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Abstract This study aims to provide insights into the role of learners' knowledge structures about a socio-scientific issue (SSI) in their informal reasoning on the issue. A total of 42 non-science major university students' knowledge structures and informal reasoning were assessed with multidimensional analyses. With both qualitative and quantitative analyses, this study revealed that those students with more extended and better-organized knowledge structures, as well as those who more frequently used higher-order information processing modes, were more oriented towards achieving a higher-level informal reasoning quality. The regression analyses further showed that the "richness" of the students' knowledge structures explained 25 % of the variation in their rebuttal construction, an important indicator of reasoning quality, indicating the significance of the role of students' sophisticated knowledge structure in SSI reasoning. Besides, this study also provides some initial evidence for the significant role of the "core" concept within one's knowledge structure in one's SSI reasoning. The findings in this study suggest that, in SSI-based instruction, science instructors should try to identify students' core concepts within their prior knowledge regarding the SSI, and then they should try to guide students to construct and structure relevant concepts or ideas regarding the SSI based on their core concepts. Thus, students could obtain extended and well-organized knowledge structures, which would then help them achieve better learning transfer in dealing with SSIs.

Keywords Socio-scientific issue · Knowledge structure · Informal reasoning · Genetically modified foods

Introduction

Improving learners' scientific literacy has been recognized worldwide as a key educational goal in science education (Kolstø 2001). However, tremendous advancements in science and technology have led to the re-definition of scientific literacy (Cajas 2001). In particular, in the twenty-first century, students, as citizens of democratic societies, have an increasing

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number of opportunities to encounter a variety of social dilemmas with conceptual or technological associations with science, and they may also need to make some decisions or take positions on these issues. As both the social and scientific aspects take the central roles in these issues, these social dilemmas are often termed "socio-scientific issues" (SSIs) (Sadler 2004).

SSIs, such as environmental issues, energy usage problems, and the use of genetic engineering technology, are relevant and significant to the citizens and society in which they live. However, they are typically contentious, open-ended, consist of ill-structured problems, and resolution and negotiation are both difficult (Sadler 2004). Therefore, the need to equip students with the ability to deal with SSIs has been highly advocated (e.g., AAAS 1989, 1993; NRC 1996). In general, reasoning and decision making regarding an SSI have been recognized as the process of informal reasoning (Sadler 2004; Wu and Tsai 2007). Consequently, when trying to deal with an SSI, an individual's informal reasoning ability has been recognized to play a crucial role (Sadler 2004; Sadler and Zeidler 2005b).

As SSIs are relevant to students and can bridge school science and students' life experiences, they have been used to provide meaningful learning contexts in science classes (Cajas 2001; Kolstø 2001; Zeidler et al. 2005). Educators and researchers have also recognized that SSI-based instruction can be used as a platform or vehicle for students to acquire science content knowledge (e.g., Sadler et al. 2007; Zohar and Nemet 2002). Also, it has been advocated that students' acquired knowledge in science classes can serve as a tool for dealing with SSIs (e.g., Kolstø 2001). For educators, learners' application of learned knowledge in novel contexts (i.e., the transfer of learning) is always one of the crucial issues (e.g., Haskell 2001; Rittle-Johnson 2006). Therefore, the exploration of how the students' conceptual understanding regarding an SSI contributes to their informal reasoning on this issue should be of much importance.

Some previous studies have initially addressed the aforementioned important issue, and have revealed positive relationships between learners' conceptual understanding and their informal reasoning regarding this issue (e.g., Hogan 2002; Sadler and Zeidler 2005a). However, it should be noted that most of these studies were conducted qualitatively. Besides, in each one, only a small subset of informal reasoning, such as group decision making (e.g., Hogan 2002), informal reasoning quality (e.g., Sadler and Zeidler 2005a), or moral reasoning (e.g., Fowler et al. 2009; Zeidler and Sadler 2008), was investigated. Therefore, further research has also been suggested to more robustly describe the role of learners' conceptual understanding in their informal reasoning regarding this issue (e.g., Sadler 2004; Wu and Tsai 2011a). In most of these studies (e.g., Sadler 2005; Sadler and Zeidler 2005a), the participants' conceptual understanding was assessed by way of traditional forms of achievement assessment, such as multiple-choice questions, rather than by knowledge structure assessment, which has been regarded as one of the alternative assessments of students' conceptual understanding (Shavelson et al. 1990; Tsai 2001). It seems that further research with refinement in data collection and analyses could be helpful in providing deeper insights into the role of learners' conceptual understanding in their reasoning on SSIs. This study was therefore conducted to carefully examine the role of students' knowledge structures in their informal reasoning regarding an SSI. To this end, multidimensional analyses of both the students' knowledge structures and informal reasoning regarding an SSI, as well as both qualitative and quantitative analyses, were adopted.

Formal Reasoning, Informal Reasoning, and Argumentation

Reasoning is the process of constructing and evaluating arguments (Shaw 1996). Traditionally, scientific reasoning often refers to formal reasoning characterized by rules of logic and mathematics. In these reasoning tasks, learners are presented with well-defined problems. They are asked to assume the premises of problems are true and to draw or approve only conclusions that necessarily follow (Evans and Thompson 2004). During reasoning, learners are required to avoid taking their background knowledge and personal beliefs into account, and they should try to solve a problem only with the information provided in the problem (Evans and Thompson 2004).

