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Reasoning about science-related uncertain issues and epistemological perspectives among children

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Abstract In order to fulfill social responsibility, one of the goals in science education is to equip students with the competence of scientific reasoning. Nevertheless, psychological studies have found that people in general do not have adequate ability to make scientific arguments in everyday situations. Later studies found that the inadequate ability was associated with the development of personal epistemology. However, the conclusion is drawn mostly from research with adults or adolescents. This study attempted to examine the relation between scientific reasoning in informal contexts and the epistemological perspectives demonstrated by elementary school pupils. Participants of the study were 62 sixth graders who were interviewed to criticize two science-related uncertain issues. Content analysis showed that most children had developed the absolutist form of personal epistemology. Chi-square analyses suggested that the more multiplist view toward the certainty of knowledge and the process of knowing, the better coordination of theory and evidence as well as reflective reasoning. In addition, children's beliefs about the certainty of knowledge, source of knowledge and concept of justification were seemingly consistent across different issues. Nevertheless, content analysis showed that the criteria used to make judgments varied with problem contexts.

Keywords Personal epistemology · Epistemological development · Informal reasoning · Scientific reasoning

Introduction

In the community of science, the processes of arguments shape the foundation for the establishment of knowledge because it is through the evaluation of claim and observations

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or evidence that scientific conjectures can become public knowledge (Newton et al. 1999). Thus, the process of argumentation is the key feature of scientific reasoning. One of the goals of science education is therefore to equip students with the scientific reasoning as a "habit of mind" (AAAS 1990; Driver et al. 2000) that will help modern citizens to fulfill social responsibility in science-related policy making. In psychological research, the development of scientific reasoning has been widely discussed (e.g., Kuhn et al. 1988, Kuhn 1991; Zimmerman 2000). Nevertheless, most studies were placed in the domain-specific context, and those examining factors contributing to the performance of scientific reasoning often focused on the role of domain-specific knowledge (Zimmerman 2000). Only until recently have issues concerning reasoning in informal contexts and underlying contributors, such as motivation and personal beliefs at the epistemic level, caught serious attention (Duschl and Osborne 2002; Hofer and Pintrich 1997; Kuhn 1999; Mason and Scirica 2006; Pintrich 1999; Sandoval 2005). However, most of these studies were conducted with adolescent or adult participants. In this study, an attempt was made to discuss the role of epistemological beliefs and its effect on the performance of scientific reasoning in informal contexts among young thinkers.

According to Kitchener (1983), human cognition can be differentiated into three levels of processing when individuals are encountering ill-structured problems. First of all, the cognitive level includes memorizing, reading, perceiving, and problem solving. The second is the metacognitive level which monitors the first-level activities. The third level of activities, the epistemic level, involves personal reflections on the epistemological assumptions about knowledge and knowing. Based on the three-level model, the purpose of the present study was to examine the associations, if any, between the performances of scientific reasoning in the cognitive and metacognitive levels and the epistemological perspectives (the epistemic level of cognition) displayed by elementary pupils when they encounter issues that are science-based but ill-structured by nature.

Scientific reasoning as argumentation

As emphasized by philosophers of science, psychologists, and science educators, science is characterized by the processes of hypothesis/theory generalization (process of discovery) and hypothesis testing (process of justification) (e.g., Duschl 1990; Kuhn 1970; Newton et al. 1999; Toulmin 1958; Zimmerman 2000). It is through the process of argument in which scientific conjectures are justified by accountable evidence that scientific knowledge become pubic (Giere 1991; Newton et al. 1999). According to Toulmin (1958), the structure of argument consists of four basic components including data (evidence), claim (theory), warrants and backing. What counts as theory and evidence in science are socially agreed by the scientific community. In short, the rationality of science is founded on the ability to construct persuasive and convincing arguments that relate explanatory theories to observational data (Duschl and Osborne 2002). Accordingly, the fundamental structure of scientific reasoning is argumentation.

For a number of years, researchers have conducted studies about scientific reasoning in the domain-specific context where problems tend to be well-structured and the reasoning demonstrated by the learner is based on the application of scientific concepts and rules that will lead to a solution. Scientific reasoning habits are also important in daily experiences since they provide important ways to make rational and sound judgments about controversial issues in social contexts. Nevertheless, it was often found that students experienced difficulty of making scientific arguments when encountering such issues (e.g., Jonassen 1996; Kortland 1996; Land and Hannafin 1996; Yang 2004; Zeidler 1997). Whether the

difficulty of reasoning about the ill-structured problems is a matter of cognitive and/or developmental constraint or caused by the lack of relevant knowledge is in debate (e.g., Kuhn 1991; Zimmerman 2000). Hence, more studies are needed to reveal mechanism behind scientific reasoning in informal contexts.

Scientific reasoning in informal contexts

According to Perkins (1985a), formal reasoning is defined as reasoning over well-structured problems which have fixed premises and a well-formed argument that leads to a final conclusion. It concerns only forms of arguments and emphasizes the rules of logic. On the other hand, informal reasoning is a process that is more directly applicable to situations where the problem is ill-structured and requires the use and evaluation of evidence relevant to the problem (Means and Voss 1996; Voss et al. 1991; Willis and Schaie 1993). Formal logic along cannot effectively resolve ill-structured problems. Some scholars proposed that in informal contexts, reasoning often involves the construction of internal mental models based on the conditions of the encountered event (Johnson-Laird and Byrne 1991; Johnson-Laird and Shafir 1994; Perkins 1985a). As Perkins (1985a) argued, reasoning in informal contexts is a process of situation modeling which requires the reasoner to build a mental model of the situation that articulates the dimensions and factors involved in the issues. A variety of common sense, causal, and intentional principles are invoked to construct mental models. Based on the mental model, conclusions about the encountered issue or event can be drawn. To validate the conclusions, a thinker would need to search for alternative mental models to see if the conclusions can be falsified (Johnson-Laird and Byrne 1991). According to above arguments, formal reasoning and informal reasoning actually share the same form of argumentation. They differ largely in the structures of problems to be solved, the bases of arguments and criteria for justification.

To sum up, according to Voss et al. (1991), formal reasoning depends on formal logic. A formal argument consists of premises and a conclusion which is valid if it follows from premises that are consistent with logic rules. Thus, formal reasoning is in general restricted to well-structured problems with clear premises and well-formed arguments. Informal reasoning on the other hand involves inferences, justifications of beliefs, and explanations for observations. It is usually referred to reasoning on ill-structured problems that have numerous arguments on both sides of the problem to be solved. Soundness of informal reasoning is justified through the process of mental modeling as mentioned by mental model theorists (e.g., Perkins 1985a, b; Johnson-Laird and Byrne 1991).

As illustrated in the previous section, scientific reasoning is often regarded as reasoning on well-structured, domain-specific problems which have fixed premises and correct conclusions. In other words, it is often considered as formal reasoning. Nevertheless, problem solving in science (and many other disciplines) does not rely exclusively on formal modes of reasoning. In many incidences in science, informal reasoning plays a crucial role to solve disputes (ill-structured problems) and even results in great discoveries. In short, scientific reasoning by definition is not limited in reasoning on well-structured problems. Therefore, we used "scientific reasoning in informal contexts" in the study to emphasize informal reasoning on issues that involved uncertain scientific or technological information.

Following Kuhn's studies (1988, 1991) about scientific reasoning, we investigated skills of argument focusing on the coordination of theory and evidence. In addition, pupils' reflective reasoning was also examined in the study. To make reasonable arguments in informal contexts, a thinker needs to be critical and reflective toward one's own theory/

belief as well as viewpoints from others in order to connect supporting or refuting evidences with assertions so that argument can be moved to resolution (Kuhn 1993). The process of reflective reasoning by nature is a metacognitive activity which requires thinkers to contemplate or monitor their own cognition, knowledge and experiences related to the encountered tasks (Brown 1987; Flavell 1979; Kuhn 1999; Olson and Astington 1993; Perkins et al. 1991). Numerous studies have supported that the critical and reflective feature in reasoning is not only important in thinking about well-structured problems but also vital in daily decision makings. (e.g., Kitchener 1983; Kuhn 1999; Perkins et al. 1991; Talaska 1992). Therefore, in addition to the coordination of theory and evidence, reflective reasoning that is essential in making judgments on theory and evidence is identified as an important aspect of scientific reasoning.

In King and Kitchener's study (1994), it was found that people's reflective judgment can be classified into several developmental stages and each stage is related to distinct epistemic assumptions. Although the reflective reasoning defined in the study is not exactly the same as reflective judgment, the two constructs have the same objective in describing the ways people justify their beliefs about ill-structured problem. Hence, it was hypothesized that the development of reflective reasoning as defined in the study is corresponding to the development of personal epistemology.

Scientific reasoning and personal epistemology

While many studies suggested that the performance of scientific reasoning has much to do with the acquisition of domain-specific knowledge (Driver et al. 2000; Lehrer and Schauble 2006; Yang and Anderson 2003; Zimmerman 2000), there are studies showing that the effect of domain-specific knowledge was not clear when the problems in discussion were ill-structured by nature (Mason and Scirica 2006; Perkins 1985b). In recent psychological research, there is an increasing awareness about the active role of the personal epistemology which concerns personal beliefs about the nature of knowledge and knowing in reasoning and knowledge acquisitions. It has been shown that personal epistemology plays a role in mediating reasoning, argumentation, teaching and learning approaches (Hofer and Pintrich 1997, 2002; King and Kitchener 1994; Kitchener 1983; Kuhn 1991, 1999; Mason and Scirica 2006; Schommer-Aikins 1993; Tsai 1998, 1999, 2000; Yang et al. 2008). Kuhn (1991) showed that performances of argument skills which were found to be aligned with personal epistemological theories improve with age. Recently, a study conducted by Weinstock et al. (2006) found that older high school learners with greater epistemological sophistication identified more of informal reasoning fallacies. It seemed that the development of reasoning competencies goes along with development of personal epistemology. However, these studies were done with adolescent and/or adult participants.

