Senior high school students’ preference and reasoning modes about nuclear energy use

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This study examined senior high school students’ cognitive orientation toward scientific or social information, designated as information preference, and associated preferential reasoning modes when presented with an environmental issue concerning nuclear energy usage. The association of the information preference variable with some academic and personal background attributes of the participants was also examined. A questionnaire, preference survey test and interview methods were used to gather the data. Students’ preference test scores fell within $-0.66$ to $2$ on a scale of $-4$ (social orientation) to $4$ (scientific orientation). Statistical analyses showed that students’ performance in science was a good predictor of the information preference exhibited by students. Interview content analysis showed that students’ preferences and reasoning modes were mutually consistent. Particularly, subjects of neutral preference, whose preference scores fell between $0$ and $1$, displayed a reasoning mode that is considerably integrated containing references to both scientific and socially relevant content.

Introduction

This study examined secondary school students’ preferred type of information (social vs. scientific) as examined by a questionnaire and to what extent their verbal reasoning mode during an interview were similar to their preferred type of information when presented with an environmental issue related to nuclear power plant construction in Taiwan. Nuclear energy was used as a topic since this presently is of widespread interest in Taiwan and thus should be familiar to the students. A second aspect of this study examined the relationship between certain academic and social background variables of the students and their preferred mode of reasoning.

Literature survey

Modern scientific literacy standards and the science technology and society (STS) educational movement inspired this research. Definitions of ‘scientific literacy’ vary over time due to different social and cultural conditions in a given period. At the present time, definitions of scientific literacy include not only affective and cognitive dimensions of an individual’s understanding of science but also an appreciation of the relationship of society broadly to the scientific enterprise (e.g. Daedalus 1983, Rutherford and Ahlgren 1990, Bybee 1993). Accordingly,
mastering scientific concepts and skills does not ensure that a person is scientifically literate. Of increasing importance is whether this person is capable of taking social responsibilities through his/her correct use of scientific knowledge (Fleming 1989, Bybee 1993, Bingle and Gaskell 1994, Yager 1996).

A major aim of STS education is to promote this kind of social responsibility by promoting instructional design that emphasizes student understanding of the dynamic relationship among society, science and technology (Aikenhead 1979, Bybee 1985, Rosenthal 1992, Yager 1996). STS curricula especially emphasize decision-making processes concerning societal issues related to science and technology. These issues, typically grounded in inconclusive knowledge claims, are defined as ‘socio-scientific’ issues by STS educators (Wessel 1980, Ziman 1980, Aikenhead 1985, Bybee 1995). In keeping with this rationale, the current study was designed to investigate students’ reasoning within a context of the social and scientific dimensions of nuclear power development.

An assumption of this study is that a person’s decision-making behaviour is a manifestation of one’s knowledge structures and his/her epistemological beliefs about what kinds of information are important in making decisions. This assumption is grounded in current constructivist theories of epistemology; namely, that each individual constantly and actively creates personally-relevant representations of the external world based on prior knowledge, perceived importance of the incoming information in problem solving and adapting to one’s social and natural environment, and social enculturation. Also, cognition is a process of organizing information about the external world, rather than a logical positivistic representation of ‘external reality’ (Piaget 1971, Vygotsky 1978, Ginsburg and Opper 1988, Hirschfeld and Gelman 1994, von Glasersfeld 1995). These structures dynamically interact with incoming information to enhance or suppress certain aspects depending on the compatibility with existing knowledge. Consequently, an individual’s prior knowledge and information processing schemas become important in determining how information is accessed and used in decision making.

Johnson-Laird and Byrne (1992) have proposed a plausible ‘mental models’ theory about decision making in everyday context. Accordingly, problem solvers construct mental models of premises in a problem based on his/her knowledge and beliefs, and then form a conclusion to the problem that is most consistent with these models. Thus, in making a decision, an option stands out when it matches the decision-maker’s mental understanding of the related problem.

Decision making usually ends up being a process of option selecting. According to psychological theory, a selection is made based on the expected utilities of the range of possibilities calculated by the thinker (Savage 1954, Keeney and Raiffa 1976). In such a process, personal beliefs, values and emotions play a significant role in determining the weights of possibilities (Simon 1978, Bell 1982, Baron 1988, Tversky and Shafir 1992). The infusion of beliefs, values and emotions in reasoning is not always irrational in that it is the personal beliefs, values and emotions that empower our knowledge. Recent neurocognitive research supports the theory that emotional valence (partially mediated by the limbic system of the brain) is important in rational information processing and that emotional tone constantly accompanies, and may be necessary for, efficient decision-making (e.g. Damasio 1994). Hence, science instructional design should take into account affective in addition to cognitive dimensions of learning,
especially in the potentially, emotionally laden arena of problem solving with STS issues (Anderson 1997).

In sum, based on constructivist viewpoints and cognitive psychological studies, individual decision making is complex encompassing a multi-faceted interaction among a range of information processing variables including prior knowledge, information processing schemas, emotional valence and the perceived relevance of the problem to the individual’s ability to adapt to the environment. Among the complex dimensions of information processing during problem solving, we identify three that are relevant to this research:

1. The students’ preferences for different kinds of information, such as scientific versus socially-based;
2. Their understanding of how information can be used in reasoning;
3. Their preferred mode of processing information during problem solving.

These three dimensions appear to be important in determining the kind of problem solutions generated by students. Based on this rationale, three research questions were examined.

**Research questions**

1. When exposed to the environmental issue concerning nuclear energy use, what are the characteristics of the information preference of the senior high school students in Taiwan?
2. To what extent are students’ verbal reasoning modes associated with their preferred type of information?
3. To what extent do the students’ background characteristics predict their information preference during decision making?