Unlike formal reasoning which is used in the formal contexts of mathematics and symbolic logic, informal reasoning is the reasoning applied outside the formal contexts of mathematics and symbolic logic (Zohar and Nemet 2002), and is also identified as a rational process of constructing and evaluating arguments (Kuhn 1993). There are some fundamental distinctions between formal reasoning and informal reasoning. As aforementioned, the problems for formal reasoning tasks are well defined; the premises are always explicit and clear, and there are definite conclusions or solutions for these reasoning tasks. However, the problems of informal reasoning are not well defined. Additionally, the premises of informal reasoning tasks may not be explicitly stated. As a result, the conclusions derived from the arguments in informal reasoning may not be easily demarcated. Moreover, a reasoner's background knowledge and personal beliefs often play important roles in the process of informal reasoning. In general, informal reasoning often involves the generation and evaluation of positions in response to complex issues that lack clear-cut solutions, and are often used in situations where reasons exist both supporting and against the conclusions, such as making decisions about what to believe or what actions to be taken (Shaw 1996; Sadler 2004).

To conclude, what makes some reasoning "formal" and other reasoning "informal" is the nature of the reasoning task in which the reasoning is applied. Formal reasoning is used in the formal contexts of mathematics and symbolic logic, while informal reasoning is the reasoning applied outside the formal contexts of mathematics and symbolic logic. As SSIs are typically contentious, open-ended, and ill-structured, an individual's reasoning and decision making on an SSI is recognized as the practice of informal reasoning (Sadler 2004; Wu and Tsai 2007). For example, if a student is asked to reason "if he or she agree with the development of the technology of genetically modified foods, and why?", the problem is not well defined, and the reasoning task is informal in nature. Thus, the student will possess informal reasoning to solve the problem.

Moreover, it should be acknowledged that there is an essential distinction between informal reasoning and argumentation in regards to its scope. To illustrate, informal reasoning is the internal cognitive processes where the individual constructs arguments and retro-inspects the generated arguments. Similar to informal reasoning, argumentation also involves argument construction and argument evaluation. However, in a different scope, argumentation involves social processes where two or more individuals construct and evaluate arguments (Kuhn and Udell 2003; Nussbaum 2002), and argumentation is a social situated activity that enables discourse among learners (Erduran et al. 2004; Sadler and Fowler 2006; Wu and Tsai 2011c). During argumentative discourse, learners have to make their internal cognitive processes public (i.e., they have to explicitly express arguments derived from their own reasoning to others), and they also assess the arguments proposed by their counterparts. Meanwhile, based on the critiques they received for their arguments, learners may re-construct their arguments internally.

Multidimensional Analyses of Informal Reasoning Regarding an SSI

Arguing about different positions is an essential part of informal reasoning (Mason and Scirica 2006). Mean and Voss (1996) have also argued that the basis of informal reasoning was the skill in argument generation and evaluation (i.e., argumentation skills). Therefore, arguments are considered as cognitive constructions of individuals who reason on a SSI (Mason and Scirica 2006). Similar to Mason and Scirica (2006), this study explicitly asked the participant students to formulate arguments, counterarguments, and rebuttals regarding a SSI, and then individual students' informal reasoning from the arguments they constructed was evaluated.

In previous studies, participants' informal reasoning on socio-scientific issues was often assessed qualitatively, and was only assessed from one single aspect, such as informal reasoning patterns (Sadler and Zeidler 2005b), reasoning mode (Yang and Anderson 2003; Patronis et al. 1999), or informal reasoning quality (Sadler and Zeidler 2005a). For example, Sadler and Zeidler (2005b) identified that college students revealed three patterns of informal reasoning on genetic engineering scenarios, including rationalistic, emotive, and intuitive forms. Rationalistic informal reasoning is the reasoning with reason-based considerations; emotive informal reasoning is the reasoning with care-based considerations; and intuitive informal reasoning is the reasoning based on immediate reactions to the context of a scenario. According to the information that senior high students used during the problem task involving nuclear energy usage, Yang and Anderson (2003) also identified two reasoning modes: scientific-oriented reasoning (i.e., reason with scientific-oriented information) and social-oriented reasoning (i.e., reason with social-oriented information). Through analyzing students' arguments on a socio-scientific issue, Patronis et al. (1999) summarized students' qualitative arguments into four aspects: social, ecological, economic, and practical. That is, learners may generate arguments regarding a socio-scientific issue from social, ecological, economic, or practical considerations. Moreover, to assess university students' informal reasoning quality in six genetic engineering scenarios, Sadler and Zeidler (2005a) utilized the four criteria: intra-scenario coherence, inter-scenario non-contradiction, counter-position construction, and rebuttal construction. According to Sadler and Zeidler (2005a), intra-scenario coherence assesses whether the rationale supports the stated position; inter-scenario non-contradiction evaluates whether the positions and rationales from each of the related scenarios are non-contradictory with one another; counter-position construction assesses whether the participant can construct and explain a counter-position; and rebuttal construction evaluates whether the participant can construct a coherent rebuttal. If an individual is able to form a coherent position, a counter-position, and a rebuttal, then s/he displays flowed reasoning. Kuhn (1993) has also argued that rebuttals are critical in informal reasoning because these rebuttals complete the structure of argument, integrating argument and counter-argument.