Psychological research regarding theory of mind found that the development of the ability to reason and act in accordance with beliefs starts in early childhood (Lee and Homer 1999; Wellman et al. 2001). In addition, the ability to distinguish objective reality and subjective belief which is vital to the understanding of evidence evolves with age (Astington et al. 2002; Burr and Hofer 2002; Mansfield and Clinchy 2002). Accordingly, people should be able to perform scientific reasoning in early age. Based on the research about theory of mind and studies about reasoning and personal epistemological beliefs as mentioned previously, it is hypothesized in the study that a developmental trend between scientific reasoning and personal epistemology can be found among children.

In literature, various models of personal epistemology have been identified with different theoretical dispositions. For example, many researchers emphasized the

developmental nature (e.g., Baxer Magolda 1992; King and Kitchener 1994; Kuhn 1999; Perry 1999); some claimed the independence between different epistemological dimensions (Schommer-Aikins 2002), whereas others argued for systematic or ecological interrelation (e.g., Hofer 2001). Our previous studies that dealt with adolescents' reasoning with socio-scientific issues (Yang 2004, 2005) revealed a developmental link between performance of scientific reasoning and epistemological status. Hence, the developmental framework was employed in this study. The original developmental model was proposed by Perry (1999), who suggested that the forms of personal epistemology as a result of educational experiences progress through dualism, multiplicity, contextual relativism, and commitment within relativism. Individuals in different developmental stages or positions exhibit different contemplations about knowledge and learning. Other developmental models, though using different terminologies, also point to a similar progression. For example, Kuhn (1999) found personal epistemological understanding evolved from the realist, absolutist, multiplist to the evaluativist form.

Although there might be no consensus about which epistemological model can best represent the personal epistemology, the discussion about personal epistemology consistently falls into four dimensions, including certainty of knowledge, simplicity of knowledge, source of knowledge and justification for knowing (Hofer and Pintrich 1997). The former two dimensions are in the scope of nature of knowledge while the later two belong to the nature of knowing. Summarized from renowned studies (e.g., King and Kitchener 1994; Kitchener et al. 1993; Kuhn 1991, 1999; Perry 1999), a conceptual scheme from developmental perspective was constructed as displayed in Table 1. In the scheme, personal epistemology is divided by definition into two aspects which are beliefs about the nature of knowledge and beliefs about nature of knowing. Epistemological beliefs described in the scheme fall mainly into three dimensions mentioned by Hofer and Pintrich (1997), including certainty of knowledge, source of knowledge and justification for knowing. 'Simplicity of knowledge' was not included the study because the category which suggests a range of beliefs from a view of knowledge as isolated, unambiguous bits to that as highly interrelated concepts (Hofer and Pintrich 1997; Schommer 1990) was not a main focus of the study. In fact, 'simplicity of knowledge' was proposed by Schommer (1990, 1994). Many existing developmental models did not explicitly include or discuss this dimension (King and Kitchener 1994; Kuhn 1999; Perry 1999). Consequently, not much information can be referred to for classifying different epistemological perspectives. Hence, the dimension was left out in our study.

Thus in the study, questions concerning certainty of knowledge reflect belief about nature of knowledge, whereas those regarding source of knowledge, for example, views about experts or authority, and concepts of evidence and justification as discussed in many studies (King and Kitchener 1994; Kitchener et al. 1993; Kuhn 1991, 1999; Perry 1999) belong to belief about nature of knowing. Moreover, Kitchener (1983) argued that epistemic cognition includes individual's knowledge about the limits of knowledge, the certainty of knowing, the criteria for knowing and strategies used to identify problems and solutions. Hence, we explored and discuss criteria and strategies used by students for judging information to reveal the cognitive process in the epistemic level.

As presented on Table 1, the levels of epistemological understandings suggested by Kuhn (1991, 1999) were employed in the study to distinguish the different forms of epistemological beliefs while the meanings or viewpoints for each form were collected from different epistemological models. It should be noticed that since the levels or forms of epistemology are not always consistent across different models, Table 1 actually presents a rather subjective epistemological scheme that could accommodate different theoretical

Table 1 Coding scheme for epistemological perspectives (Summarized from studies by Perry 1999, Kuhn 1991, 1999 and King and Kitchener 1993, 1994)

Epistemological aspects	Classifications and interpretations
Nature of knowledge: views toward certainty of knowledge	1. *Absolutist perspective* A. Knowledge in general is certain and definite; there are right and wrong answers (Perry—Positions 1–3; Kuhn—Absolutist; King and Kitchener—Stage 2) B. Uncertainty and complexity is allowed but they are temporary and resolvable (Perry—Position 2; King and Kitchener—Stage 3) C. Reality is directly knowable via senses or authority figures (King and Kitchener—Stage 2; King and Kitchener—Stage 3) D. Assertions are facts that are correct or incorrect in their representation of reality (Kuhn—Absolutist) 2. *Multiplist perspective* A. Most knowledge is uncertain but in some areas we still have certainty about knowledge (Perry—Position 4) B. Knowledge claims are idiosyncratic to the individual: everyone has the right to her or his own opinions (Perry—Position 4; King and Kitchener—Stage 4) C. Expert claims (assertions) are opinions freely chosen by and accountable only to their owners (Kuhn—Multiplist) 3. *Evaluatist perspective* A. All knowledge is contextual (Perry—Position 5; King and Kitchener—Stage 5) B. All knowledge is disconnected from the concept of truth (Perry—Position 5) C. Expert claims/opinions can be evaluated and compared based on argument and evidence (Kuhn—Evaluatist; King and Kitchener—Stage 5)
Nature of knowing: views toward source of knowledge and concepts about justification	1. *Absolutist perspective* A. Expert/authority figure is the source of knowledge or source of right way to find knowledge (Perry—Position 2 and 3; King and Kitchener—Stages 1 and 2) B. Expert claims provide a source of knowledge to defend beliefs or ideas (King and Kitchener—Stage 3) C. Expert claims are assertions which are either right or wrong (Kuhn—Absolutist) (In other words, there are good and bad experts) 2. *Multiplist perspective* A. Expert/authority figure is the source of process of thinking (Perry—Position 4) B. Expert/authority models the use of supportive evidence (Perry—Position 4) C. Experts may disagree with each other and hence we cannot know if expert claim is right or wrong with certainty (Kuhn—Multiplist) D. Personal beliefs are justified by given reasons or evidence such as expert opinions but the choice of or evidence is situational and/or idiosyncratic. No distinctions between opinions of experts and one's own opinions (King and Kitchener—Stage 4; Kuhn—Multiplist) 3. *Evaluatist perspective* A. Expert/authority figure is the source of professional knowledge, not the source of certain knowledge (Perry—Position 5) B. Expert information should be justified by reasons and evidences (Kuhn—Evaluatist) C. Beliefs (viewpoints) are justified within a particular context by the rules of inquiry for that context and by context specific interpretations of evidence (King and Kitchener—Stage 5 and above; Kuhn—Evaluatist)

models to some maximum degree. For instance, Perry's Position 3 was originally classified as the early multiplicitism. However, since it signals an early transition from dualist to mature multiplicity, in which individuals still carry the absolutist belief that experts "will someday soon uncover the underlying Laplacean order" (Perry 1999, pp. 107), the position 3 was recognized in the study as the absolutist stand.

Given that personal epistemology seems to play a critical role in mediating human cognition, it was hypothesized in the study that children who were supposed to be in the early developmental stage of personal epistemology would show underdeveloped scientific reasoning in informal contexts. The hypothesis seems instinctive but it is the detail of the reasoning structure that the present study intends to describe.

Research questions

By examining the 6th graders' informal reasoning on science-related uncertain issues, we intend to address the following research questions.

1. What forms of epistemological perspectives regarding the nature of knowledge and knowing would the children display when they are exposed to the science-related uncertain issues?
2. To what extent would children in the study perform scientific reasoning concerning the coordination of theory and evidence, as well as reflective reasoning, when they are asked to evaluate the science-related uncertain issues?
3. To what extent would the epistemological perspectives interact with the modes of scientific reasoning investigated in the study?
4. Would the epistemological perspectives displayed by children be consistent across different contexts of issues?

Method

Participants

The target population of the study was elementary school students at the ages of 11 or 12. Participants came from 12 classes in an elementary school locating at an outskirt of Taipei (The capital of Taiwan). According to the school administrators, the majority of their students were from the middle-class families. There was almost no ethical issue in the school and all their students spoke in Mandarin. For the purpose of the study, this study employed the criteria-based selection for sampling which is used as a means of ensuring that the best candidate is selected on the basis of their ability to do the job required. (Le Compte and Preissle 1993). By this strategy, we intend to discuss the typical reasoning ability among 6th graders rather than the highest or lowest performances of ability in this age group. Two criteria for sample selection were set up. First, since the study aims to demonstrate children's typical reasoning ability, average language proficiency is required. Second, because this study also involves reading and reasoning on some science-related news, average academic performance is necessary to assure that students are in the same level of conceptual understanding. It should be noted that the use of language proficiency and academic performance as the criteria to distinguish students of typical reasoning ability could be questionable. However, since cognitive development and schooling is inseparable, it is therefore assumed that the development of reasoning ability is parallel to the experience in the formal school settings.