**Methodology**

The population was 12th grade, academic high school students in Taiwan. Twelfth grade students were deemed to be sufficiently cognitively mature, possess adequate ability to render moral judgments and sufficiently able to understand social relationships to engage effectively in STS-based problem solving (Inhelder and Piaget 1958, Turiel 1983). Eighty-six males and 96 females from four intact classes in two academic senior high schools in Taiwan participated in the study. About half of the participants were enrolled in a science study oriented curriculum and the majority of these (78%) were male, while the other half were in a social science study oriented curriculum with a majority of females (87%). Science study oriented students received one year more of science education than those who were social science study oriented. Like most of the high school classrooms in Taiwan, teaching and learning in the target classrooms is teacher-centred. Participating teachers reported that socio-scientific issues were seldom brought up in the classrooms.

In this study, there were three variables. The first was information preference that was defined as preference for either scientific or social information concerning the merits of building nuclear power plants as assessed by a paper and pencil instrument. The reasoning mode variable pertained to the type of information participants actually used in a decision-making situation as assessed by interview data. The third variable was student background characteristics as listed in table 1,
including gender, school performances, self-expectations, learning styles, family attributes and personal belief system.

A preference survey test was used to determine the students’ preference for social or scientific based information. The survey test consisted of 12 social and 12 scientific viewpoints selected mainly from Boardman’s (1985) questionnaire that was modified to include some locally relevant issues to make the test more culturally relevant. Subjects were asked to rate the importance of each viewpoint on a scale of 0 to 4. In order to encourage engagement in thinking, participants were instructed to rate firstly those statements that were familiar to them and then the unfamiliar ones (see appendix for more information). Unexpectedly, this technique was found to be associated with difference in the gender effect, which will be described later in the article. The reliability of the test for the internal consistency (Cronbach alpha value) was 0.85.

The social information items were weighted with a $-1$ and the scientific items with a $+1$ for the purpose of statistical analysis. A pilot study was done to verify the appropriateness of the test. The responses were analysed as a statistical frequency distribution. For purposes of further analyses as explained below, individuals whose scores fell within one standard deviation around the mean were assigned to a middle group without a clear preference. Those who were below this interval (toward the negative pole) were categorized as ‘socially-oriented’ while those who were above it (toward the positive pole) were categorized as ‘scientifically oriented’.

<table>
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<th>Table 1. Background characteristics.</th>
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<tr>
<td><strong>Category</strong></td>
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Champagne and Newell (1992) suggest alternative methods, such as performance assessments and portfolio, to assess scientific literacy because standardized test cannot really probe students’ ability pertained to thinking and reasoning. Thus, to explore students’ reasoning modes, a semi-structured interview was conducted using a protocol similar to Fleming’s (1984) that concerned a hypothetical nuclear power plant water pollution incident, except the story was based on actual events that occurred in Taiwan to make it more culturally relevant. Subjects were asked to ‘reason aloud’ if the nuclear power plant or some other cause caused the incident. During the interview, some scientific data about nuclear energy were also presented to subjects. The interview plan including three phases is outlined in table 2.

To analyse the qualitative data, a content coding analysis was applied (LeCompte and Preissle 1993, Bernard 1994). The basic unit of analysis is the response to each proposed question. The type of information (scientific, social information or a combination) used by interviewees in reasoning about the cause of the proposed incident during each interview phase was the main coding target. Two trained coders cross-examined the interview data and the intercoder reliability was higher than 80% based on Cohen’s method (1960). Some coding examples will be presented in the result and discussion section. To ensure the validity of the interview procedure, a preliminary pilot study with the same design as the full-scale study described here was done in an urban school in New York City. There were 21 students in the pilot study with nine participating in the interview. In the full-scale study, 27 students with varying preference scores

<table>
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<th>Table 2. The interview plan.</th>
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<tr>
<td>Phase 1: Introduction of the incident</td>
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<td>Procedure: Two news reports were given to students to read. One report described pollution caused by a nuclear power plant where some significant amount of radioactive water was released without being cooled down. The other report simply stated that, a few days later, some dead fish was found on the seashore near the power plant.</td>
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<tr>
<td>Question: what do you think caused the fish to die?</td>
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</table>

| Phase 2: Presentation of the scientific data  |
| Procedure: A scientific narrative was given to students to read. The reference consisted of data about radioactivity, nuclear energy and other energy forms used by humans.  |
| Question: do you change your mind after reading the scientific reports?  |

| Phase 3: Presentation of various opinions  |
| Procedure: Some more news reports concerning opinions from various sources – including the AEC in Taiwan, a plant manager, student researchers and environmentalists – were given to students. The AEC group said the amount of radiation released was within official limit. The plant manager mentioned the possibility of illegal fishermen. The student researchers reported that the released radiation was not threatening. Some environmentalists also conducted a private study after the incident and claimed found that a high radiation rate exists around the water.  |
| Question: at this point, what do you think caused the fish to die?  |
were selected as described above for interview to examine students’ verbal reasoning mode and relate it to their reasoning preference.

Twenty-three background characteristics were assessed by the following instruments:

1. The Second International Science Study (SISS) questionnaire on family background characteristics, student interests and study habits (e.g. Anderson 1990);
2. The science performance records at the schools;
3. Pomeroy’s questionnaire (1993) for epistemological views of science;
4. A nuclear science knowledge test constructed by the author using items extracted from some widely available sources.

These background variables include both continuous and categorical types as shown in table 1.

The nuclear knowledge test contained multiple-choice items about the properties of atoms and radioactivity. There were additional questions concerning energy transformation that required some mathematical calculations based on examples from textbook and several popular teaching references in Taiwan. Items and questions in the test were selected by the author and examined for face validity by science teachers who taught the subject in the schools. However, as the teachers pointed out, since the nuclear energy topic was not assessed formally by examinations in their curricula, little attention was typically given to this subject in their classes. A low performance could be expected. Noticeably, the distribution of the test scores (skewness = 0.48, mean = 35.5, median = 33.5, SD =15.7) indicated that the distribution approximated a normal curve.

