on the two scales, 'development' ($r = 0.27$, $p < 0.05$) and 'justification' ($r = 0.33$, $p > 0.05$), were significantly correlated with their construction of rebuttal, which is an important indicator for higher-level reasoning. It indicated that the more the students were oriented to believe that scientific knowledge as an evolving and changing subject, the more they were oriented to achieve a higher informal reasoning quality. Also, the more the students were oriented to recognize the role of experiments in the justification of scientific knowledge, the more they were prone to achieve a higher informal reasoning quality.

The Relationship between Students' Cognitive Structure Outcomes and their Informal Reasoning Outcomes

As shown in Table 7, the results derived from *t*-test analyses revealed that, in this study, the students of evidence-based and intuitive decision groups did not show any significant difference on the extent and the richness of their cognitive structures regarding nuclear and nuclear power usage ($p > 0.05$). Also, no significant difference was found on their usage of the two information processing modes, 'comparing' and 'inferring or explaining.' It seems that students' cognitive structures regarding an SSI may be not correlated with their decision-making modes toward this issue.

A series of the Pearson's correlation analyses were also conducted to examine the correlation between the students' cognitive structure regarding nuclear power usage and informal reasoning outcomes regarding this issue. Table 8 showed that the three variables regarding students' cognitive structures, including 'extent' ($r = 0.27$,

Table 5. Students' responses on the scales of SEBS between different decision-making mode groups

	Source		Certainty		Development		Justification	
	Mean (*SD*)	*t*	Mean (*SD*)	*t*	Mean (*SD*)	*t*	Mean (*SD*)	*t*
Evidence-based ($n = 55$)	3.69 (0.69)	–0.53 (ns)	3.82 (0.56)	0.24 (ns)	4.25 (0.50)	–0.70 (ns)	4.01 (0.40)	1.28 (ns)
Intuitive ($n = 13$)	3.59 (0.62)		3.78 (0.38)		4.15 (0.46)		3.84 (0.45)	

Note. ns: non-significant.

Table 6. Correlations between students' responses on the scales of SEBs and their informal reasoning outcomes ($n = 68$)

	Source	Certainty	Development	Justification
Supportive argument	0.04	0.01	–0.07	–0.06
Counterargument	–0.18	–0.03	–0.01	–0.04
Rebuttal	0.05	0.05	0.27*	0.33**
Total number of arguments	–0.03	0.01	0.16	0.18

*$p < .05$; **$p < .01$.

$p < 0.05$), 'richness' ($r = 0.30$, $p < 0.05$), and the usage of the 'comparing' information processing modes($r = 0.36$, $p < 0.05$), were significantly correlated with their rebuttal construction, an important indicator for higher-level reasoning. It indicated that the more extended and the more integrated the students' cognitive structures were, the more they were oriented to achieve a higher informal reasoning quality. In addition, the more frequently an individual learner tended to utilize the information processing mode 'comparing' in organizing concepts, the more he/she was oriented to proceed higher-level informal reasoning. Moreover, the results in Table 8 also showed that the 'richness' of students' cognitive structures was significantly correlated with their 'number of reasoning modes' ($r = 0.25$, $p < 0.05$), suggesting that the students, having richer cognitive structures, were more oriented to utilize multiple reasoning modes. Besides, Table 8 also revealed that the 'extent' ($r = 0.31$, $p < 0.05$) and the 'richness' of students' cognitive structures ($r = 0.33$, $p < 0.05$) were significantly correlated with their 'number of ecology-oriented arguments,' indicating that the more extended their cognitive structures regarding nuclear power usage were, the more ecology-oriented arguments participants proposed. It may be that 'nuclear power usage,' by nature, is a more ecology-oriented SSI. As a result, the more extended the participants' cognitive structures were, the more ecology-oriented concepts or ideas they might generate. As a result, they might have more tendencies to propose ecology-oriented arguments. In other words, it seems that the nature of the SSI for students to reason may affect learners' usage of a specific reasoning mode.