Based on previous studies, Wu and Tsai (2007) developed an integrated framework for analyzing an individual's informal reasoning on an SSI. In this framework, an individual's informal reasoning is analyzed from multiple aspects, including decision-making modes, reasoning modes, and reasoning quality. With a series of qualitative and quantitative analyses, several qualitative indicators and quantitative measures for representing an individual's informal reasoning on an SSI can be obtained (the details of this integrated analytical framework are described in the "Method" section). Recently, this multidimensional analytical framework has also been used in some follow-up studies and has revealed satisfactory usefulness (e.g., Wu and Tsai 2011a, b). To conduct multidimensional analyses of learners' informal reasoning regarding an SSI, the integrated framework developed in Wu and Tsai (2007) was used in this study.

Multidimensional Analyses of Knowledge Structure About an SSI

Educators and cognitive scientists have attempted to represent pre-acquired knowledge in terms of "knowledge structure" (Pines 1985). A knowledge 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. For a long time, the use of alternative assessment of students' conceptual understanding has been highly advocated by science educators (Mintzes et al. 2001). Knowledge structure assessment has been regarded as one of the alternative assessments of students' conceptual understanding (Shavelson et al. 1990; Tsai 2001).

As previously mentioned, the participants' conceptual understanding was mostly assessed by traditional assessment methods, such as multiple-choice questions, in previous studies (e.g., Sadler 2005; Sadler and Zeidler 2005a). Previous research has shown that these traditional assessment methods are limited to providing sufficient information regarding how learners' conceptual understanding of an SSI actually contributes to their reasoning. For example, Sadler and Fowler (2006) found that some high school students had learned content knowledge regarding an SSI, as evidenced by their performance on the achievement test; however, their conceptual understanding was not robust enough to actually contribute to their dealing with the issue. Sadler and Fowler (2006) further proposed that learners must have well-developed knowledge structures in order to transfer knowledge in argumentation. The perspective above seems to suggest the use of knowledge structure assessment in further research. Therefore, knowledge structure assessment was used in this study.

In this study, the flow-map method, the "meta-listening" technique, and "core concept analyses" were used to obtain multidimensional data regarding students' knowledge structures about an SSI. According to the review conducted by Tsai and Huang (2002), the flow-map method proposed by Anderson and Demetrius (1993) is one of the most useful methods for representing an individual learner's knowledge structure. The flow-map method proposed by Anderson and Demetrius (1993) can represent knowledge structures in graphical and quantitative terms, and display the sequential and multinational ideation of narrative expressed by the interviewed respondent (the details of the flow-map method are described in the "Method" section).

Coupled with the flow-map method, the "meta-listening technique" (Tsai 2001) and "core concept analyses" (Tsai and Chou 2005) were also used to obtain a more detailed picture of individual students' knowledge structures of a specific topic. The "meta-listening technique" was proposed by Tsai (2001), and is used to elicit additional relevant ideas in a learner's knowledge structure (The details of the "meta-listening" technique are described in the "Method" section). The "core concepts analyses" were used to identify the "core" concept and "anchored" concept within an individual learner's knowledge structure regarding a specific topic (Tsai and Chou 2005).

In recent years, rapid development in genetic engineering has raised relevant SSIs, such as gene therapy, cloning, stem cells, and genetically modified organisms. Among these relevant issues, the use of genetically modified foods (GMFs) is relatively more relevant to the general public. For example, we may eat genetically modified corn and drink soybean milk made with genetically modified soy in our daily life. Moreover, genetically modified crops may be expected to resolve the food requirements in poor countries. It seems that genetically modified foods may have positive impacts on individual human daily life. However, the harmlessness of GMFs is far from being proven. Some circumspect people may decide to buy GMO-free products, and ask that consumers should always be informed about the presence of transgenic ingredients in products. The debate on GMFs could be considered a SSI closer to people's everyday lives because it regards a fundamental need for food.

In the recent years, students' ability to deal with socio-scientific issues thoughtfully has been recognized as one important component of scientific literacy (Kolsto 2001; Sadler 2004), which has made achieving scientific literacy becomes a crucial educational goal worldwide for science educators (Laugksch 2000). However, most of the citizens may not have sufficient science backgrounds. Therefore, the ability of these non-science major citizens' dealing with SSIs should be highlighted. In particular, non-science major university students' reasoning and decision making on SSIs should be highlighted by educators and researchers in science education. For non-science major university students, the debate on GMFs connects their everyday lives. Undoubtedly, the use of GMFs provides a meaningful context for them to practice reasoning and decision-making regarding a SSI, and the exploration of non-science major university students' knowledge structures regarding GMFs and their informal reasoning on the use of GMFs should be of much importance.

To sum up, this study was conducted to provide deeper insights into the role of non-science major university students' knowledge structures regarding an SSI in their informal reasoning on this issue. To this end, both qualitative and quantitative analyses were used in this study. Besides, multidimensional analyses of a group of non-science major university students' knowledge structures and their informal reasoning regarding the use of GMFs were conducted. The research questions of the current study are:

1. What are non-science major university students' knowledge structures regarding GMFs?
2. What are non-science major university students' informal reasoning outcomes regarding the use of GMFs?
3. What is the relationship (if any) between non-science major university students' knowledge structures and informal reasoning outcomes regarding GMFs?
4. How do non-science major university students' knowledge structures regarding GMFs contribute to their informal reasoning quality?

Method

Participants and the Socio-Scientific Issue

The participants in this study were 42 volunteer university students (8 males and 34 females) from a national university of education in Taiwan. They were all non-science majors, and were enrolled in the general education course, "Nature, Technology and Society," for non-science majors.