Based on the above prerequisites, children with average academic performances (falling around 50 and 60 percentiles) were distinguished first, and because there was no standardized language proficiency test in those schools, five or six of students in each selected class were recommended by their teacher in accordance with the overall language performance. As a result, 62 6th graders, with 37 females and 25 males, were selected for the study. Thirty-four interviewees were at the age of 12 while 28 at the age of 11 at the time when the interview was conducted.

Data collection and analysis

Although various paper-pencil tests and written measures have been developed, the interview procedure is deemed as a very significant methodological strategy to study personal epistemology because it allows for deep probing of individual's beliefs (Duell and Schommer-Aikins 2001). Considering children's limited language proficiency at such a young age, this study employed the interview method for data collection. Since the main purpose of the research design was to probe students' reasoning about theory and evidence, uncertain science-related issues were employed as the problem contexts for the study. Several science-related news reports discussing issues with contradictory or uncertain information were put into the test, including the topics of global warming, the impact of El Nino, earthquake prediction and land subsiding. By taking the knowledge background and familiarity of the issues into account, two issues were finally applied for the interview content. One was a pure-science issue that discusses whether earthquake prediction is feasible. The other is a socio-scientific issue that reports a protest in a city against the well-drilling project due to suffering from land subsidence. The design of the earthquake issue, which asked students to justify evidences from different expert sources, was to see if participants were able to tell the merits of sound evidence. Whereas, the purpose of land-subsidence issue, which tested if students were able to discriminate expert or authority opinions as personal claims or evidence-supported theories, was to examine if students understand that theory should be supported by evidence.

Several pilot interviews were then conducted to adjust the wording of the news in order to match with the participants' language proficiency. In testing, participants were not given information in advance about what kinds of issues they would be evaluating. We simply told them that there were some in-dispute news reports for them to think about. During interviewing, we also avoided wording that might imply the different nature of the two issues. Since these two issues had not been dealt with at school, students would have little prior knowledge. This will allow us to examine better the role of belief.

Appendices A and B show the interview content and procedure. As displayed in Appendix B, before reading of the earthquake news reports, individual's general views toward the certainty of knowledge were assessed (by questions 2 and 3). What followed were questions revolving around source of knowledge and concept of justification to uncover beliefs about nature of knowing in different contexts. For example, questions 5 and 6 assessed participants' beliefs about knowing in the pure-science context while questions 9 and 11 did the same thing in the socio-scientific context. The coordination of theory and evidence was assessed particularly by the last question in each issue (questions 7 and 12) where participants were asked to identify supports for personal theories or claims made by experts. At last, the reflective reasoning was probed by the third question in context of the land subsidence issue (question 10). Each of the participants was interviewed individually by the 12 questions and it took about 30–40 min for each interviewee. It should be noted that the investigation of the study was aimed to explore the effect of

personal epistemological beliefs on scientific reasoning in the everyday situations. Therefore, participants were placed in the natural setting without researchers' further assistance on reasoning.

In the study, children's epistemological understandings were first categorized in accordance with the conceptual scheme as presented in Table 1. For example, when responding to question 2 (Do you think scientists or experts have the same opinions, when considering the prediction issue? Why?), a participant's response that "No. Everyone has his own opinion" might indicate the multiplist point of view at the first glance. However, when responding to question 3 (When doing any scientific research, do you think experts would reach an agreement eventually? Why?), the student changed the initial statement to "The experts will reach an agreement eventually because there is only one answer." This participant was then assigned to the category of "absolutist perspective" because his/her statements concur with the criteria that "Uncertainty and complexity is allowed but they are temporary and resolvable" under the absolutist category as listed in Table 1. If a participant responded to interview question 2 with an initial answer that "No. Everyone has his/her own opinions" and later responded to question 3 by saying "Experts won't reach an agreement," the student would be classified as the multiplist perspective because his/her statements are consistent with the criterion for the multiplist perspective that "Knowledge claims are idiosyncratic to the individual: everyone has the right to her or his own opinions." To present the student's responses in a more contextual way, their responses in the same epistemological categories were mapped together as displayed in Figs. 1, 2, 3 so that readers can have a better picture about the patterns of student responses to interview questions that probed beliefs about knowledge and knowing. In addition, patterns of responses to interview questions were also measured in percentages or frequencies to show the differences among opinions.

As far as scientific reasoning was concerned, the coordination of theory and evidence was coded based on whether participants were able to identify science-based evidence to support their theories or expert claims. For example, when responding to question 7 (What the other experiment could be done to make you believe?" in the earthquake prediction issue by different selection groups?), statements such as "Do more experiments to see if the result was the same," "Test the fish in different conditions." etc., indicated the recognition of coordination of theory and evidence. For reflective reasoning, participants' responses to whether they were confident or unconfident with their own ideas or theories in the land-subsiding issue (question 10) were analyzed to reveal if the self-reflections were a matter of self-assurance or critical evaluation on personal thoughts. For instance, some children who responded that they were sure of their ideas because "I have read similar reports before" were identified as practicing reflective reasoning for self assurance. Some others who were not sure of personal ideas because "I do not have enough knowledge" were identified as being critically reflective on personal thoughts. The Chi-square analyses were then conducted to examine any differences between reasoning modes as well as the associations with the forms of personal epistemology. Two independent coders performed the content analyses. The results of content analysis by the two coders for each interview transcript were compared. Reliability was obtained by doubling the number of agreed categories for all interview questions, and then the doubled number was divided by the sum of numbers of categories found by the two coders. It was found that the inter-coder agreements ranged from 0.83 to 0.91 (0.88 in average). The difference was resolved through discussions.

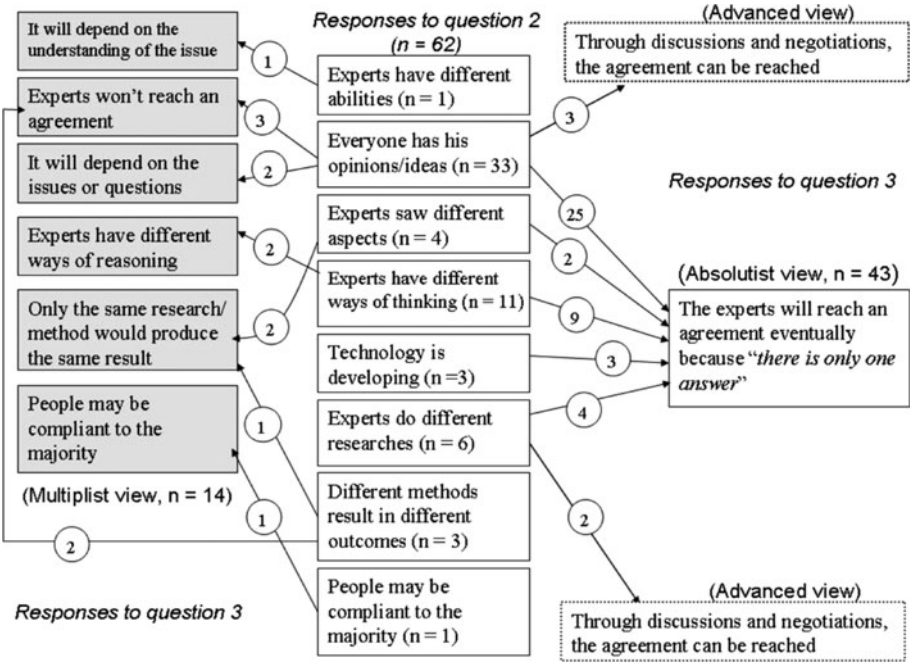

Fig. 1 Patterns of responses to questions 2 and 3. *Note*: The middle column shows the students' responses to questions 2, and the left and right columns are responses to question 3. The arrow lines indicate changes of responses from questions 2 to 3, and the numbers in circles are the numbers of changes. 1. Student responses were categorized into 'absolutist view', 'multiplist view' and 'advanced view'. The *grey boxes* indicate *multiplist* view, *white boxes absolutist* view, and *boxes with dash lines advanced* view. 2. 'Advanced view' actually suggests the evaluativist perspective. However, since only one relevant response was found, and the total number of the response was small, whether these students held an evaluativist view toward certainty of knowledge was a question that needs to be further studied. Therefore, we used 'advanced view' instead of 'evaluativist view' to imply the evaluativist position

Results and discussions

Results of the study are presented and discussed in this section. First, the analyses for the topic of personal epistemology are presented, then followed by those for scientific reasoning. Discussions of each topic are organized with respect to different problem contexts except for belief about certainty of knowledge and reflective reasoning which are assessed in earthquake-prediction and land-subsidence issues respectively.