To analyse the relationships between information preference and background attributes, statistical regression, ANOVA and a general factorial analysis were applied in accordance with the variable types (continuous or categorical). Given the diversity of variables provided by these instruments, a multivariate analytical approach would also have been appropriate. However, with only one dependent variable, it is not possible to apply multivariate statistics.

Results and discussion

Information preference

The first research question concerned students’ information preference. The frequency distribution of students’ preference survey test scores was approximately a normal curve with the mean and median at around 0.5 as shown in figure 1. It appears that the central tendency is towards a more neutral position with respect to information processing preference. For the convenience of the interview process, students with scores ranging from 0.0 to 1.0, which was about one standard deviation from the mean, were characterized as having a ‘equally disposed’ style. There were 125 (69%) with 65 females and 60 males who belonged to this category as was expected for one standard deviation around the mean. Thirty-four students (18 females and 16 males) with scores higher than or equal to 1 were assigned to the ‘scientifically oriented’ group (approximately 18%). There were 23 (c. 13%; 13 females and 10 males) whose scores were below 0.0 and were assigned to the ‘socially-oriented’ group.
The preference survey test implied that most students in this study were open to both types of information. Although for purposes of further analysis, some participants were classified here as either ‘scientifically oriented’ or ‘socially oriented’ based on their position in the statistical distribution, their reasoning scores ranging from −0.66 to 2 indicate that none of them strongly favoured one type of information.

The finding that all participants took both scientific and social information into consideration suggests that the majority of 12th grade academic students in the study were able to recognize the multi-dimensional nature of the nuclear energy issue. This finding is somewhat different from Fleming’s study (1986a, b), where the author found that most subjects in his study tended to approach socio-scientific issues with social concerns. To further explore the epistemological texture of the students’ orientation, an interview study was conducted as presented below and also showed that the students were able to use a variety of reasoning patterns though there was a significant relationship between information preference and kind of information used in reasoning during the interview.

**Reasoning modes**

To determine the similarity between students’ information preference and reasoning modes, the kind of information used in reasoning during the problem task involving nuclear energy by subjects in different preference groups was examined.
The result of the coding analysis is presented in table 3, which displays the numbers of subjects within each preference category and the type of information used in reasoning. As table 3 shows, ‘scientifically oriented’ students tended to reason more with the aid of scientific information while ‘socially oriented’ ones considered more social factors other than the scientific evidence. The ‘equally disposed’ students used rather diverse sources of information, and more subjects were able to consider different perspectives. Examples from transcripts are presented below.

Interview – phase 1: introduction of the incident; Question: what do you think caused the fish to die?

Answer by the scientific-oriented student A (Preference net score = 1.50):

It was the wastewater . . . the newspaper said that it was the radioactive wastewater. The water was used to cool the reactor, it could have very high temperature . . . They also mentioned the radiation . . .

Answer by the scientific-oriented student B (Preference net score = 1.58):

The cause was probably the wastewater because the amount of radiation humans can take might be very different from what the fish can take.

Answer by the socially-oriented student A (Preference net score = −0.66):

I believe it was the plant which caused the death . . . because I was a member of ‘Debate Society’ club in school, and we had discussed this issue. Besides, we once visited a nuclear power plant and found the plant unsafe . . . I think it was the radioactive nuclear waste and the water with high temperature. The seawater temperature would be increased a lot . . .

Answer by the socially-oriented student B (Preference net score = −0.5):

I think maybe the nuclear power plant emitted something which is toxic and probably the fish were killed by that . . .

<table>
<thead>
<tr>
<th>Group</th>
<th>Information type</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
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<tbody>
<tr>
<td>Scientifically oriented</td>
<td>Scientific</td>
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<td>4</td>
<td>4</td>
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<td></td>
<td>Social</td>
<td>1</td>
<td>2</td>
<td>1</td>
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<td></td>
<td>Combination</td>
<td>1</td>
<td>2</td>
<td>4</td>
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<tr>
<td></td>
<td>No information use</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Socially oriented</td>
<td>Scientific</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<td></td>
<td>Social</td>
<td>4</td>
<td>4</td>
<td>7</td>
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<td></td>
<td>Combination</td>
<td>1</td>
<td>1</td>
<td>2</td>
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<tr>
<td></td>
<td>No information use</td>
<td>4</td>
<td>3</td>
<td>0</td>
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<tr>
<td>Equally disposed</td>
<td>Scientific</td>
<td>3</td>
<td>4</td>
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<td></td>
<td>Social</td>
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<td>No information use</td>
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*Male; F = Female
Answer by the equally disposed student A (Preference net score = 0.0):

I think the plant had something to do with the death . . . if warm water is released suddenly, the fish can’t adapt themselves to the temperature and as a result, they might die . . .

Answer by the equally disposed student B (Preference net score = 0.0):

I don’t know . . . maybe other kind of pollution killed them . . . like the industrial wastewater from other sources . . . the plant should have good prevention systems and any activities in the plant should have been constantly monitored.

Based on the students’ responses from this phase of the interview process, it is evident that students’ initial responses for how fish had been killed varied across different groups. Content analyses (table 3) indicated that scientifically oriented subjects used scientific information more frequently to back their theory while socially oriented ones tended to base what they knew on personal experiences or beliefs. Furthermore, a considerable number of these two groups of students did not use any evidence to support their conjectures. They often mentioned that the cause of death was obvious and circumstantial. Below are two examples.

Response by a scientifically oriented student:

I think they [radioactive wastewater and the incident] were directly related. Such an incidence would not happen under normal situations. . . . The leaking accident happened first and then the fish die, therefore, I think they are related directly.

Response by a socially oriented student:

It [the incidence] must be related to that [the nuclear power plant] . . . 99% . . . otherwise, it's impossible that fish would die only a few days after the accident happened. It ought to have something to do with the plant . . .