This course had one 2-h class period per week and was designed to improve non-science major students' conceptual understanding of SSIs, such as nuclear power usage, global warming and genetic engineering, and, more importantly, to facilitate their ability to thoughtfully reason, discuss and make personal decisions on these issues. Each week, one SSI was chosen by the instructor as the instructional topic. During a 2-h class period, the instructor firstly briefly introduced the issue. Then, the students were asked to read a relevant report provided by the instructor and discuss the issue in small groups. Finally, they were asked to present and share their ideas regarding the issue to the whole class.

In recent years, rapid development in genetic engineering has raised relevant SSIs, such as gene therapy, cloning, stem cells, and genetically modified organisms. Therefore, "the use of genetically modified foods (GMFs)" was selected as one of the class topics in the "Nature, Technology and Society" course. In the class, the relationship between DNA and genes, and several different techniques related to gene transfer to plants was introduced first. Then, several examples of modern GMFs were provided, and a short video regarding the history and the main developments of GMFs was played. Finally, the students were asked to discuss this issue in groups. In this study, "the use of genetically modified foods (GMFs)" was used as the socio-scientific issue for exploring the significance of the university students' knowledge structures about GMFs in their reasoning regarding this issue. Before taking part in the study, the participants had already learned about "the use of genetically modified foods (GMFs)" in the course the week before.

Data Collection and Data Analyses

In this study, the participants' knowledge structures regarding GMFs were probed first, and then their informal reasoning outcomes about the use of GMFs were assessed. The participants' GMF knowledge structures were explored by tape-recorded interviews coupled with a "meta-listening technique;" afterwards, their interview narratives were analyzed with the flow-map method coupled with the analyses of "core concept" within their knowledge structures. The participants' informal reasoning outcomes regarding the use of GMFs were assessed with an open-ended questionnaire, and their responses on the questionnaire were analyzed qualitatively and quantitatively with the multidimensional analytical framework developed in Wu and Tsai (2007).

A detailed description regarding the data collection and data analyses in this study are as follows:

Multidimensional Knowledge Structure Exploration

There are two stages when collecting data regarding the participants' GMF knowledge structure in this study. In the first stage, a participant's knowledge structure was obtained by tape-recorded interviews with the following non-directive questions:

1. Can you tell me what you know about GMFs?
2. Could you tell me more about the ideas you have already mentioned?
3. Could you tell me the relationships between the ideas you have already mentioned?

Then, in the second stage, the "meta-listening technique" for exploring the participant's additional conceptual knowledge regarding GMFs was conducted after the tape-recorded interview conducted in the first stage. When using the "meta-listening" technique, the original tape-recorded interview record obtained in the first stage was replayed immediately to provide the interviewed participant with an opportunity to recall additional ideas about GMFs that he/she did not mention in the first stage. The participant's response in the second stage was also recorded with a second tape recorder (for the details of the flow-map method and the meta-listening technique, please refer to Wu and Tsai 2005a, b). In this way, a relatively more complete picture of the learner's knowledge structure in a non-directive manner could be obtained.

In this study, the "total" interview narrative of an interviewed participant, including that expressed in the second stage, was transcribed to produce a flow map representing his/her GMF knowledge structure. Figure 1 shows one student's GMF flow map about GMFs. Basically, the flow map is constructed by entering the statements mentioned by the learner in sequence (for further details about the flow-map method, see Anderson and Demetrius 1993; Tsai 2001).

To obtain a relatively more complete picture of the students' knowledge structures regarding GMFs, the following three analyses regarding their knowledge structures regarding GMFs were conducted:

1. Analyzing the extent and richness of the students' knowledge structures regarding GMFs

   The students' interview narratives analyzed with the flow-map method could provide the following two important quantitative variables for representing their knowledge structures (Tsai 2001; Wu and Tsai 2005a, b):

   (a) Extent: the total number of ideas shown in the student's flow map.
   (b) Richness: the total number of recurrent linkages revealed in the participant's flow map.

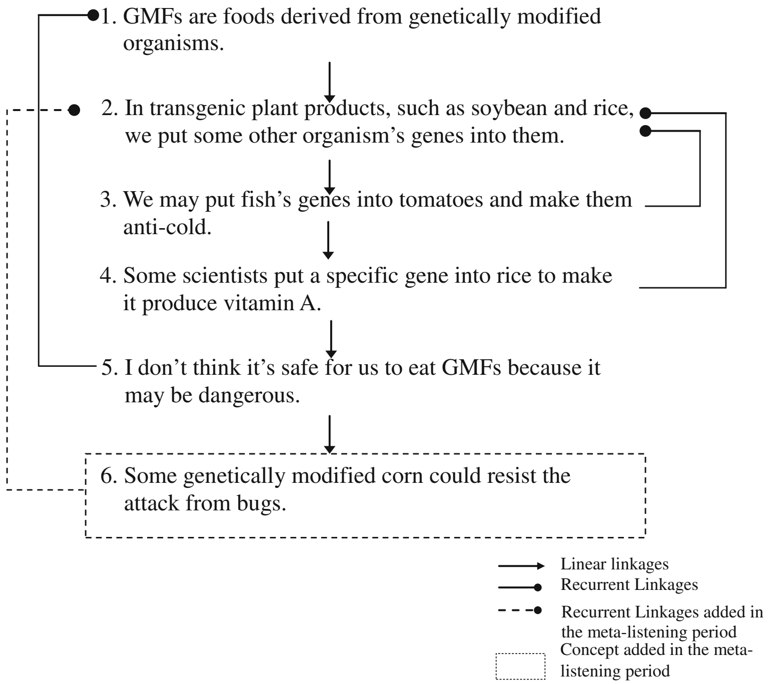

Fig. 1 A student's flow map about GMFs. The student's narrative shows a sequential pattern beginning with the definition of GMFs to examples of transgenic plant products. The student also mentioned his/her personal position regarding GMFs. In a flow map, recurrent arrows are inserted by linking revisited ideas to the earliest step where the related idea first occurs. For example, statement 5, "I don't think it's safe for us to eat GMFs because it may be dangerous" includes one major revisited idea "GMFs". Therefore, statement 5 has one recurrent arrow drawn back to statement 1 (i.e., "GMFs are foods derived from genetically modified organisms."). The "extent" of the student's knowledge structure (i.e., the total number of ideas revealed in the student's flow map) is "6," and the "richness" of the student's knowledge structure (i.e., the total number of recurrent linkages) is "4"