Predictors for Students' Informal Reasoning on SSI

This study also examined whether the students' SEBs or their cognitive structure outcomes are significant predictors for students' informal reasoning on this issue. To this end, a series of stepwise regression analyses were conducted, and all the variables regarding students' SEBs as well as those concerning their cognitive structure outcomes were used as the predictors. As aforementioned, the students' rebuttal construction was viewed as the indicator for their informal reasoning quality in this study. In addition, Wu and Tsai (2007) have proposed that learners' usage of multiple reasoning modes might help them propose more arguments and, in particular,

Table 7. Students' cognitive structure outcomes between different decision-making mode groups

	Extent		Richness		Comparing		Inferring or explaining	
	Mean (*SD*)	*t*	Mean (*SD*)	*t*	Mean (*SD*)	*t*	Mean (*SD*)	*t*
Evidence-based ($n = 55$)	2.84 (1.58)	−0.17 (ns)	1.33 (1.49)	−0.12 (ns)	0.45 (0.66)	1.48 (ns)	0.67 (0.96)	0.75 (ns)
Intuitive ($n = 13$)	2.92 (1.71)		1.38 (1.94)		0.23 (0.44)		0.46 (0.66)	

Note. ns: non-significant.

Table 8. Correlations between students' cognitive structure outcomes and their *argument construction for different purposes* (*as well as their usage of reasoning modes*) (n = 68)

	Extent	Richness	Describing	Comparing	Inferring or explaining
Supportive argument	0.04	0.06	–0.05	–0.04	0.15
Counterargument	–0.12	–0.08	0.01	–0.19	–0.05
Rebuttal	0.27*	0.30*	0.06	0.36**	0.16
Total number of arguments	0.10	0.12	–0.02	0.09	0.15
Number of science-oriented or technology-oriented arguments	–0.07	–0.01	–0.06	–0.03	–0.03
Number of economic-oriented arguments	–0.01	–0.02	–0.12	0.10	0.07
Number of ecology-oriented arguments	0.31*	0.33**	0.21	0.15	0.19
Number of social-oriented arguments	–0.01	–0.06	–0.03	0.05	–0.03
Total number of reasoning modes	0.15	0.25*	0.14	0.05	0.08

*p < .05; **p < .01.

generate more counterarguments, which may act as precursors to their rebuttal construction. Therefore, stepwise regression analyses for explaining the students' reasoning quality and their usage of multiple reasoning modes were conducted.

A stepwise multiple regression analysis was also conducted to examine the ability of students' SEBs and cognitive structure outcomes as predictors for their rebuttal construction. Table 9 shows the results derived from the stepwise multiple regression models for explaining the students' rebuttal construction by using their scores on the four scales of SEBs and their cognitive structure outcomes. It was revealed that both the students' usage of the information processing mode, 'comparing,' and their score on the 'justification' of SEBs were the significant predictors for their rebuttal construction ($p < 0.05$). It indicates the importance of learners' usage of the 'comparing' information processing mode and their beliefs on the justification of scientific knowledge in their rebuttal construction. Moreover, it should be noted that, at the first step of the model, the frequency of the students' usage of the 'comparing' information processing mode entered the equation (as revealed in Table 9), suggesting that the students' usage of the 'comparing' information processing mode was the best predictor for their informal reasoning quality. At the second step in the regression, the students' scores on the 'justification' scale of SEBs entered the equation, indicating that the students' beliefs on the justification of scientific knowledge was the second best predictor for their informal reasoning quality.

Similarly, a stepwise multiple regression analysis was also conducted to examine the ability of students' SEBs and cognitive structure outcomes as the predictors for their amount of using reasoning modes. As shown in Table 9, the richness of the students' cognitive structures was the only significant predictor for the amount of their reasoning modes ($p < 0.05$). It highlights the significance of the richness of learners' cognitive structures regarding an SSI in their reasoning from multiple perspectives.

Discussion

This study explored the relationship between high school students' SEBs and their informal reasoning regarding nuclear power usage. Also, the relationship between

Table 9. Stepwise regression model testing the predictors of students' rebuttal construction and usage of reasoning modes

Dependent variable	Predicting variables	B	SE	β	t
The amount of rebuttal	Comparing	0.31	0.12	0.30	2.58*
	SEB justification	0.42	0.18	0.25	2.19*
	Constant	−1.23	0.73		−1.70
The amount of reasoning modes	Richness	0.10	0.05	0.25	2.12*
	Constant	2.07	0.10		21.74**

*$p < .05$.

Note. $R^2 = 0.19$; adjust $R^2 = 0.17$.

their cognitive structures of nuclear power usage and their informal reasoning regarding this issue was examined. Moreover, the ability of students' SEBs as well as their cognitive structures for predicting their informal reasoning regarding nuclear power usage was investigated. Implications for teaching practice and suggestions for further research are discussed below.