On the other hand, equally disposed students showed diverse reasoning modes and they were able to reason their hypothesis.

Interview – phase 2: presentation of scientific data; question: do you change your mind after reading the scientific reports?

Answer by the scientifically oriented student A:

I first thought the radioactive material and the warm water were the suspects . . . but . . . from the scientific report, it seems the radiation was not really related to the death . . .

Answer by the scientifically oriented student B:

I think maybe they died because of some kind of infection . . . the report said that the radiation was low. It should not have given too much impact on human or fish . . .

Answer by the socially oriented student A:

I don’t think I would change my mind . . . when I, with a group of students, visited a nuclear power plant. They could not answer satisfactorily the questions we gave them. . . . These scientific data here may be done by people from the plant . . . I believe what I saw . . . the workers in the plant had to be replaced every month . . . If the plant is safe, workers do not need to be replaced . . . A lot of information I know showed that residents around the plant have a higher probability of getting cancer and giving birth to handicap babies. Also, the sea water pollution and ecosystem changes there were severe . . .
Answer by the socially oriented student B:

I don’t know . . . probably it was the toxic stuff . . . I heard from TV that the nuclear power plant produce nuclear energy . . . if they are not careful, the plant could emit something very destructive . . . I also saw from newspapers pictures of mutant fish caused by the ocean pollution. I think maybe the environment around the plant has been polluted. As a result, fish were affected.

Answer by the equally disposed student A:

I first think it was the warm water and radiation had few impacts . . . but it [the scientific report] said that both coal plants and the nuclear power plants produce warm water pollution . . . Why the coal plants receive few complaints? [Interview: You tell me.] Generally people are more afraid of nuclear waste, radiation and so . . . I am starting to think if the radiation has something to do with the death . . . I don’t know. Numbers [on the report] can’t tell you everything. I can’t make judgment based on numbers . . . IF the fish died at the time when the leaking of radiation occurred, the radiation might not be the cause [because the impact should be slow]. But, if fish die after the leaking, it would be the radiation leaking, more or less . . . Both warm water and radiation were possible . . .

Answer by the equally disposed student B:

. . . According to the data, the plants emit less than 1 millirem. It seems that the amount was really low . . . I think it [the death of the fish] may be due to the overtime accumulation of radiation . . . but the report said that the accumulation rate is very low . . . Other kinds of pollution such as wastewater with heavy metal produced by some factories or something like that might be possible . . .

During the second phase of the interview, scientific data were given to students. At this point, regardless of whether students were prepared to change their initial answers, scientifically oriented students still attached more significance to scientific information in reasoning about the proposed issue even though some of them began to think more critically about the reliability of the scientific data. As shown in some of the foregoing examples, although some socially oriented students considered the scientific perspectives of the issue, they tended to display a distrustful attitude toward data from the scientific report when it appeared to contradict their initial views. In phase 2, more equally disposed subjects referred to either scientific information or both information sources when reasoning about the issues in the problem situation. Apparently, these students were more open-minded to various perspectives of the issue.

Interview – phase 3: presentation of various opinions by a variety of people to stimulate respondent’s thinking; Question: at this point, what do you think caused the fish to die?

Answer by the scientifically oriented student A:

The stories in these reports contradicted to each other. Seems that the radiation was irrelevant. . . . I think it was the warm water that killed fish. The biology teacher once told us that the high temperature has a big impact on the marine life. We also heard of the mutant fish due to the warm water. It is rare to hear that the radiation released from the nuclear power plant would result in damage of this sort.
Answer by the scientifically oriented student B:

They [student researchers] mentioned warm water. If the warm water was released to the sea, and the sea temperature changes because of that, the fish might not be able to adapt to the change and die . . . The warm water seemingly has something to with the death . . . However, I think the human factor (illegal fishermen) is also likely for even if the warm water was released, fish could swim away from it.

Answer by the socially oriented student A:

I once heard from a biology teacher saying that, since marine studies need funds to proceed, and most of the funds are provided by the nuclear power plants, even though the pollution from the plant is severe, a lot of real data could not be revealed. I believe it is the case. Maybe there were some students who detected higher radiation but they were afraid of speaking it out.

Answer by the socially oriented student B:

. . . Now I am not insisting . . . the illegal fisherman could be the killer . . . Usually I get information from TV news and the newspapers. They sometimes interview experts. I would like to hear what the experts say about the incident. If I feel the experts' words make sense, I would believe them.

Answer by the equally disposed student A:

I think . . . [According to the scientific data] the nuclear power plant releases warm water regularly. If the fish died because the released water, then each time when the plant releases water, some fish should die. It does not make sense here that in this particular incident, the warm water alone causes more fish than ever to die. It's possible that fish has been dying regularly because the environment is being changed [by the warm water] . . . the leaking of water also resulted in the sudden increase of the radioactive waste, consequently more fish died.

Answer by the equally disposed student B:

They [student researchers] found warm water released . . . I think . . . our biology teacher once mentioned that the nuclear power plants affect the environment not because of the radiation but because of the high temperature water. I think the death was not caused by only one element. It should be that many factors together result in the death. I don’t think the plant alone killed the fish. There must be something else, like industrial wastewater, together to cause the damage.