2. Analyzing the students' usage of different information processing modes

   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 and Tsai 2005a):

   (a) Defining: Providing a definition of a concept or a scientific term, e.g., "GMFs are the foods derived from genetically modified organisms."
   (b) Describing: Depicting a phenomenon or a fact, e.g., "Most of the GMFs are transgenic plant products, such as soybean and corn."
   (c) Comparing: Stating the relationships between (or among) subjects, things, or methods, e.g., "Compared with normal fruit, genetically modified fruit is low-priced."
   (d) Inferring or Explaining: Describing what will happen under certain conditions or offering an account to justify the causality of two facts or events, e.g., "If we transplant drought-resistant genes to crops, these crops could be cultivated in severely dry areas. And, then, the crops will be lower-priced."

The first two information processing modes (i.e., "defining" and "describing") are viewed as lower-level information processing modes, while the other two (i.e., "comparing" and "inferring or explaining") are regarded as higher-level information processing modes (Tsai 2001; Wu and Tsai 2005a). In this study, the students who frequently used higher-order information processing modes (i.e., "comparing" and "inferring or explaining") were viewed as having better strategies for organizing information during recall.

3. Identifying the "core concepts" within the students' knowledge structures

   In Tsai and Chou (2005), the "core concept" within an individual's knowledge structures regarding a specific topic knowledge domain was identified. Before conducting the "core concepts analyses," the participants' knowledge structures were represented using the flow-map method. Then, the "core concept" and the "anchored concept" within the knowledge structure were further identified by calculating the number of concepts connected with each concept. By definition, the "core concept" is that concept connected with the most other concepts within one's knowledge structure regarding a specific topic, while the "anchored concept" is the concept connected with the second most concepts. In Tsai and Chou (2005), the importance of the "core" concept and "anchored" concept in one's knowledge recall has been revealed. By using "core concept analyses," this study also attempted to identify the core concepts within the students' knowledge structures. For example, in Fig. 1, the second idea (i.e., "GMFs" means we put some other organism's genes into plants and make them change) has the most recurrent linkages (i.e., three recurrent linkages). Thus, it is recognized as the core concept within the student's knowledge structure.

   In this study, an independent researcher was asked to transcribe a total of ten students' narratives into flow maps. The inter-coder agreement for the sequential linkages in the diagramming flow map and the inter-coder agreement of recurrent linkages were greater than 0.8. Similarly, the inter-coder reliability of the content analysis of information processing modes in each unit was also obtained in this study. Also, the inter-coder agreement was greater than 0.8. In sum, the content analysis of the students' GMF knowledge structures was adequately reliable in this study.

Multidimensional Informal Reasoning Analyses

Wu and Tsai (2007) have developed an open-ended questionnaire for assessing learners' informal reasoning on nuclear power usage. Similarly, an open-ended questionnaire for evaluating the students' informal reasoning outcomes about GMFs was developed in this study. This open-ended questionnaire consists of the following questions:

1. Do you agree with the development of the technology of genetically modified foods (GMFs)? (assessing students' position on GMFs)
2. If you want to convince your friend of your position, what arguments would you propose to convince him/her? (evaluating students' ability to generate supportive arguments for their positions)
3. If someone holds an opposite position with you on this issue, what arguments may he/she have? (assessing students' ability of counterargument construction)
4. According to the arguments proposed in question 3, can you write down your opposing ideas to justify your position? (evaluating students' ability of rebuttal construction)

The students were asked to write down their answers to these questions in the open-ended questionnaire. In this study, each of the individual students' arguments shown in their responses to these open-ended questions were analyzed both qualitatively and quantitatively with the multidimensional framework proposed in Wu and Tsai (2007). Then, several qualitative indicators and quantitative measures could be acquired to represent the students' informal reasoning regarding GMFs. Detailed descriptions of these indicators and measures are as follows:

1. Qualitative indicators: Two qualitative indicators could be used for representing students' informal reasoning regarding GMFs, including:

   (a) Reasoning quality: Kuhn (1993) has argued for the significant role of rebuttals in informal reasoning. Therefore, a student's reasoning quality was categorized as "lower level" if he/she only made simple claims (supportive arguments) or counterarguments, while his/her reasoning quality was categorized as "higher level" if he/she generated not only simple claims (supportive arguments) and counterarguments but also rebuttals.
   (b) Reasoning mode revealed in each argument: The students may generate their arguments regarding GMFs from different aspects, such as "social-oriented," "economic-oriented," and "science or technology-oriented" perspectives. In this study, each argument proposed by the participants was analyzed qualitatively, and then the major reasoning modes emerged from the arguments proposed in the current study.
2. Quantitative measures: After the qualitative analyses above, the following quantitative measures could also be obtained for representing students' informal reasoning about GMFs:

   (a) Number of supportive arguments: The number of supportive arguments that a student proposes. The more supportive arguments proposed, the more the student is able to provide supportive evidence for his/her position.
   (b) Number of counterarguments: The number of counterarguments that a participant proposes. This measure assesses the ability of a learner to reason from the opposite position.