Students' Belief Bias Revealed in Informal Reasoning on Nuclear Power Usage

Evans (1996) has argued that people decide first and think afterward in order to justify choices that are unconsciously determined. In addition, based on dual-process theory, Evans and Curtis-Holmes (2005) further proposed a central phenomenon in reasoning, 'belief bias,' which is the tendency to evaluate the validity of an argument on the basis of whether or not it agrees with the conclusion. In this study, the participants were asked to write down the arguments supporting both positions toward nuclear power usage before and after they wrote down their personal positions toward nuclear power usage. The results showed that the students significantly proposed more counterarguments before making personal decisions than they did after making personal decisions. In other words, after making their personal decisions on an SSI, learners may tend to ignore some counterarguments they have known. It seems that, as proposed by Evans (1996), students will make their personal decisions toward an SSI first, and, after making their personal positions, their 'belief bias' will cause them to ignore some counterarguments they have known. As a result, when being asked to propose counterarguments again, they will propose less counterargument than they do before they express their personal positions toward this issue. The finding above suggests that, in the learning tasks regarding reasoning and making decisions on SSIs, science teachers should try to improve students' usage of System 2 to evaluate evidences and justify their initial decisions. Thus, learners may achieve more rational reasoning and make more thoughtful decisions regarding SSIs.

Students' Cognitive Structure Outcomes between Different Decision-Making Mode Groups

As aforementioned, learners' application of learned knowledge in novel contexts (i.e., the transfer of learning) is always an important issue for educators (e.g., Haskell, 2001). However, no significant difference on cognitive structure outcomes was found between the students in the two different decision-making mode groups. It implies that students of more extended and more integrated cognitive structures may not necessarily make evidence-based decisions. In other words, some learners may have abundant knowledge regarding an SSI; however, they may not be able to apply their relevant knowledge in their decision-making on an SSI and still tend to make intuitive decisions. This situation is worthy of receiving more attention from science instructors. More attentions should be paid to improving learners' ability to apply their acquired scientific knowledge to making thoughtful decisions on the SSIs they encounter.

Students' SEBs and their Informal Reasoning Quality

With qualitative analyses, previous studies mainly focused on the relationship between students' beliefs on NOS and their informal reasoning on SSIs, and have suggested that students' informal reasoning on an SSI is related to certain aspects of beliefs about NOS, such as social embeddedness of science and tentativeness of science (Sadler et al., 2004; Zeidler et al., 2002). As aforementioned, 'beliefs on the NOS' and 'SEBs' highlight some different issues. In particular, SEBs are more concerned with beliefs about the nature of knowing science, such as the beliefs on the justification of scientific knowledge. The result of this study revealed that the students' scores on the two scales, 'development' (a scale related to the beliefs on the nature of scientific knowledge) and 'justification' (a scale related to the beliefs on the nature of knowing science), were significantly correlated with their construction of rebuttal, which is an important indicator for higher-level reasoning. The finding above not only concurs with what has been revealed in previous studies that students' beliefs about NOS are correlated with their informal reasoning quality (e.g., Bell & Lederman, 2003; Sadler et al., 2004; Zeidler et al., 2002) but also suggests a relationship between learners' SEBs about the NOS knowing (in particular on the justification of scientific knowledge) and their informal reasoning quality.

More importantly, this study found that students' beliefs only on the justification of scientific knowledge, related to the beliefs on the nature of knowing science, could positively predict the amount of rebuttal they constructed. Hofer and Pintrich (1997) have argued students' beliefs on the nature of knowing involves the role of evidence and the processes of justifying knowledge, and these processes are usually assumed to be cognitive processes of a higher quality than simple inductive reasoning or general critical thinking. From their perspective, learners' beliefs on knowing science play an important role in their reasoning and decision-making regarding SSIs. The finding in this study concurs with the perspective above, suggesting the importance of learners' beliefs on the nature of knowing science on their informal reasoning quality.