Belief about certainty of knowledge

Even though it belongs to the domain of specific knowledge, the earthquake predication issue is largely an ill-structured problem for it involved inconclusive information from two expert groups. Therefore, the issue provided an anchor context for children to reflect on their views toward the certainty of knowledge. The analysis on the responses to the first interview question which probed students' prior belief showed that half of the participants (50%) thought that earthquakes were predictable while the other half unpredictable. The participants were then asked if experts would have the same opinion toward the same research problem such as the earthquake prediction. Initially, almost all participants answered that experts would not have

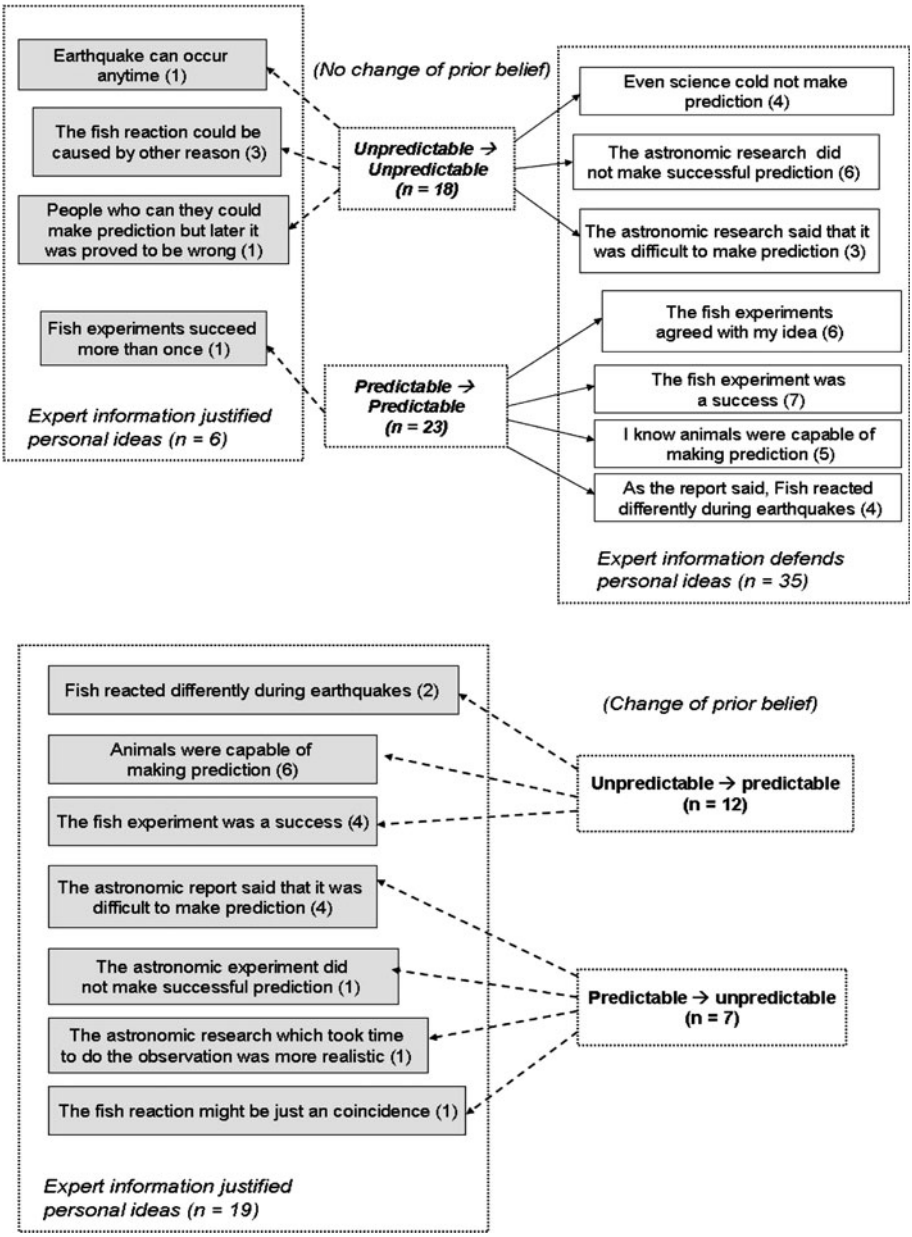

Fig. 2 Flow maps of thoughts for change or keeping of personal ideas about earthquake prediction. *Note*: 1. The *white boxes* indicates the concept of "expert information defend personal ideas" ($n = 35$) while *grey boxes* "expert information justified personal ideas" ($n = 25$). 2. *Numbers in the parentheses* show the number of respondents

the same opinion. When they were asked further whether, for all research in science, experts would eventually reach an agreement, 43 out of 62 (69.4%) interviewees expressed that experts would be lead to a final conclusion because "there is only one answer." These responses were

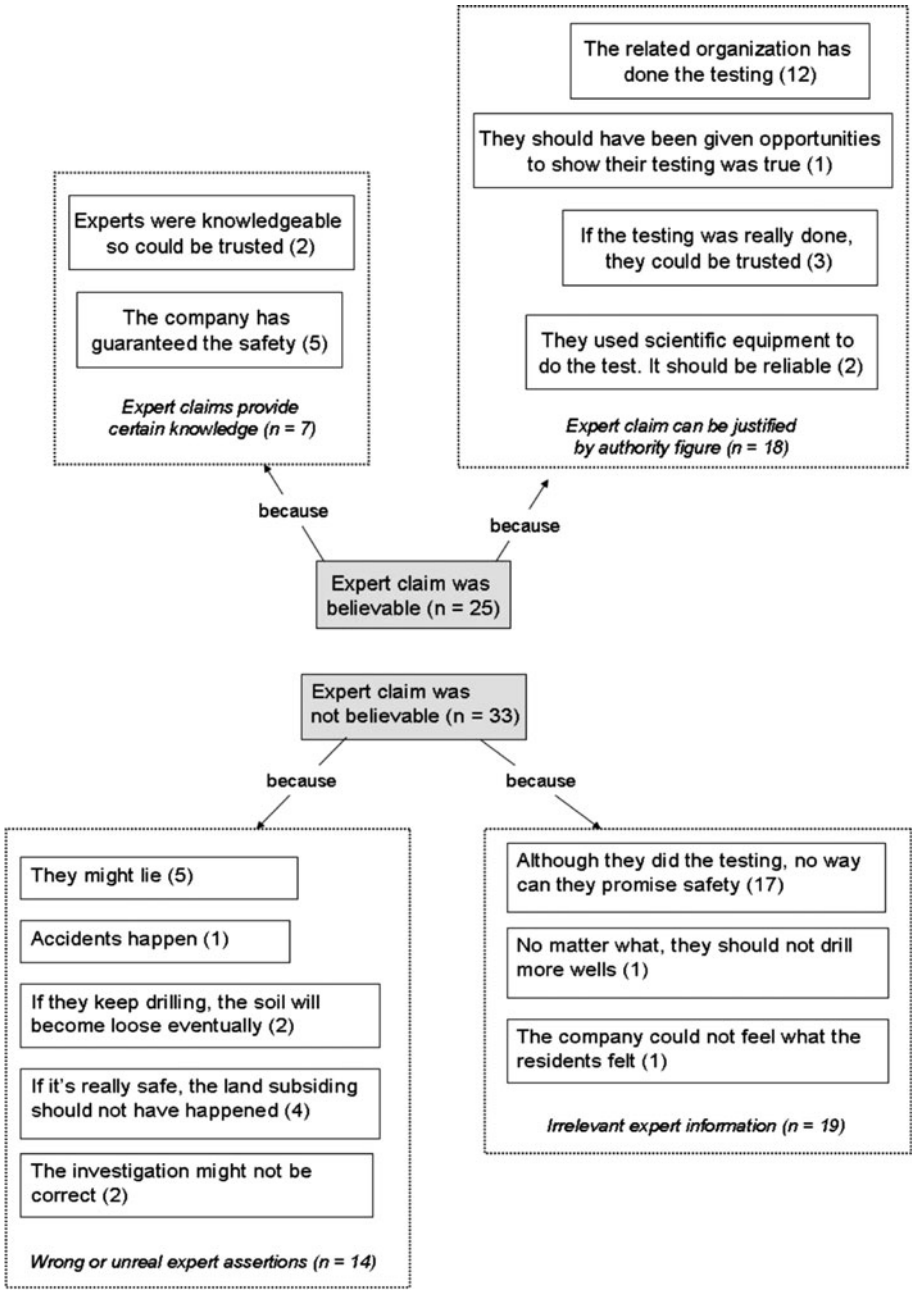

Fig. 3 Patterns of responses to question 4 concerning "sources of knowledge" in the land-subsiding issues. *Note*: 1. *Numbers in parentheses* indicate the numbers of respondents. 2. Four participants (two in the "expert claims are believable" group and two in the "expert claim are not believable" group) did not stress their reasons for why they think expert claim was excluded

assigned to the "absolutist view" toward the certainty of knowledge. The rest of the participants ($n = 14$, 22.6%) expressed the multiplist perspectives such as "experts have different ways of thinking" or "Different experiments would lead to different results." These patterns of responses were presented in Fig. 1.

As shown in Fig. 1, the central column shows responses to question 2 and corresponding numbers in parentheses. The left and right columns list responses to question 3. The arrow lines indicate changes of responses from questions 2 to 3, and the numbers in circles are the numbers of changes. For example, initially 33 responses of "Everyone has his opinions/ideas" were identified in question 2. Afterward, five out of the 33 responses remained multiplist views such as "Experts won't reach an agreement" ($n = 3$) and "It will depends on the issues or questions" ($n = 2$), 25 switched to absolutist view (Experts will reach an agreement eventually because "*there is only one answer*") and 3 evaluativist view (Through discussions and negotiations, the agreement can be reached).

According to children's responses as displayed in Fig. 1, it was apparent that most of the participants (over 69%, $n = 43$) held absolutist understanding toward certainty of knowledge. Noticeably, among the participants, five children (8%), as displayed in Fig. 1, stated that "agreement could be achieved through discussions and negotiations" when responding to question 3. Such an expression seemed to imply that these children could have achieved a more advanced personal epistemology that was getting closer to the evaluativist view that "claims or opinions can be evaluated and compared through argument and evidence." However, the number of responses was too small to be significant.

Belief about the nature of knowing

Perspectives about expert knowledge and concepts about justification in the pure-science issue context

After the initial questions that probed belief about knowledge, a news report about earthquake prediction (Appendix A, issue I) was provided for the students to read. Before reading the report, the students were probed about their prior beliefs about the prediction of earthquake (questions 1 and 2 in Appendix B). Afterward, participants were first asked to describe the news report with their own words (question 4), and then asked again if they thought earthquakes were predictable (question 5). The preliminary analysis indicated that 67% ($n = 41$) of the interviewees retained their prior belief while 33% ($n = 21$) changed after reading the report. Chi-square analysis showed that students who thought earthquakes were predictable (24 out of 31) were more likely than those unpredictable (17 out of 31) to retain their prior views (Pearson Chi-square = 3.53, Adj. R value = 1.9, $p < 0.1$).