(c) Number of rebuttals: The number of rebuttals that an individual student generates. The more rebuttals the student constructs, the more he/she is able to justify his/her position.
(d) Total number of arguments: The total number of the aforementioned three kinds of arguments (i.e., supportive arguments, counterarguments, and rebuttals). This measure evaluates an individual learner's ability to make arguments regarding GMFs.
(e) Total number of reasoning modes: The total number of reasoning modes an individual utilizes in his/her informal reasoning. Similar to Wu and Tsai (2007), each argument proposed by an individual student was categorized. Then, the total number of different reasoning modes used was calculated. The greater the total number, the more the learner tended to reason about GMFs from multiple perspectives.

In this study, the reliability evaluations for the informal reasoning analyses were also conducted. To this end, another researcher was asked to independently analyze a total of ten students' responses on the open-ended questionnaire, and all the inter-coder agreements for these analyses were greater than 0.80, revealing that the analyses regarding students' informal reasoning outcomes were sufficiently reliable. Besides, during data analyses, all the discrepancies were discussed to achieve the final agreements.

Results

Students' Knowledge Structures Regarding GMFs

Table 1 shows the students' GMF knowledge structure outcomes. On average, the "extent" and "richness" of the students' knowledge structures were 5.21and 4.21, respectively. Moreover, Table 1 also reveals the students' usage of different information processing modes. As shown, the mode that the students used most frequently was "describing" (mean=4.00), followed by "inferring or explaining" (mean=0.62), "defining" (mean=0.33), and "comparing" (mean=0.26). It seems that, in general, the university students in this study tended to retrieve SSI-related concepts by using lower-level information processing strategies.

Students' Informal Reasoning Outcomes Regarding GMFs

Through qualitative analyses, five major reasoning modes, including "human benefits-oriented," "risk-oriented," "science or technology-oriented," "nature or ecology-oriented," and "social equity-oriented" considerations, emerged from data collected in the current study. The descriptions and examples of these major reasoning modes are presented in Table 2.

Table 1 Students' knowledge structure regarding GMFs (n=42)

	Mean	S.D.	Range
Extent	5.21	2.47	1–11
Richness	4.21	3.39	0–14
Defining	0.33	0.48	0–1
Describing	4.00	1.86	0–8
Comparing	0.26	0.45	0–1
Inferring or explaining	0.62	1.01	0–5

Table 3 shows the students' informal reasoning outcomes regarding GMFs. The university students in this study, on average, proposed more than four arguments (mean=4.31). In particular, they generated more than one supportive argument (mean=1.90) and one counterargument (mean=1.69); however, they proposed, on average, less than one rebuttal (mean=0.71). Besides, they generated, on average, a total of more than four arguments (mean=4.31). In our previous study (i.e., Wu and Tsai 2007), high school students' insufficient ability to construct rebuttals was found. Similarly, the university students in this study did not show sufficient ability to construct rebuttals, which could be viewed as an important indicator of informal reasoning quality.

Table 3 also reveals that the students, on average, proposed relatively more "human benefit-oriented" arguments (mean=1.52), followed by "risk-oriented" (mean=1.07), "nature or ecology-oriented" (mean=1.07), "science or technology-oriented" (mean=0.52), and "social equity-oriented" (mean=0.17) arguments. This indicates that the students in this study were more oriented towards proposing arguments regarding the use of GMFs based on the possible positive or negative impacts on human beings, possible unknown risks, or possible impacts of GMFs on nature or the ecology, while being less prone to reason on this issue from science or technology-based or social equity-oriented considerations. In addition, they generated, on average, a total of more than three argumentation modes (mean=2.21), suggesting that the university students in this study tended to reason on the issue regarding GMFs from multiple perspectives.

Correlations Between Students' Knowledge Structures and Informal Reasoning Regarding GMFs

Table 4 shows that the "extent" and "richness" of the students' knowledge structures regarding GMFs were significantly correlated with their rebuttal construction ($p<0.05$), which could be viewed as an important indicator of higher-level reasoning. Besides, their

Table 2 Different reasoning modes for GMFs used by the students

Reasoning mode	Description	Example
Human benefit-oriented	Students proposed arguments regarding the use of GMFs based on their possible positive or negative impacts on human beings.	Student 1 proposed that "GMFs can be transported long distances with a lower loss or cost."
Risk-oriented	Participants proposed arguments regarding GMFs focusing on possible unknown risks.	Student 7 argued that "We don't know what happens if the new characteristics are transferred to crops"
Science or technology-oriented	Students proposed arguments related to science or technology.	Student 16 proposed that "GMFs have been tested many times by scientists before they are sold"
Nature or ecology-oriented	Students proposed arguments according to possible impacts derived from GMFs on nature or ecology.	Student 25 argued that "I think that GMFs are unnatural, and may destroy the food-chain in the wild."
Social equity-oriented	Students proposed arguments regarding addressing social equity issues.	Student 39 proposed that "A monopoly on GMF techniques may happen, and I think that is unfair"

Table 3 Students' informal reasoning outcomes regarding GMFs (n=42)