In this phase (phase 3, the final phase), various opinions from a plant manager, local politician and environmentalist were presented. The findings at this point are intriguing. Many scientifically oriented subjects began to take into consideration the social factors but the reasoning modes of 'socially oriented' students were even more socially oriented. They expressed more personal feelings and distrust of the scientific data. Some 'socially oriented' students would refer to information from TV and newspapers to support their thoughts. These observations suggest that in teaching, it would be unwise to overlook or underestimate the importance of personal feelings and attitudes toward scientific information since these factors may be deeply entrenched in the student’s belief systems and carry significant emotional valence in rendering judgments about socially relevant issues. Remarkably, students who were classified as equally disposed to both types of information displayed reasoning strategies that were more sophisticated and rather multi-dimensional compared to students with a more narrow information preference. Frequently, these students approached questions with different perspectives and were also more open to various possibilities.
The above analysis suggested that the varied reasoning modes displayed by different preference groups could be attributed to their underlying beliefs, values and emotions that are activated during the problem solving process. For example, ‘scientifically oriented’ students seemed to have greater confidence in the objective power of science and technology while ‘socially oriented’ respondents verbalized their emotional response and shared personal experiences in justifying their responses. Interestingly, ‘equally disposed’ subjects who also showed a high tendency to use scientific information in reasoning, offered more alternatives to explain the death of the fish than respondents in the other categories. Since different disciplines offer different ways of knowing (Phenix 1964, Bruer 1993), it is reasonable to say that people who are open to different knowledge perspectives could be more capable in pinpointing possible diverse sources of information in reaching solutions to a problem, especially when the question is inherently multidimensional such as the socio-scientific issue used in this case.

In conclusion, our investigation showed that students’ information preferences are consistent with the kind of information used in reasoning about complex issues. Namely, the stronger the polarity in using either scientifically or socially oriented information, the greater the tendency in using scientific or social information in reasoning. More significantly, our research finding leads to a conclusion that individuals with a more composite preference (equally-disposed) were particularly able to integrate prior conceptions and new information from diverse sources to form enriched mental models and to draw productive inferences from them. This is particularly encouraging since the majority of our subjects were categorized as equally disposed. The findings, moreover, also imply that highly polarized modes of reasoning mode, i.e. extremely scientific or social do not guarantee a thorough decision making response to complex socio-scientific issues.

Background characteristics and information preference

The third research question examined students’ background characteristics in relation to their information preference scores. Measures of students’ background information used both continuous and categorical data. Regression, ANOVA and a general factorial analysis were used as appropriate to the particular background variables to examine the data. Among 23 background variables as listed in table 1, only two background variables: science performance and knowledge about nuclear energy, were statistically associated with the information preference variable as displayed in table 4. Although the score distribution showed that female participants seemed to be more socially oriented or neutral in terms of information preference, no statistical association was found between either programme of study or gender and preference.

The finding above implies that students who performed well on science subjects including nuclear energy may develop stronger cognitive representations or mental models of the scientific knowledge relevant to the problem situation. They are able to more readily assimilate and evaluate scientific information relevant to the problem situation. This may explain why they were willing to reason with the aid of scientific information regardless of whether the ensuing mental representations or models they formed were formally correct from a scientific perspective or even whether they were able to employ the information appropriately in solving the socially complex environmental problem.
Gender differences. According to the statistical analysis, no gender difference was found with respect to students’ information preference. However, the preference survey data provide some indirect information that there may be some gender differences in the extent and kind of information that men and women students access when solving these kinds of complex problems.

It was mentioned in the methodology section that to encourage thinking activity, students were instructed to begin first with the questionnaire statements that were familiar to them and then proceed to the unfamiliar ones. It was found that most of the unfamiliar items were in the scientific perspective category. If the scores of these unfamiliar items were ignored, that is, only familiar items were analysed, a significant association could be found between gender and the current preference ($p < 0.01$) in which male subjects had relatively higher preference toward scientific information. In addition, between the two predictors of information preference, namely, knowledge of nuclear knowledge and performance of science in school, the former was found to be associated with the gender variable ($p < 0.05$) where male students performed better on the nuclear knowledge dimension.

Since the main focus of this study was not on gender differences in reasoning, the selection of the interview samples and the interview design (scientific information was given during the interview and may contaminate respondents’ opinions) might not be appropriate for an analysis of gender issues. More studies are needed to address the gender aspect. Nevertheless, our investigation showed that female interviewees (eight out of 13 cases) spoke more frequently than did males (five out of 14 cases) about the social dimension concerning the nuclear energy issues during phase 1.

### Table 4. ANOVA tables for the associations between information preference and science subject performances.

(a) Information preference vs. school science performance

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1.222</td>
<td>1</td>
<td>1.222</td>
<td>5.111</td>
<td>0.026$^b$</td>
</tr>
<tr>
<td>Residual</td>
<td>19.838</td>
<td>83</td>
<td>0.239</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>21.060</td>
<td>84</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$Dependent variable: scores of information preference; $^b$independent variable: (constant), science performance at school.

Note: data were collected from the science study classes only.

(b) Information preference vs. knowledge about nuclear energy

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>1.133</td>
<td>1</td>
<td>1.133</td>
<td>4.708</td>
<td>0.031$^b$</td>
</tr>
<tr>
<td>Residual</td>
<td>40.912</td>
<td>170</td>
<td>0.241</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>42.044</td>
<td>171</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$Dependent variable: scores of information preference; $^b$independent variable: (constant), knowledge about nuclear knowledge.
In case of the nuclear energy issue, several implications can be drawn from above data. First, obviously some scientific information was not accessible for the general public, especially females. Second, whether academic achievement and formal knowledge in science play a determinant role in the capacity to think flexibly and exhibit alternative preferences between social and scientific information needs a further investigation. Third, in the familiar context, females seemed to pay more attention to the social factors than the males did. Whether this phenomenon is related to the gender difference in ways of knowing or epistemological approaches is an interesting question worthy of some in-depth investigation. Moreover, since the main statistical analysis on the preference survey showed no gender difference, females might not be so ‘unscientific’ as many people would think as long as they are given chance to expose to the scientific information in a context that they find intellectually relevant and consistent with their experiences and socio-emotional orientation to phenomena. A social context for scientific problem solving may indeed be highly productive in helping female students become more engaged with scientific issues. Overall, the above findings further suggest that more in-depth investigation of gender issues in this kind of complex problem solving is warranted.