When the participants were further asked to provide reasons for why they, after reading the news report, thought that earthquakes were or were not predictable (question 5), two kinds of views about expert knowledge were identified as displayed in Fig. 2. Those who referred expert opinions to back their ideas (indicated by the white boxes) were assigned to "expert information defends personal ideas," while those who justified personal ideas by given reasons or arguments based on situational evidences such as expert opinions or experiment results (indicated by the grey boxes) belonged to the view that "Expert information justified personal ideas." As Fig. 2 indicated, among 60 valid respondents (two participants did not give specific reasons), the majority of the children (58.3%, $n = 35$) belonged to the former class while the rest (41.7%, $n = 25$) the later one. The first type of view that "expert information defends personal ideas" was categorized as the absolutist concept of justification because, as shown in Table 1, absolutists think that

expert or authority figure is the source of certain knowledge or source of right way to find knowledge, and expert claim is also a source of knowledge to defend beliefs or ideas. Meanwhile, according to King and Kitchener (1994), those who referred situational evidences such as expert claims to justify personal beliefs reflected the multiplist concept of justification. The above findings suggested that the absolutist perspective about the process of knowing was prevailing among the majority of young children in the study.

Justification criteria activated in the pure-science context for evaluating expert information

In question 6, children were asked to choose a report that they believe more between the two conflicting experiments in which the fish experiment seemingly predicted an earthquake successfully while the astronomic equipment failed. The result was that 33 participants (53%) favored the fish experiments, 24 (39%) picked the astronomic experiment and five children (8%) could not decide which one was more believable. According to children's responses, those who favored the fish experiments made the selection mainly from the fact that the fish made the prediction successfully ($n = 19$), or the personal belief that some animals possess the prediction ability ($n = 14$). For those who went for the astronomic, the main reason was the belief that the modern equipment should be more reliable ($n = 26$). Among those who could not decide which experiment was more believable, four mentioned that the success of experiments was an important criterion for making choices. Although frequency distribution as listed in Table 2 showed that children with the prior belief that earthquake was predictable had a higher tendency to pick the fish experiment, and those with unpredictable idea went more with the astronomic experiment. The Chi-square analysis showed that there was no statistical effect of the prior belief on the selection of experiments.

Nevertheless, if the data of those who could not decide what experiment was more believable were neglected because of the limited participant number, the chi-square association became approximately significant (Adj. R value $= 1.7$, Pearson Chi-square $= 2.97$; $p < 0.1$). In summary of above findings, it was apparent that those who thought earthquake was predictable tended to favor the fish experiment which made a successful prediction while those who thought man could not make predictions on the occurrence of earthquake would prefer the astronomic research which failed to make a prediction. Children's responses implied that the consistency with personal belief was a significant criterion for evaluating expert knowledge or information. Such a "confirmation bias" phenomenon was often found in reasoning related to hypothesis testing (Baron 1994).

In brief, when participants of the study encountered conflicting scientific information, the main references for judgment were the prior belief and the certainty of experimentation. Although a couple of students mentioned the importance of repetition of the research result, the cases were not enough for the result to be significant. The analysis at this far suggested that the judgment criteria used by children in the study for evaluating expert

Table 2 Frequency cross-tabulation of different beliefs versus favored experiments in the prediction issue

Belief	Favored experiment			Total
	Fish experiment	Astronomic experiment	Both are believable	
Unpredictable	13	*15*	3	31
Predictable	*20*	9	2	31
Total	33	24	5	62

The italicized values indicate more favorable choice by the students

information in the pure-science issue matched with the absolutist views about the certainty of knowledge.

Perspectives about expert knowledge and concept about justification in the socio-scientific context

The scientific information involved in the land subsidence issue is less domain-specific because it also concerns loses of properties and human lives. The first question asked about participants' understandings toward the cause of land subsiding in the news. In general, young participants in the study knew that the well drilling, the overly use of underground water and earthquakes together, had something to do with the land subsidence. However, most of them could not explicitly explain the consequences of the excessive use of underground water. According to the oral records, there were only five children seemed to be able to describe in details about the relationship between the causes and effects of this issue.

The following question asked if the participating students agreed with the protest established by residents. Among the 62 respondents, three respondents who disagreed with the protest mentioned that there should be better ways instead of protesting for showing personal opinions. Content analysis over the oral responses given by the majority who agreed with the protest indicated that although some arguments were seemingly knowledge-based, most participants built up their personal theories about the reality largely based on past experiences, limited information from news reports and/or personal feelings. The references used for drawing personal theories were shown in Table 3.

Then, a further question asked if the participants believed the claim made by the water company who claimed the safety of well drilling. About 44% ($n = 27$) approved while 56% ($n = 35$) disapproved the authority claim. Content analysis on the reasons provided by those who believed in the authority claim, as Fig. 3 shows, found two types of views toward the expert information. One is "expert claim can be justified by expert or authority figure ($n = 18$)," and the other "expert or authority is the source of certain knowledge ($n = 7$)." For example, those who stated that the expert claim was believable because "the

Table 3 Modes of reasoning for constructing personal understandings about the land-subsidence issue

Mode of reasoning	Examples	*N*
Making inferences based on past experiences	• Many houses collapsed during the previous earthquake. It might happen again • The land subsiding have caused collapses of hundreds of houses	10
Making inferences based on in-depth scientific understanding	• If they keep pumping up the underground water, the soil will become loose. When the earthquake comes, the land will subside consequently	1
Making inferences based on the current situations or partial scientific understanding	• If there are too many wells, the houses might collapse • If they keep drilling, the subsiding will get worse • Pumping the underground water would land the land crashes • Continuing of drilling wells would cause houses crash	25
Personal feelings	• They should protect their home • In order to protect their properties, they have to do it • They were afraid of losing their houses	18
Irrelevant arguments	• Their protest will reduce the subsiding • The water company should satisfy the request	2

related organizations have done the testing," were assigned to the category of "claim can be justified by expert/authority figure" while children who simply argued, "the company has guaranteed the safety," were referred to "expert or authority is the source of certain knowledge." The former opinion seemed to suggest the multiplist perspective that authority figures model the use of supportive evidence (Perry 1999), whereas the later showed absolutist standpoint that knowledge from authority source is certain (Kuhn 1991; Perry 1999). On the other hand, content analysis on responses which disapproved authority claims, as also mapped in Fig. 3, showed that many children ($n = 19$) thought that the scientific testing or studies were unrelated to the safety issue in this case. For the rest of the children who opposed expert opinions ($n = 14$), they pointed out that the expert information was wrong. In short, children who disapproved expert information viewed "expert or authority claims as assertions which would be wrong or unreal" which actually indicated the absolutist view about the nature of knowing (Kuhn 1999). In summary, three major types of views about expert opinions were found in this part of analysis. They are "expert claim can be justified by expert or authority figure," "expert or authority is the source of certain knowledge," and "expert or authority claims as assertions which would be wrong or unreal."

Justification criteria activated in the socio-scientific issue for evaluating expert information

As mentioned above, children's responses to whether the expert claim was believable were classified into three types of views related to the concept of justification. In these responses, source of authority and relevance and/or validity of expert information were important criteria frequently mentioned by children in the study to make judgment on the validity of the expert information. In addition, a few children were able to take into account the social and human aspect of expert information. For example, some students mentioned that experts were not believable because "experts might lie" ($n = 5$) or "the company could not feel what the residents felt" ($n = 1$). Apparently, when the children were asked to evaluate expert information in the socio-scientific context, they applied complicated judgmental criteria. Nevertheless, none of the participants in the study directly pointed out that evidence was in need to support the claim, while in a previous study (Yang 2004), evidence was a crucial element for many high school students to make judgments. In other words, these young participants had limited ability to justify expert claim with evidence.

Scientific reasoning

In the previous section, we discussed students' epistemological perspectives about the nature of knowledge and knowing. In the current section, the presentation is focused on the modes of scientific reasoning regarding the coordination of theory and evidence and reflective reasoning.

Coordination of theory and evidence in the pure-science issue

To probe pupils' performance of coordinating theory and evidence, the last question in the earthquake issue asked about what the inferior experiment could do to enhance their credibility. It was found that only about 37% of the participants ($n = 23$) were able to pinpoint that any scientific claim should be supported by evidence. Further cross-

comparison between the performance of coordinating theory and evidence and choice of experiment showed that those who believed in modern scientific equipment were more aware of the relation between theory and evidence. The patterns of responses are compared in Table 4.

As displayed in Table 4, participants who picked the fish experiments attached strongly to the belief that earthquakes were predictable. Consequently, their statements focused on how the other experiment should do in order to produce the same result. This was obvious that these young participants were taking "effect as evidence of its cause" (Kuhn 1991). On the other hand, suggestions proposed by participants who went for the astronomic experiment were more objective and emphasizing the objectivity of the experiment with less effect of prior belief. Chi-square analysis found that those who picked the astronomic experiment (15 out of 24) were more capable of recognizing the role of evidence than those who chose the fish experiment (eight out of 33) (Adj. R. value = 2.9, Pearson Chi-square = 8.45, $p < 0.01$). In short, while many children did not understand that scientific claims should be evidence-based, it was those who believed in the modern scientific equipment were more aware of the relation between theory and evidence.