	Mean	S.D.	Range
Argument construction for different purposes			
Supportive argument	1.90	0.57	1–3
Counter-argument	1.69	0.72	0–3
Rebuttal	0.71	0.67	0–2
Total number of arguments	4.31	1.44	0–7
Usage of different reasoning modes			
Benefit-oriented	1.52	0.74	0–3
Risk-oriented	1.07	0.87	0–5
Science or technology-oriented	0.52	0.59	0–2
Nature or ecology-oriented	1.07	0.75	0–3
Social equity-oriented	0.17	0.49	0–2
Total number of reasoning modes	3.19	0.89	1–5

usage of the information processing mode, "inferring or explaining" was also significantly correlated with their rebuttal construction (p<0.05). This implies that those students with more extended and better-organized knowledge structures, as well as those who used a higher-order information processing mode (i.e., "inferring or explaining") more frequently in organizing the concepts they had learned, had a greater tendency to achieve a higher-level informal reasoning quality.

When reasoning on an SSI, a satisfactory number of arguments and reasoning from multiple perspectives are fundamental for students to achieve a higher-level reasoning quality (Wu and Tsai 2007). The results in Table 4 also show that the "extent" and "richness" of the students' knowledge structures, as well as their use of the "describing" and "inferring or explaining" information processing modes, were significantly correlated with the number of arguments they proposed. This suggests that those students who had more extended and more integrated knowledge structures, and those who more frequently used a higher-order information processing mode were able to generate more arguments regarding the use of GMFs. Moreover, those students more oriented towards using the information processing mode "describing" were more able to propose arguments when reasoning on the use of GMFs. Table 4 also reveals that those students with more organized knowledge structures were more oriented towards using multiple reasoning modes, suggesting the significance of integrated knowledge structures in students' reasoning on an SSI from multiple perspectives.

Table 4 Correlations between students' knowledge structure outcomes and informal reasoning outcomes regarding GMFs (n=42)

	Extent	Richness	Defining	Describing	Comparing	Inferring or explaining
Supportive argument	0.40*	0.25	0.27	0.38*	0.26	0.13
Counter-argument	0.23	0.23	0.24	0.18	−0.05	0.24
Rebuttal	0.46**	0.52**	0.30	0.29	0.01	0.45**
Total number of arguments	0.51**	0.47**	0.17	0.40**	0.10	0.39*
Total number of reasoning modes	0.28	0.34*	0.13	0.21	−0.01	0.25

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

Significant Predictors of Students' Informal Reasoning Quality

Table 5 shows the result derived from the stepwise multiple regression model for explaining the students' rebuttal construction using their knowledge structure outcomes. As revealed in Table 5, only the "richness" of the students' knowledge structures significantly predicts their rebuttal construction ($p<0.05$). Moreover, regression mode in Table 5 also shows that 25 % of the variation of students' rebuttal construction was explained by the "richness" of the students' knowledge structures. This suggests the importance of learners' integrated knowledge structures in their reasoning quality regarding an SSI.

Comparisons of Informal Reasoning Outcomes Between Students with and Without Core Concepts Within Their Knowledge Structures

This study initially attempted to explore the possible significance of the "core" concept within one's knowledge structure in one's informal reasoning regarding an SSI. To this end, this study compared the informal reasoning outcomes between those students with and without core concepts within their GMF knowledge structures. Table 6 shows that those students with core concepts within their knowledge structures significantly outperformed their counterparts in terms of the number of arguments proposed, the use of multiple reasoning modes, and their rebuttal construction ($p<0.05$). The findings above provide some initial evidence for the "core" concept within one's knowledge structure playing a significant role in one's informal reasoning regarding an SSI.

Discussion and Implications

With a mixed methodology and the use of multidimensional analyses, this study reexamined the role of students' knowledge structure in their informal reasoning outcomes regarding an SSI. Some important findings derived from this study are discussed further below.

A Worldwide Understanding Regarding Students' Dealing with SSIs

In the past, some studies have explored participants' considerations when dealing with genetic engineering related SSIs (e.g., Ekborg 2008; Sadler and Zeilder 2005b; Sadler and Fowler; 2006; van der Zande et al. 2009; Zohar and Nemet 2002). However, most of these studies were conducted in western contexts, rather than the eastern context of this study. In this study, university students' usage of different reasoning modes about the use of GMFs was also explored. It should also be noted that there are some interesting differences between the reasoning modes expressed by the participants in this study and the considerations expressed by the participants in the previous research. For example, in Sadler and Fowler (2006), the university students and high school students most frequently proposed arguments

Table 5 Stepwise regression model testing the predictor of students' rebuttal construction

Dependent variable	Predicting variables	B	S.E.	β	t	Adjusted R^2
The amount of rebuttal	Richness	0.10	0.27	0.52	3.84*	0.25
	Constant	0.28	0.14		1.94	

*$p<.01$

Table 6 Comparisons of students' informal reasoning outcomes between two different knowledge structure groups (n=42)

	With core concept (n=13)		Without core concept (n=29)		t
	Mean	S.D.	Mean	S.D.	
Supportive argument	2.00	0.41	1.86	0.74	0.77
Counter-argument	1.92	0.76	1.59	0.68	1.43
Rebuttal	1.15	0.69	0.52	0.57	3.12**
Total number of arguments	5.08	1.12	3.97	1.45	2.45*
Total number of reasoning modes	3.62	0.87	3.00	0.85	2.16*