Further discussions on the equally disposed group

It has been mentioned that equally disposed students tended to take into account both scientific and social concerns when reasoning about a nuclear plant incident. Since their reasoning is likely to be more complex and more information on their cognitive processing of information may be helpful in addressing their educational needs, we include additional in-depth analyses of their reasoning. It should be mentioned first that due to research constraints, only 11 equally disposed transcripts were available for analysis, but they were randomly selected and should be representative of the group.

Multiple-cause theorists

Kuhn (1991) used ‘multiple-cause theories’ to describe one particular type of theory structures produced by thinkers in which multiple causes were identified for some social problems. Borrowing the term, we found that most equally disposed individuals (seven out of 11) in our study could be categorized as multiple-cause theorists for they were able to identify more than one alternative cause besides their own initial theory concerning the death of fish. The following subject (noted as SL) had an initial theory that the fish died naturally but also includes plausible other contributory factors upon further probing by the interviewer after Phase 3:

[SL] (Phase 2: After you read these reports, have you changed your thought?) I still think they might die naturally. According to the data, the amount of radiation produced by nuclear plants is less than that from nature. Therefore, I think the impact was not as severe as what the residents thought . . . (Phase 3: Do you change your mind after you read the last two reports?) Maybe a little. The reports said that there was warm water coming out of the nuclear plant. Since the temperature of water may affect the ecology of fish a lot . . . eventually the fish died . . . (Do you think of anything
else which might kill the fish?) It’s possible they were killed by humans, such as the illegal fishermen. I have not considered the impact of humans. As a matter of fact, humans are the original source of any kind of pollution.

The next subject (noted as LW) identified multiple causes for the death from the beginning of the interview:

[LW] (Phase 1: What would be the cause you think?) In fact, it’s hard to say. Many things out there could cause the fish to die. . . . Some people might try to catch fish by using electrical shock; oil leaking may also kill fish. . . . (Phase 2: What do you think about the cause now?) I don’t think the [scientific] data are showing anything about the death. Since the radiation was lower than the official limit, I think the plant was fine. (Are you saying that the plant had nothing to do with the death?) Not that it had nothing to do with the incident. They should be more or less related, but I think the impact should not be sever . . . (Phase 3: What do you think about the cause now?) Half and half [indicating power plant and other causes]. I think you can’t blame completely on one side. Nowadays, a lot of people do things without considering others. . . . (Do you think of any other possibilities?) Maybe the ecology in water has been changed.

These multiple-cause theorists usually did not hold a particular viewpoint strongly when they first encountered the proposed issue. Although most of them formed hypotheses at the beginning of the interview, they were able to identify alternative causes and make evaluations on both initial theory and later alternatives once more information was received.

In contrast to multiple-cause theorists, ‘single-cause theorists’, among the equally disposed group, were usually governed by strong personal beliefs. The following is an example found in the equally disposed group:

[UJ] (Phase 1: What do you think caused the fish to die?) . . . I believe it was the radiation even though they said that the amount of radiation was insignificant to the environment. As a matter of fact, they did not really know how much dose the fish could take . . . the radiation is made by human being, not gradually gained from nature. If it were gradually gained from nature, the fish would eventually develop some immune systems. Since they suddenly released the radiation, the fish must have died because of that . . . (Phase 2: What do you think now after you read the scientific report?) It says that the amount of radiation was lower than the official limit. However, . . . they could not foresee that gradually, even a little amount may hurt . . . it’s accumulative . . . (Phase 3: What do you think now killed the fish after reading the two other reports?) Although it’s possible the illegal fishermen killed the fish, but if you set aside the possibility of illegal fishermen, and if the incident did not happen, the death will still happen in the future . . . Maybe after a while . . . it’s an unknown future. (What information you need to make better judgment?) Basically I think the nuclear power plant is not good because the effects of radiation is beyond what humans can deal with . . . I know a lot of reports say that the radiation is harmful only when the amount reaches to a certain level and I also know that nature may also emit some radiation. However, radiation from power plant is artificial, which must be damaging to some extent.

Apparently, this subject’s prior belief that radiation from the power plant which is man-made and cumulatively is harmful surpassed all other information that might give rise to alternatives. Noticeably, however, the subjects’ belief concerning radiation involved scientific ground.
Information as different reasoning tools

Based on the interview data, it was found that equally disposed students regarded scientific and social information as playing different functions. Scientific information was usually used to justify theories while social information provided constraints on the extent to which scientific information or other claims could be applied.

Use of scientific information as evidence to support an initial theory. We found that about half of the equally disposed students (six out of 11) were able to logically stress their theories in accordance with scientific information when they first encountered the issue. Examples are listed below:

[JL] (Phase 1: What do you think caused the fish to die?) As far as I know, the radioactive wastewater used to cool the nuclear reactor has very high temperature. If it was released to the sea, it would damage the coral and also changed the seawater temperature, which would make many marine lives hard to adapt the environment... It was possible the waste water and... radiation was also possible.

[BJ] (Phase 1: What do you think caused the fish to die?) The cause... I think the plant had something to do with the death... Since... like what has been reported before, the temperature problem... If warm water is released suddenly, the fish can't adapt themselves to the temperature and consequently, they may die.

Use of scientific information to justify theories. When more information was provided, most equally disposed subjects (eight out of 11) were able to weigh the merits of their personal theories by referring to the new information. The following subject had an initial theory that the radioactive water killed the fish:

[NC] (Phase 2: What do you think of the cause now?) I don't know what killed the fish... It seems that the incident had nothing to do with the nuclear power plant if the scientific data are correct... Maybe somebody tried to bomb fish around the area and caused the damage of the coral, as a result, the ecology in that area was destroyed. Consequently, a lot of fish died.

Another subject whose initial theory was that the leaking stuff from the plant killed the fish:

[FP] (Phase 2: Did you change your mind after reading the reports?) I feel that since the amount was much lower than the official limit, it seems that the plant is not as terrible as what we usually think... I might lower the possibility of radioactive stuff... it could be just coincidence... however, the plant... I still think it was a suspect.