Table 4 Responses to "what the other experiment could do to make you believe?" in the prediction issue by different selection groups (those who favored both experiments were excluded from the analysis)

Selection	Responses	*N*	Evidence
The fish experiment ($n = 33$)	1. Continue the testing and the result will eventually come out the same	5	No
	2. Do more experiments to see if the result was the same	6	Yes
	3. Stop to do animal (fish) studies	5	No
	4. Stop to do different experiments	5	No
	5. Only if they predict the earthquakes successfully, will I believe them	2	No
	6. Explain their experiment in details	2	No
	7. Do more research about the causes of earthquakes and then make predictions	2	No
	8. Compare the two experiments	1	No
	9. Invent more advanced equipment	1	No
	10. Do the same measurement in other locations where earthquake occurred frequently	2	Yes
	11. I don't believe them at all	1	No
	12. They should prove the existence of the electric waves	1	No
The astronomic experiment ($n = 24$)	1. Test the fish in different conditions	4	Yes
	2. Test if other animals produce the same reaction	5	Yes
	3. Give up the animal research	2	No
	4. Use scientific equipments instead of fish	3	No
	5. Find the causes for the fish reaction	3	No
	6. Do more testing about fish and quakes	2	Yes
	7. Do more experiments so that others will not think it is coincident	2	Yes
	8. Use equipments to measure fish reaction	1	No
	9. Conduct a long-time observation to see if the effect does exist	2	Yes

Note: Five children who could not decide which study was more believable were excluded from analysis

Coordination of theory and evidence in the socio-scientific issue

The last question in the land-subsidence issue asked how the water company could do to enhance their reliability. Only 14 participants (about 23%) were able to pinpoint that the water company should provide further evidences, such as test results or numerical data, for their claim. For other respondents, 20 students (about 32%) demanded a termination to the drilling project, 11 (18%) suggested the continuous negotiation, seven (11%) mentioned a compensation plan, and five (8%) asked for further expert/authority information. Besides, two participants thought that the company had done enough and three suggested a replacement for the project (8%). Apparently, most participants in the study did not see the need of coordinating theory with evidence. For these children, the validity or reliability of theory was not a focus for discussion. Moreover, even though 14 of the participants recognized the role of evidence in supporting claim/theory, their ideas about evidences were often simple and undeveloped. Examples are described below.

Question: What the water company should do to make the residents believe their claim?
Participant (501): They should do more testing and experiments.
Participant (610): Do the same project in another area with few residents. If the area survives during next earthquake, the project is safe.

It should be noted that the socio-scientific issue seemed to deter the performance of coordination of theory and evidence in that the successful rate of identifying evidence dropped from 37% in the earthquake issue to 23% in land-subsidence issue.

Reflective reasoning in evaluating personal theories

After stating their views toward the protest in the land subsidence issue, the participants were required to reflect on whether they were sure of their ideas (interview question 10). Preliminary analysis showed that a high percentage of the children (70%, $n = 40$) were certain about their ideas. From children's responses, it was clear that those who were confident with their ideas stuck strongly with their prior beliefs and past experiences that represented what the children perceived as the reality. Consequently, they were unable to make critical reflections on their own thoughts. For example, two types of arguments that appeared most frequently in oral responses were statements that indicated "accidences happened before" ($n = 11$) and those that showed participants' prior beliefs or existing understanding about the issue such as "I have read similar report before" ($n = 16$). Seemingly, reflective reasoning was functioning to assure thoughts. According to Kuhn (1991), absolutists tended to show high confidence toward personal beliefs.

On the other hand, most of those who were unsure about their thoughts were more critically reflective on their own ideas or the information in the news report. For example, some children ($n = 5$) expressed the multiplist idea that whether right or wrong was a matter of personal opinions. Some others pointed out the lack of relevant information or knowledge ($n = 6$). One child mentioned the role of evidence. However, the percentage of these children was relatively low. The result was radically different from a previous report (Yang 2004) where in the similar issue only about 14% of high school students expressed confidence about their own thoughts. This finding suggested that children at this age have not developed the evidence-based reflective thinking to justify claims or personal theories. Instead, the reflective reasoning was functioning to verify what they perceived as the right answer.

Interplay between epistemological perspectives and scientific reasoning

Associations between epistemological perspectives and coordination of theory and evidence in the earthquake issue

When the views toward the agreement among experts as analyzed and displayed on Fig. 1, indicating the belief about certainty of knowledge, were cross-checked with coordination of theory and evidence by the Chi-square analysis, it was found that those in the "multiplist perspective" group coordinated theory and evidence (nine out of 14) better than did children who simply believed that that experts would reach an agreement eventually (12 out of 43) (Pearson Chi-square = 6.01, Absolute Adj. R value >2.1, $p < 0.05$, Cramer's V = 0.31, $p < 0.05$). Nevertheless, the performance of coordination of theory and evidence by those who held the advanced view was not distinguishable (two out of 5). It should be noted that since only five children were identified as having the advanced view, the power of inference was limited. As far as belief about the nature of knowing was concerned (as analyzed and shown on Fig. 2), Chi-square analysis found that those who thought that expert information justifies ideas and theories seemed to coordinate theory and evidence (14 out of 25) better than did those who thought that expert was a source for defending personal ideas (nine out of 35) (Adj. R value = 2.4, Pearson Chi-square = 5.66, $p < 0.05$). The above research findings suggested that individuals who held a more multiplist view toward the certainty of knowledge and nature of knowing performed better the coordination of theory and evidence than did the absolutists in the case of earthquake-prediction issue.

Associations between epistemological perspectives and scientific reasoning in the land subsidence issue

In the land-subsidence context, the epistemological perspective discussed in the land-subsidence context concerned the belief about knowing while modes of scientific reasoning under investigation included the coordination of theory and evidence and reflective reasoning. For the coordination of theory and evidence, Chi-square analysis showed no association with whether participants held absolutist or multiplist views toward expert claims. As far as the reflective reasoning is concerned, Chi-square analysis found that those who were sure about their ideas tended to agree more that the expert claim was an assertion that could be wrong, compared to those who were unsure of personal ideas (26 out of 39 vs. 7 out of 19). Meanwhile, those were unsure about their personal ideas believed more that expert provides certain knowledge, compared to those who were sure of personal ideas (5 out of 19 vs. 2 out of 39) (Pearson Chi-square = 7.06, Absolute Adj. R value >2.1, Cramer's V = 0.35, $p < 0.05$). Seemingly, if expert opinions were different from what the children believed or knew, they disapprove them. Only when children were not confident about their beliefs or theory, children would turn to experts or authorities for right answer. In addition to the apparent "confirmation bias" in reasoning, this finding suggested that children in the study have developed the reflective thinking that complied to the absolutist level of epistemological understanding in Kuhn's model (1999) where assertions are facts that may be correct or incorrect in their representation of reality, and critical thinking is a way to compare and determine the truth or falsehood of assertions. Meanwhile, the finding is also consistent with the second stage of the reflective judgment proposed by King and Kitchener (1994) in which individuals assume knowledge is absolutely correct but not immediately available. When the individuals find that they do not know the right answer,

they seek the right answer from authority figures who are assumed to know the truth. Above all, it was deduced that most children in the study had the absolutist understanding about the source of knowledge which could explain their poor performance of evidence-based reflective reasoning.

Interactions between personal epistemology and scientific reasoning across issues

As presented in previous sections, the Chi-square analysis suggested that in the earthquake issue which is a pure-science issue, most participants were identified as holding absolutist views about certainty of knowledge. These absolutists were later found to have lower ability of coordinating theory and evidence compared to the multiplists. Moreover, between absolutist and multiplist views toward the nature of knowing, it was those who have the multiplist view performed better the coordination of theory and evidence. In the land-subsiding issue, it was found that children's reflective reasoning served not to justify claims or personal theories but to verify personal ideas or seek for certain answers. Such a mode of reflective reasoning was often found in individuals who believe that knowledge is certain (King and Kitchener 1994; Kuhn 1999). Drawing from the above findings, this study concluded that, regardless of issues, the 6th graders might believe more that knowledge is certain, and reality is knowable even though the answer is not immediately obtainable. Experts and authorities may be wrong if their claims are different from the perceived reality or what a person believed. Consequently, the coordination of theory and evidence and reflective reasoning was not in need to be performed.

The above conclusions were further examined by the cross-analyses between the epistemological perspective about certainty of knowledge assessed in the beginning of the earthquake issue and the coordination of theory and evidence identified in the land-subsiding issue. As Tables 5 shows, the frequency distribution suggested a tendency that the multiplists (identified in the earthquake issue) also coordinated better theory and evidence in the land-subsidence issue. However, the overall effect of Pearson Chi-square was not significant.

As for the belief about the nature of knowing, no association was found between epistemological perspectives identified in the earthquake issue and the performance of coordination of theory and evidence in the land-subsidence issue. However, those who thought in the land-subsidence issue that claim could be justified by expert opinion (multiplist view) (10 out of 18) were found to be more able to identify evidence in the earthquake issue than did those with the view that expert opinions were assertions that could be wrong (absolutist view) (eight out of 33) (Pearson Chi-square = 5.10, Absolute Adj. R value >2.1, $p < 0.05$). Overall, it appeared that successful coordination of theory

Table 5 The cross comparison for views toward certainty of knowledge probed *in the earthquake issue* and the coordination of theory and evidence identified *in the land-subsiding issue*

Certainty of knowledge	Acknowledgement of evidence in supporting theory		Total
	Identified	Not identified	
Absolutist	8	35	43
Multiplists	6	8	14
Evaluatists (Advanced view)	1	4	5
Total	15	47	62

Note: Pearson Chi-square = 3.44 ($p > 0.1$)

and evidence occurred more frequently in children who held multiplist view toward the process of knowing than those with the absolutist idea.