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

related to religious, social and moral norms in their socio-scientific argumentation; however, the students in this study most frequently expressed benefit-oriented considerations when reasoning on the use of GMFs. In addition, most of the studies conducted in western contexts (e.g., Sadler and Zeilder 2005b; Sadler and Fowler 2006; van der Zande et al. 2009) reported that the students tended to propose morality-related or ethics-related arguments regarding genetic engineering issues. In contrast, moral or ethical considerations were not expressed by the university students in this study. This indicates that, when dealing with genetic engineering related SSIs, some reasoning modes (e.g., economic or ecological considerations) may be commonly expressed by students in both western and eastern contexts, while some considerations (e.g., moral or ethical considerations) expressed by students in the western context may not be expressed by students in an eastern context. Nevertheless, it should be noted that the above western studies do engage student in discussion of genetic engineering, but their focus of discussion or argumentation is on issues related to gene therapy and human cloning, as opposed to GMF featured in the present study. Therefore, the aforementioned differences observed might be related to specific topics for reasoning or argumentation, although all the topics in the current and previous studies yield to the scope of genetic engineering. Whether or not these differences may exist, therein lie reasons for future studies with similar issues in the eastern contexts. Besides, the aforementioned differences observed were obtained by only one SSI was selected in this study. If more SSI topics are used in a further study to address the issue above, the differences in considerations regarding these issues between learners from different cultural contexts may be properly evidenced.

Some socio-scientific issues such as genetic engineering, global warming, and energy power usage are now becoming global issues. The solutions of these issues rely on collaboration and negotiation among citizens from all around the world. Since the ultimate purpose of science education is the advancement of science teaching and learning throughout the world, science education has become a globalized research domain (Abell and Lederman 2007). Therefore, a global and cross-cultural understanding of learners' dealing with a specific global SSI should be taken into consideration. To this end, cross-national or cross-cultural research on students' dealing with a global SSI is also suggested.

The Role of Sophisticated Knowledge Structure and the Use of Higher-Order Information Processing Modes in Informal Reasoning Regarding an SSI

Transfer of learning is always one of the important issues for educators (e.g., Haskell 2001; Potgieter et al. 2008; Rittle-Johnson 2006). For science educators, learners' better transfer of their content knowledge to deal with SSIs has also been highlighted (e.g., Sadler and Fowler 2006). To account for the relationship between student content knowledge and their argumentation quality regarding an SSI, Sadler and Donnelly (2006) proposed a "Threshold Model of Knowledge Transfer." This model hypothesizes that argumentation is related to content knowledge, but that the relationship is nonlinear. In the follow-up empirical study, Sadler and Fowler (2006) argued the significance of satisfactory extent and well-organized knowledge structure in transferring an individual's content knowledge to achieve a higher-level socio-scientific argumentation quality. Further research examining the perspective above was also suggested by Sadler and Fowler (2006). In this study, by using multidimensional knowledge structure analyses, it was revealed that those students with more extended and better-organized knowledge structures were more oriented towards reasoning from multiple perspectives; also, they were more prone to achieve a higher informal reasoning quality. Moreover, the regression analysis also shows that the "richness" of the students' knowledge structures is the only significant predictor for their rebuttal construction. The findings above indicate the significance of well-organized knowledge structures in students' transfer content knowledge in terms of reasoning about an SSI, providing some initial empirical evidence for Sadler and Fowler's (2006) perspective above.

The Role of the Core Concept Within Knowledge Structure in Informal Reasoning on a SSI

In Tsai and Chou (2005), the significant role of the "core" concept within one's knowledge structure in one's knowledge recall has been revealed. However, one may also be interested in the role of the core concept in students' reasoning regarding an SSI. This study also attempted to address this issue. The findings provide some initial evidence for the significant role of the "core" concept within one's knowledge structure in one's informal reasoning regarding an SSI. In recent years, Cognitive Load Theory (CLT) has been highlighted by educators and instructional scientists. This theory may provide some possible explanations for this aspect of the findings. According to CLT, there are three types of cognitive load (i.e., working memory load): intrinsic load, germane load, and extraneous load (Clark et al. 2006). Intrinsic load is the mental load imposed by the complexity of the content being learned and is primarily determined by instructional goals; extraneous load is unnecessary extra load due to poorly designed instruction; germane load is the load that contributes to learning. To improve efficiency in learning, learners' extraneous load should be minimized, and their germane load should be maximized. When learners try to apply their conceptual understanding in reasoning regarding an SSI, they firstly have to retrieve relevant concepts or ideas from their knowledge structures; then, afterwards, they could make use of these concepts or ideas to generate various arguments, including supportive arguments, counter-arguments, and rebuttals. Since the core concept within a student's knowledge structure may help the individual to retrieve relevant concepts and ideas more efficiently, the difficulty of the learning task is reduced (i.e., the intrinsic load is reduced). Then, he/she may be able to put more mental effort (i.e., germane load) into generating rebuttals, and consequently could achieve a higher-level informal reasoning quality. That is, the core concept within a student's knowledge structure may be helpful in reducing intrinsic load while increasing germane load.

The findings above may also provide some implications for the practice of science education. For example, to facilitate better transfer of learning in dealing with SSIs, the development of students' better-organized knowledge structures, as well as the significance of the core concept within a student's knowledge structure, should be highlighted by science instructors. In SSI-based instruction, science instructors should try to identify students' core concepts within their prior knowledge regarding the SSI, and then they should try to guide students to construct and structure relevant concepts or ideas regarding the SSI based on their core concepts. Thus, the students' knowledge structures may be well organized, and may help them achieve a higher-level of informal reasoning quality.

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