The next subject opined that the initial suspect was the warm water but changed opinion after more information was presented:
[BJ] (Phase 2: What do you think about the cause of death after you read the information?) I first thought the released radiation was low . . . it might have been gradually accumulated . . . After reading this, the released amount found in the sand sample was high . . . probably it was more severe than the released warm water.

One subject even pointed out that only further information about the amount of radiation that fish can take could rightly justify whether radiation was the killer:

[JC] (Phase 2: What do you think about the cause of death after you read the information?) I still think it was the wastewater [warm water]. As far as the radiation is concerned, nothing in the report can be referred to the death. (Could you explain more about your opinion?) Fish . . . maybe they take . . . I mean the amount that humans can take might be harmful for fish. Therefore, if they want to show that radiation was the killer, they should at least indicate how much the fish could take because these data referred to only humans. Based on the human standards, the amount is much lower than the official limit . . . I think they should not have against it.

Seemingly, this equally disposed subject was attempting to offer some judgmental criteria. Also apparent in the response is that, inferences about a causal relationship need to be based upon available scientific facts.

Formulated an initial theory in the social and personal context. In our study, all equally disposed subjects were able to consider the social aspects of the proposed issue. As mentioned above, about half of the equally disposed subjects (six out of 11) formed initial theories that were either explicitly or implicitly backed by scientific information. For the rest, the subjects’ initial theories were formulated largely within a social and personal context. The following are some examples. The first took into account the safety system and design of the plant:

[PL] (Phase 1: What do you think caused the fish to die?) They might have been dying naturally. (Why do you make such a statement?) I think the design of the nuclear power plant is supposed to be very advanced. Many scientists should have constantly monitored what they said about this event. Maybe the fish have being dying from time to time before but people did not discover the phenomenon. This time, because of the accident, they paid attention to the change of environment and blamed the plant.

In the next example, the subject formed an initial theory based on personal experiences:

[LC] (Phase 1: What do you think caused the fish to die?) The first I would think of is the wastewater from other factories. There are many factories in Taiwan. On the way home from school, very often I saw wastewater released to rivers from factories. The water used to be very clear but it is not the same any more. The colour has been changed.

Another subject’s theory was seemingly grounded on intuition:

[FP] (Phase 1: What do you think caused the fish to die?) I think it more or less had something to do with the leaking stuff. The incidence happened near the plant so it’s hard not to think of the plant.

As these examples show, subjects who formulate initial theories in the social and personal context did not provide information directly related to the death of the fish. Rather, their ‘evidences’ for the cause were usually indirect and sometimes intuitive.
Use of social information to justify claims or scientific information. In the last phase (phase 3) of the interview, interviewees were presented with reports containing information about investigation results obtained from a private organization and some student research group. Most of the equally disposed subjects reflected critically on these results, within a socially oriented context. Three examples are presented below:

[UJ] *(What do you think about the two investigations?)* I think any news on newspapers is only a reference. You should not completely believe it. Sometimes, the news is exaggerated, and some other times, since they know you are going to look for some scientific investigation, they made up stories.

[WY] *(What do you think about the two investigations?)* Maybe it [the private study] was made up. *(Why?)* Because they tried to oppose the plant. People elect their favourite congressmen. If people who voted for them disagree with the plant, the congressmen would need to fight with the plant.

[FP] *(What do you think about the two investigations?)* I think it depends on what side they are standing. If they agree with using nuclear power, they might make a report affiliated with the plant ... I don’t think I would believe either side. I believe what I really experience.

In addition to expressing a critical attitude toward studies conducted by individuals, a few equally disposed subjects used information from a social or personal context to reflect on the applicable extent of scientific information. The subject below initially held that it was the warm water that killed the fish but later tended to give greater credence to the possibility of radiation as the cause:

[BJ] *(Could you explain to me why you think radiation was related?)* The numbers [in the report] ... To be frank, the investigation was done by humans. It is understandable that the residents did not believe the report from the nuclear power plant.

The subject below though did not point a finger specifically to the power plant but throughout the interview gave reasonable doubts on scientific data:

[LW] *(Phase 3: What do you think about the cause now?)* Half and half [indicating the power plant and other illegal sources] ... *(You don’t eliminate that power plant as being a suspect?)* No. I don’t ... On the second thought, I am not quite comfortable with the [scientific] data because it seems to me that the power plant might have indeed emitted more than one millirem of radiation ... The reason that such an accident did not sound serious may be that the government tried to suppress the truth. Things like that do happen a lot.

As mentioned, most equally disposed interviewees were able to examine the proposed issue from different perspectives, but few of them (only two cases as just demonstrated) criticized the scientific information from non-scientific perspectives. Although many of them were able to recognize the limitation of scientific information, the recognition was often anchored in the scientific perspective. For example, four participants acknowledged that the official limit of radiation was based on human standards not fish. On the contrary, socially oriented students had a higher tendency to leave scientific information in the social context during reflection. However, when socially oriented subjects did so, their attitude toward scientific information was often distrustful as mentioned previously.

In summary, equally disposed subjects in our study used scientific and social information as different reasoning tools. Scientific information was useful as a way of obtaining direct evidence for theory evaluation. Although about half of the
interviewees formulated initial theories in the social or personal context, most of them were able to make use of scientific information at a later point when more relevant information was received. Social information was mostly employed to justify claims and, in some cases, it was used to question the reliability of the scientific data. The recognition of diverse knowledge and knowledge expressed with some caution and uncertainty implies that the intellectual development of equally disposed subjects was reaching a point of multiplicity as proposed by W. G. Perry and his followers (Perry 1970, Knefelkamp and Sleipitza 1978) and the stage three of pre-reflective thinking proposed by King and Kitchener (1994).