Meanwhile, while content analysis did not show significant performance of reflective reasoning among those identified as either absolutists and multiplists in the earthquake issue, four out of five children who were recognized as holding more advanced epistemological perspective (as exhibited in Fig. 1) were found to be rather introspective toward their personal thoughts. Chi-square analysis for the views about the certainty of knowledge identified in the earthquake issue and self-assurance analyzed in the land-subsidence issue shows that the effect of the epistemological perspective about the nature of knowledge on reflective reasoning was more significant in those who held advanced epistemology (four out of five) compared to the other two groups of participants (11 out of 43 for the absolutists and four out of 14 for the multiplists) (Pearson Chi-square = 6.28, Absolute Adj. R value >2.1, $p < 0.05$). Due to the fact that there were only five participants in the advanced group and more than 20% of expected counts are >5, the symmetric measures (Cramers' V) are reported to indicate the degree of association between variables. It was found that Cramer's V is equal to 0.32 ($p < 0.05$), indicating a moderate association. The finding implied that the development of reflective reasoning could have been encouraged by the development of the advanced epistemology. However, as mentioned earlier, since there were only five children who were identified as having the advanced epistemology, more in-depth studies are in need to further clarify the association.

Drawing from above findings, it was concluded that, regardless of the domain specificity, children's performance of scientific reasoning in informal contexts can be predicted by their epistemological perspectives, This finding along with the result obtained from a previous study (Yang 2005) in which the 10th graders who were mostly identified as multiplists displayed higher successful rate of scientific reasoning support the idea that the development of scientific reasoning is parallel to the development of personal epistemology.

The effect of context on the display of personal epistemology and use of judgmental criteria

In Table 1, personal epistemology was divided into two aspects which are belief about nature of knowledge and belief about nature of knowing. In the former aspect, certainty of knowledge is the center for discussion while source of knowledge and concept about justification are the main elements entailed in belief about nature of knowing. According to Kitchener (1983), the epistemic level of cognition at work also includes individual knowledge about criteria and strategies for knowing. Hence, an investigation on the criteria used for judging information was also conducted in the study to provide more in-depth information about cognitive processing. In this section, we first inspected whether the epistemological dimensions as mentioned by Hofer and Pintrich (1997) were consistent across different issues, then explored if the criteria used by participants to evaluate conflicting information were also consistent across issues.

As presented in the issue of earthquake prediction, most children in the study held the absolutist view that experts might disagree with each other temporarily but the agreement will be reached in time because "there is only one answer." Expert or authority opinions were used largely to support or defend one's own belief. In the issue of land subsiding, although the certainty of knowledge was not specifically posted as an interview question, children's responses about why they accepted or objected the authority claim revealed that children made judgments based on whether the expert claim was aligned with what they

believed as truth or reality. Such a reasoning mode implies the early stage of reflective judgment proposed by King and Kitchener (1994) in which individuals assume knowledge as absolutely certain. In short, the qualitative result of the study suggested that, regardless of issues, most participants of the study would believe that knowledge is certain.

By cross-comparisons on the understandings about the source of knowledge and concept of justification identified in both issues, it was found that children who recognized that personal ideas can be justified by expert opinions, which is the multiplist views about source of knowledge according to Table 1, in the earthquake issue would agreed more with authority claim in the land-subsiding issue, because "it has been tested by related organizations" (11 out of 18, Adj. R value >2.1). The view that authority itself represents evidence actually complies to the multiplist perspective about justification, as discussed in Table 1, that authority figure is the source of process of thinking and models the use of supportive evidence. Meanwhile, those who took expert claim as a source to defend their beliefs, which is the absolutist views about source of knowledge as shown in Table 1, in the earthquake issue would appear to be more likely to reject authority claim in the land-subsiding issue because the expert claim was regarded as a wrong assertion (23 out 32, Adj. R value = 1.8). According to Table 1, the idea that expert claims are assertions which could be wrong signals the absolutist disposition about justification. Chi-square analysis and symmetric measure showed that the above relations almost reaches the 0.05 significant level (Pearson Chi-square = 5.63, $p = 0.06$, Cramer's V = 0.31, $p = 0.06$). Accordingly, an inference can be drawn that the displays between personal beliefs about expert as a source of knowledge and concepts about justification were consistent across different issues.

Finally, this study examined the children's judgmental criteria across issues. Although beliefs about certainty of knowledge, source of knowledge and concepts about justification seemed to be consistent across issues, children actually activated different judgmental criteria to evaluate different issues. The conclusion came from the finding by the content analysis that in the earthquake issue, most participants, when making judgments, considered whether the information was aligned with what they believed, whether the research method was objective, and whether the experiment provided conclusive results. Whereas in the land-subsiding issue, the personal feelings and values aroused by the problem context became the key judgmental criteria. Strategically speaking, participants seemingly adjusted their criteria to identify problems and choose solutions for different problem types. The above findings seem to be parallel to Louca and colleagues' claim (Louca et al. 2004) that personal epistemologies are better understood as made up of finer grained cognitive resources whose activation depends sensitively on context.

The effect of context found in the study suggests that exhibition of personal epistemology regarding belief about the nature of knowing is complicated by the issue or problem that the thinker is encountering. Thus, we need to be careful of trying to label students as 'absolutist' or 'multiplist' particularly when evidence in science can vary widely in the degree of certainty we might attach to it, and when coming up with possible experiments to validate an idea might depend on quite explicit knowledge in the domain. To obtain a whole picture of cognitive processing in the epistemic level, more studies should be conducted to examine the criteria and strategies used in different justification processes.

Educational implications

In recent years, the advancement of scientific reasoning in the form of argumentation has become one of the most important issues in science education (Duschl and Osborne 2002;

Driver et al. 2000). For one thing, argumentation activity is the heart of science which needs to be explicitly introduced to students. For another, all citizens are required to equip themselves with rational reasoning as "habit of mind" to fulfill the social responsibility. However, the promotion of argumentation in classroom has not received great attention. One and perhaps the most critical reason is that the mechanism of scientific reasoning in informal contexts is not fully understood. While domain-specific knowledge is recognized as a crucial factor affecting reasoning performance (Zimmerman 2000), in their study, Lawson et al. (2000) pointed out that there are yet-to-be identified factors that determine the extent to which the scientific reasoning can be applied. From the literature, the personal epistemological belief is identified as one of the fundamental factors that needs to be thoroughly examined (e.g., Duschl and Osborne 2002; Kolsto et al. 2006; Kuhn 1999; Kuhn et al. 1988; Lawson et al. 2000; Mason and Scirica 2006; Sandoval 2005; Schauble et al. 1991; Yang 2004, 2005; Zeidler 1997; Zeidler et al. 2005). Thus the study made an attempt to explore the association between personal epistemological beliefs and modes of scientific reasoning.

By probing the beliefs about knowledge and knowing, this study has revealed that most students in the study developed the absolutist understanding about the nature of knowledge and knowing in which experts or authorities were regarded as the source of certain knowledge to support or defend what a person believes. The epistemological perspectives regarding the nature of knowledge and concept of justification were found to be stable across issues. Nevertheless, content analysis showed that in a pure-science issue, children made judgments based on their prior beliefs/experiences and the certainty of information, but children's decision-making over the socio-scientific issue was likely to be affected by information included in the issue and the personal affections. As far as scientific reasoning was concerned, children in the study could not refer evidence to support theories or claims. And, their reflective reasoning was performed mainly to find certain answers. Although the socio-scientific context seemed to deter the performances of scientific reasoning, Chi-square analyses suggested a consistent tendency across issues that the more multiplist views toward the nature of knowledge and concept of justification, the better performance on the co-ordination of theory and evidence. The above findings suggested the performance of scientific reasoning in informal contexts among children is mediated by personal epistemological beliefs. Putting together the results of this study and previous studies with 10th graders (Yang 2004, 2005), it was deducted that personal epistemology and scientific reasoning could have been progressing together with age and educational experiences. Moreover, implied by the correlations found in the study, the development of scientific reasoning and personal epistemology could be conceptualized as a two-way process. In other words, while personal epistemological beliefs mediate the performance of scientific reasoning, the mastery of scientific reasoning might in turn help advance personal epistemology.

Hence, to support the practice of argumentation in classrooms, instructors not only need to allow pupils to experience the social process of scientific inquiry, but also should pay attention to the effect of pupils' epistemological beliefs on reasoning. What teachers can do, first of all, is to expose children in groups to anomalous or conflicting data in science which would allow them to socially construct scientific knowledge, and to evaluate critically the relation between theory and evidence (Chinn and Brewer 1998; Collins and Pinch 1993; Giere 1988). During group discussions, it is important that teachers provide proper scaffolding to guide student discourses (Duschl and Osborne 2002) so that students can gradually master argument skills. While social discussions are required to promote argumentation, individual students also need to explicitly examine their own views about

what knowledge is and how knowledge is constructed. As Hogan (2000) and Sandoval (2005) pointed out that students' personal epistemological beliefs in science will mediate the understanding of formal epistemology of science. Teachers need to encourage children to reflect on their own epistemological thoughts rather than force them to accept the formal epistemology of science. As reported in the study, questions such as "In your opinion, what scientists can do to solve the issue? And why do you think so?," "What do you think can be done more to solve the issue?" or "what information do you need to make better decision? And why is the information important?" will support students to reflect on their epistemology. Such a strategy is metacognitive by nature and is compatible with suggestions made by psychologists who advocate the fostering of critical thinking (Kuhn 1999; Pithers 2000; Tsai 2001). Moreover, given that the factor of context seems to activate different criteria for justification as shown in the study, students need to practice argument skills in various domains or contexts in order to acquire a more sophisticated judgmental system for justifying information. This task can be put into practice by properly utilizing online resources as Tsai (2004) suggested with the use of internet as an "epistemological" tool.