Students' Cognitive Structure Outcomes and their Reasoning Quality (as well as their Usage of Different Reasoning Modes)

Kolsto (2001) has argued that students' knowledge can serve as tools for their informal reasoning and decision-making on controversial issues. Previous qualitative studies, in which student conceptual understanding was mostly assessed by traditional assessment methods, such as multiple-choice questions, have suggested a relationship between learners' conceptual understanding of science content and their informal reasoning on an SSI (e.g., Hogan, 2002; Sadler & Zeidler, 2004; Zohar & Nemet, 2002). With the flow map method for probing students' cognitive structures, this study also aimed to explore the relationship between what students had already learnt about an SSI and their informal reasoning on this issue. In this study, it was revealed that the more extended and more integrated the students' cognitive structures were, the more they were able to propose rebuttals, which was an important indicator for their reasoning quality. In other words, both the quality (i.e., the richness of their cognitive structures and their use of higher-order information processing modes) and the quantity (i.e., the extent of their cognitive structures) of students' conceptual understanding regarding an SSI are correlated with their informal reasoning quality.

In addition, this study showed that the more frequently an individual learner tended to utilize the 'comparing' information processing mode, the more he/she was oriented to precede higher-level informal reasoning. It seems that the more learners tend to retrieve and organize relevant concepts or ideas from their cognitive structures by comparing both advantages and disadvantages of nuclear power usage, the more they are likely to achieve higher-level reasoning quality. The finding above suggests the importance of students' usage of the 'comparing' information processing mode on their informal reasoning quality.

Besides, Dole and Sinatra (1998) proposed that the usage of metacognition has a profound influence on learners' cognitive learning outcomes, and a meaningful processing or refinement of information should be involved in metacognitive activities. The usage of metacognition likely plays an essential role in the process of constructing cognitive structure. It is plausible that learners' metacognitive engagement will also influence how they make use of their learnt concepts and ideas regarding an SSI in dealing with this issue. In addition, the students' usage of metacognition might also help them to retrieve the arguments they had proposed from the opposite positions when constructing rebuttals. In other words, their usage of metacognition may facilitate their rebuttal construction and help them to achieve higher-level reasoning quality. However, still little research has addressed the role of students' usage of metacognition on their informal reasoning for an SSI. Therefore, further studies are also suggested to address this topic.

Significant Predictors for Students' Informal Reasoning on SSIs

This study initially attempted to address that, among the variables regarding students' SEBs and their cognitive structures, which is a better predictor for students' informal reasoning on this issue. The results of this study imply that students' cognitive structures, in particular their information processing mode, may be the most significant factors influencing their informal reasoning quality, and their SEBs, in particular their beliefs on knowing science, are also important factors influencing their informal reasoning quality. In particular, the students' usage of the information processing mode, 'comparing,' was found to be the most significant predictor for their rebuttal construction, highlighting the importance of students' usage of the 'comparing' information processing mode on their informal reasoning quality. Hence, to improve learners' informal reasoning quality, they should be encouraged to compare the arguments supporting two contrasting positions toward an SSI when they try to retrieve or organize relevant concepts or ideas from their cognitive structures. Recently, educational psychologists have proposed dual-process theories to account for the mechanism of human's thinking and reasoning. Wu and Tsai (2007) have argued that the construction of rebuttal may be viewed as one of the productions of operating System 2. From their perspective and the results of this study, students' frequent usage of the 'comparing' information processing mode as well as their sophisticated beliefs on the nature of knowing in science is likely correlated with their better usage of System 2 in the deliberation stage.

It should be also noticed that 17% of the variations of students' rebuttal construction was explained by their cognitive structures and SEBs (Table 9). It seems that some other factors may also account for learners' informal reasoning quality on an SSI, such as students' usage of metacognition or their personal experiences regarding this issue (proposed by Sadler & Zeidler, 2004). With the factors above, we may be able to get more complete and systematic insights into learners' informal reasoning on an SSI.

In conclusion, learners' informal reasoning regarding an SSI is a complex cognitive process or cognitive activity. The findings derived from this study may provide some insights into learners' informal reasoning on SSIs. However, to improve our better understanding of the nature of students' informal reasoning on an SSI, further research will be needed. For example, further studies may be conducted to explore the role learners' usage of metacognition as well as their personal experiences regarding this issue plays in their reasoning and decision-making regarding an SSI. Also, how different science learning environments affect students' reasoning quality regarding SSIs may also be investigated. In particular, some studies can be conducted to examine the effects of Internet-based inquiry in supporting learners' reasoning dealing with SSIs they encountered. With a better understanding derived from further research, science instructors may modify their teaching practice to improve learners' ability in dealing with socio-scientific dilemmas. Thus, students' scientific literacy may be improved.

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