**Reasoning involving hypothesis testing**

In the last phase of the interview, we asked the subjects what further information they would need to make a better judgment. It was found that most equally disposed subjects (seven out of 11) adopted a reasoning strategy much like hypothesis testing. Here are three examples. The first subject’s personal theory was that the power plant had something to do with the death of fish:

**[BJ]** *(What kind of information you need to make a more thoughtful judgment?)* I want to see . . . before and after the building of the nuclear power plant as well as before the accident, how the fish were doing there, and what their living conditions are . . .

Although this individual did not specify the cause, he was able to relate the information needed to the personal theory. The second subject hypothesized that warm water was the killer while recognizing that the official limit of radiation in the scientific report was for humans:

**[JC]** *(What kind of information you need to make a more thoughtful judgment?)* The amount of radiation that fish can take, the amount of radiation in the wastewater, the temperature of sea water there and the normal temperature of sea water.

The third example stated initially that the warm water and/or radiation killed the fish. Later in the interview, the subject mentioned the possibility of wastewater from industrial factories:

**[JL]** *(What kind of information you need to make a more thoughtful judgment?)* I would like to see the reports in the recent two years about the ecological change around that area, how they [the plant] deal with warm water and the nuclear waste, and how they manage the plant. In addition, I want to know more about the whole geographical environment, see if there are other factories or so around that area.

The examples above demonstrated that these equally disposed students were capable of distinguishing theories from evidence. They knew well what major variables were in their theories and were able to manipulate variables when necessary.

**The dynamic mental models.** The above mental model theory is employed to explain the reasoning behaviour of the equally disposed group. In the first of three stages of thought, reasoners use their knowledge of the world to understand the premises of an event and then construct an internal model of the state of affairs that the premises describe. In the second stage, they make inferences from the constructed models and formulate conclusions. In the final stage, reasoners search for alternative models of the premises to determine if the current conclusions can
be falsified. If no such alternative model is found, the conclusion is accepted as valid. Otherwise, if the conclusions are not logically supported by relevant alternative models, the reasoners go back to the second stage to look for any other conclusion that is true in all constructed models.

As the reasoning process diagram in figure 2 shows, equally disposed subjects formed initial theories (in stage 2) in accordance with their mental models about the incident. Since most of them held various perceptions about the incident, multiple models were often produced (stage 1). Consequently, most of the equally disposed interviewees were categorized as multiple-cause theorists.

As the study proceeded, more information, both scientific and social, was presented which then induced alternative models to represent the incident (stage 3). When the alternative mental models tended to be in conflict with the

Figure 2. The mental-model reasoning process.
initial theories, the subjects examined all of the constructed models including the alternative ones and then reformulated their theories (back to stage 2). The reasoning loop would go on until a valid theory was found. Noticeably, alternative models also can arise by self-reflection on one’s own thoughts or the expected hypothesis testing results.

**Conclusion**

Cognitive scientists point out that the acquisition of specific knowledge in various domains not only results in the acquisition of sophisticated problem-solving ability (Siegler and Klahr 1982, Siegler and Richards 1982, Bruer 1993) but also enables different kinds of learning and thinking (Glaser 1984, Carey 1985). Basically, domain-specific knowledge provides particular insights and approaches for thinking and reasoning within that subject matter domain (Siegler and Richards 1982). Although this study did not examine in detail the relationship between domain-specific knowledge and the degree of sophisticated problem-solving ability of the students, some interesting insights were gained about the flexibility of information used by students. This was particularly poignant with respect to the neutral preference group who showed considerable facility in drawing upon a wide range of social and scientific data sources in their discourse during problem solving. This nominally suggests that there is an advantage in helping students who are largely oriented toward either science or the humanities to gain sufficient competencies in knowledge and reasoning processes of the opposite line to strengthen and broaden their problem solving capacities especially with respect to environmental issues. It provides additional evidence that scientifically literate laymen can make informed decisions about issues that transcend traditional disciplinary boundaries as increasingly occur in modern, technologically advanced societies.

**References**


**Appendix: the information preference survey test (sample)**

The following statements describe some views about the building of nuclear power plants and the use of nuclear energy. Please think about the degree of importance of each statement as if you are being subject to make decisions about some related issues, then circle an appropriate score in Choice B. If some statement is new to you, please check Choice A and do the next statement. After going through all the statements, go back to those unfamiliar items. Think seriously about their importance as you first take notice of them, then, assign them a score.

Scores:

- 0 = Not important at all,
- 1 = Not important,
- 2 = Important only to some degree,
- 3 = Important,
- 4 = Very important.

1. Even if nuclear power plants are safely designed, the human errors and machine failure would still cause a big disaster.
   - A. I am not familiar with this statement. (Please Skip B and go to the next statement.)
   - B. (0, 1, 2, 3, 4)  
     **(All items in the test follow the same format)**

1. The viewpoints of the political party a person prefers are useful in making decisions.
2. It costs too much to build a nuclear power plant.
3. Building a nuclear power plant is good for the national economy.
4. The Taiwan Electrical Energy Company is not trustworthy because of their lousy management records.
5. The risk of low-level radiation is not clear.
6. According to the statistical report, the probability of an accident from a nuclear power plant is lower than many of other industries.

7. As a matter of fact, we are constantly exposed to kinds of radiation, such as cosmic radiation, terrestrial radiation, radiation from TV, computers and so on. The amount of radiation emission from a nuclear power plant is even lower than the natural background radiation.

8. When a nuclear power plant is worn out, the area of the plant can’t be re-utilized immediately because of the leftover materials in it. Some of the materials are highly radioactive and have very long half-life.

9. Geologically, Taiwan has many unstable faults; accordingly, it’s dangerous to have nuclear power plants on the small island.

Now, you have completed the test. Please go back to those statements that are new to you (you have marked them by checking Choice A). Think about their importance as if these statements would make any difference on your opinion concerning the nuclear energy use. Then, assign them a score as well.

[Note: Items 1 to 5 belong to the social perspective while 6 to 10 are scientific.]