Nevertheless, one should not expect that the advancement of scientific reasoning and personal epistemology can be accomplished in a short period of time because, as the developmental models point out, the development of personal epistemology takes time to progress and requires educational experiences (Perry 1999). Given that elementary students are largely absolutists, teachers or instructors, as supporters or defenders for children's beliefs or thoughts, need to be open-minded to various opinions given by students and furthermore allow children to have opportunities to express their own ideas. In this way, children can learn to respect different perspectives, and it will eventually lead to the multiplist stage. For elementary students, too many judgmental or critical examinations on various viewpoints, which are thought to be useful to promote more sophisticated epistemology, might hurt their confidence in developing their ideas. Perhaps, the promotion of multiplist epistemology rather than the evaluativist form should be teachers' primary goal for students at the elementary level. In short, while it is important to provide children with opportunities to reflect on their own beliefs about knowledge and knowing, and to practice argument skills, time should be allowed for the epistemic and metacognitive levels of cognition to gradually become mature.

Future research agenda

The study discussed the association between personal epistemological belief and scientific reasoning in informal contexts among children. The influence of context on the display of personal epistemology was also analyzed. As mentioned before, while many researchers stressed that domain-specific knowledge plays a critical role on reasoning performance, some recent studies indicate that domain-specific knowledge alone cannot account for the performance of higher-level evaluative reasoning, especially in informal contexts (Lawson et al. 2000; Mason and Scirica 2006). Many studies with adolescent and adult samples have confirmed that personal epistemological understanding was a significant predictor for the reasoning performance in everyday or informal (such as socio-scientific issue) situations (Mason and Scirica 2006; Kuhn 1991; Kuhn et al. 2000). Our study with elementary samples also obtained a similar result. To further clarify the role of domain-specific knowledge in informal reasoning, more studies are needed to analyze interplays between domain-specific knowledge and the development of personal epistemological beliefs.

Attention should also be placed on to what extent domain-specific knowledge affects the improvement of argumentation skills when the levels of personal epistemological understanding or belief are considered.

A further in-depth qualitative investigation will be also helpful to reveal more diverse views of students not only on the dimensions listed in this paper, but also on their understandings about different authority figures, such as experts in general, scientists and teachers. Questions regarding how their understanding of an expert in general could be different from their understanding of a scientist or their teachers will provide more explanatory information for the findings of the study. Moreover, it has been shown previously that belief about the nature of knowing was much easily affected by the context factor. Hence, to obtain a clearer picture about the cognitive processes in the epistemic level, more studies should be conducted to investigate the criteria and strategies used in different justification processes.

As mentioned in 'Introduction' section, reflective reasoning was defined as the metacognitive activity which requires thinkers to contemplate or monitor their own cognition, knowledge and experiences related to the encountered tasks, and also critically examine opinions from various sources. Since reflective reasoning was assumed as a domain-general competence, it was assessed only in land-subsidence issue which relatively involved more of considerations on personal beliefs and opinions from difference sources. As a result, how the modes of reflective reasoning may change in different problem contexts remain unanswered. Thus, future studies should include examinations on reflective reasoning in various contexts.

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Appendix A: the interview issues

Issue 1: earth quake prediction

News Reports: Report I: China Times: Focus Section II: 2003/09/26

There are a group of eel catfish that has been raised in the Miaoli Educational Sea Park (MESK). Recently, these eel catfishes became anxious, and about 10 eel catfishes died suddenly due to jumping out of the fish tank. It was observed that the event was seemingly relevant to the big earthquake just happened. No wonder, "earthquake fish" is another name for the eel catfish. Y. C. Chang, manager of MESK, stated that past experiences showed that this phenomenon could occur both before and after earthquakes, especially before earthquakes. Y. C. Chang mentioned that about 80 eel catfishes suddenly ran into one another, and 40 of them jumped out of the fish tank and died. The workers of the MESK felt puzzled toward this event, but no one knew the reason. The idea of "earthquake fish," which is a predictor of earthquakes, popped up in the mind after the occurrence of a big earthquake the other day. In fact, eel catfishes have been behaving abnormally these days, such as moving out of the habitat, running into one another, and jumping out of the fish tank. Y. C. Chang affirmed the relationship between the abnormality of eel catfishes and earthquakes that happened in Taiwan these days.

Y. C. Chang pointed out that Japan is a country where earthquakes occur frequently, and their biologists have already put efforts on the research of catfish. The researchers observe catfishes, which are raised in the laboratory, everyday, and have found out that catfishes seem to become anxious a few days before the occurrence of earthquakes with magnitude

<5. Y. C. Chang believes that the idea of "catfish" predicting earthquake can be applied in Taiwan, so that people can get sufficient time for prevention, which will lower the numbers of tragedy.

Report II: China Times: Tao Zhu Miao Section 4: 2004/02/18

In this early morning, an earthquake with magnitude of 8.0 took place in Hokkaido, Japan. Dr. Tian, an astronomer in Japan, had predicted that there would be a strong earthquake breaking out near Tokyo, Japan, so the issue of "earthquake prediction" was triggered. Dr. Tian used astronomical instruments to monitor the electronic waves in the sky before the happening of earthquakes. Dr. Yie, a researcher from Academia Sinica in Taiwan, pointed out that the astronomic method, which is scientifically based, is one of the ways used for predicting earthquakes. However, scholars and officers in the Earthquake Record Center at the Central Weather Bureau stated that Dr. Tian's predication was actually a failure because of the wrong location he predicted.

Tian's prediction of an earthquake with magnitude of 7.2 near Tokyo, Japan in September 15 or 16 did not come true. On the other hand, no researcher made any related prediction about this rare earthquake with magnitude of 8.0 occurring this early morning in Hokkaido. Dr. Yie said that earthquake prediction is the common goal for the earthquake researchers all over the world. However, the mechanisms of earthquake are extremely complicated. The rate of a successful prediction will still be low even 20 or 30 years later. Therefore, people should spend more time and put more efforts on the prevention of earthquake hazards.

Issue II: land subsidence

News Report: Residents disagree building wells (2002/05/06)

The water company has been preparing for building the 11th well in the Eastern area of a town named "Yuanlin" yesterday, but about 20 residents went to the scene for protesting this project. The director of the water company has communicated with the residents for about 2 h, but there was no common consensus at last. The residents argued that the location where the well is going to build is located upon an earthquake fault line. One doubted that the land subsidence occurring in the major earthquake 921 in 2000 was triggered by the digging of too many wells. In order to avoid the same tragedy, the residents will have to stop the water company's project.

An excavator drove into the land in the morning for digging the well. When residents received this message, they ran to the scene and stopped the construction. Mr. Tseng, the director of the local police station, went to scene for controlling the quarrel. The residents complained that the land subsidence during earthquake 921 have caused the crash of about 100 houses. In this case, it is unreasonable for the water company to build another well. They hoped the water company could take their life safety into consideration. The residents said that in a small town like Yuanlin, there are already 10 wells. Now, the water company is going to building the 11th well, which has insulted them beyond the limit. Eastern Yuanlin is located right above a fault line which is thought to relate to the earthquake 921. Because of the well-known tragedy, residents are afraid of building more wells in the Eastern Yuanlin. The water company should think about people's feeling when they plan to build another well.

Both sides communicated to each other for about 1 h under the sun, but there was no common consensus at last. The director of the water company tried to comfort the residents by stating that he had two lands in the Eastern Yuanlin, and he planned to contribute the lands for the well building. However, the residents thought that what the director said were useless. The director said, "the proposal of building wells has been examined and approved by related departments, so it will be safe." Furthermore, he asked the residents to think about the large amount of water usage beforehand.

Appendix B: interview protocol

Questions	Purpose
Phase I: Prior to the reading of any news reports	
1. Do you think the earthquake can be predicted?	Assessing participants' prior beliefs/theories
2. Do you think scientists or experts have the same opinions, when considering the prediction issue? *Why?*	Assessing participants' beliefs about the certainty of knowledge
3. When doing scientific researches (such as earthquake predication, life in Mars, global warming, etc.), do you think experts would reach an agreement eventually? *Why?*	Assessing participants' beliefs in the certainty of knowledge
Phase II: Proceed to the reading of Issue I: Earthquake prediction	
4. What is the difference between the two experiments?	Assessing participants' prior understanding about the news report
5. Do you think *now* that the earthquakes can be predicted? *Why?*	Assessing participants' beliefs about the process of knowing by examining reasons for change or keeping of prior beliefs
6. Which news do you believe more? *Why?*	Assessing participants' beliefs about the process of knowing regarding the nature of experts and evidence, as well as criteria for judgment
7. What the experiment in which you do not believe can do more to make you believe? *Please explain it.*	Assessing participants' performance on the coordination of theory and evidence, and their beliefs about experts and evidence (*Process of knowing*)
Phase III: Proceed to the reading of Issue II: Land subsidence	
8. What was the cause for land subsiding reported in the news?	Assessing participants' prior knowledge/theories about the event)
9. Do you think the protest by residents is reasonable? *Why?*	Assessing participants' beliefs about the process of knowing regarding experts opinions and justification criteria
10. Are you sure about your ideas with respect to above questions? *Why?*	Assessing participants' reflective reasoning
11. The water company claimed the safety of the well drilling. Do you believe their claim? *Why?*	Assessing participants beliefs about the process of knowing (views toward expert opinions versus evidence)
12. What do you think the water company should do to make the residents believe their claim? *Please explain it.*	Assessing participants' performance on the coordination of theory and evidence, and their beliefs about experts and evidence (Process of knowing)

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