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# Eliciting Taiwanese high school students' scientific ontological and epistemic beliefs

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**ABSTRACT**

This study employed the interview method to clarify the underlying dimensions of and relationships between students' scientific ontological and epistemic beliefs. Forty Taiwanese high school students were invited to participate in this study. Through content analysis of the participants' interview responses two ontological dimensions including 'status of nature' and 'structure of nature' were identified and found to be associated with each other. The two epistemic dimensions 'knowledge' and 'knowing' aligned with past literature were also categorised. Besides five pattern variations in terms of the aforementioned four dimensions were recognised based on the students' philosophical stances on their scientific ontological and epistemic beliefs. According to the Chi-square test results both dimensions of scientific ontological beliefs were significantly related to the two dimensions of scientific epistemic beliefs respectively. In general the students who endorsed a more sophisticated ontological stance regarding the status and structure of nature tended to express a more mature epistemic stance toward scientific knowledge and ways of knowing. The results suggest that the maturation of students' scientific epistemic beliefs may serve as a precursor and the fundamental step in promoting the sophistication of students' scientific ontological beliefs.

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## Introduction

In the past several decades, researchers have stressed the importance of learners' ontological as well as epistemic views of science for their learning processes and outcomes (e.g. Sere, 2002; Slotta & Chi, 2006). What learners think about the nature of reality as well as knowledge and knowing have been regarded as critical metaphysical assumptions in science education and a prerequisite condition to achieving scientific literacy (Duit & Treagust, 2003). As depicted by researchers (Friedrichsen, Van Driel, & Abell, 2011), questions about the nature and status of scientific knowledge could be conventionally dissected into two major dimensions, including the ontological dimension which addresses the status of reality or the existence of scientific objects, and the epistemological dimension which concerns the issues such as what counts as valid knowledge, and how knowledge is produced and warranted as reliable. Consequently, it is essential to understand students'

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assumptions about science, such as their ontological and epistemic views of the holistic nature of science.

Likewise, in science learning, conceptual change researchers (e.g. Duit & Treagust, 2003; Taber, 2006) have approached science learning as being embedded in various theoretical frames such as the epistemological, ontological, and affective dimensions. They have described that learners' conceptual change processes not only involve an epistemological perspective but also pertain to how they view the ontology of science (Duit & Treagust, 2003), implying the potential link between learners' scientific ontological and epistemic beliefs. However, there are very few studies investigating learners' scientific ontological beliefs simultaneously with their scientific epistemic beliefs, indicating that more endeavours should be contributed in this dimension. Therefore, in order to understand students' belief systems in terms of their scientific ontological beliefs as well as their scientific epistemic beliefs simultaneously, this preliminary study employed the qualitative method to clarify the underlying dimensions of and relationships between scientific epistemic beliefs and ontological beliefs.

### *Synthesising ontological and epistemological stances in science*

Ontology is the study of reality and the basic categories of being (Greene & Yu, 2014; Packer & Goicoechea, 2000). One of the core ontological questions concerns the form and nature of reality and what can be known about it (Lincoln & Guba, 2000). Philosophers of science have strived to understand the material existence of the world and the objects in it, namely, the role the external world of nature plays in our knowledge construction activities (Kwak, 2001). Philosophers of science, in order to address the issue of scientific knowledge, have been striving to explain ontology in terms of the material existence of the world and the objects in it (Nola, 2004). In general, these aspects regarding the ontology of science can be divided into two opposing positions within a continuum including realist and idealist (e.g. Nola, 2004; Yore, Hand, & Florence, 2004). Realist ontology claims that there is an existing material world apart from, and independent of, human experiences and human mental activity. In other words, this stance views reality as something 'out there' to be apprehended (Denzin & Lincoln, 2000). The other ontological position is associated with idealism. That is, an idealist tends to maintain that either there is no world outside of human experience or that such a world is ideational and constructed by our discourse and theorised as an internally coherent system (e.g. Staver, 1998). Such a reality (i.e. scientific truth) is socially constructed, subjective, and contingent (Yore et al., 2004).

Epistemology is the study of beliefs about the origin and acquisition of knowledge (Hofer, 2004). In other words, it refers to the processes that describe the activities of inquiry and determine the form of knowledge (Duschl, 1990). In a philosophical sense, epistemology concerns professional theorising about knowledge that is deeply rooted in the Greek words 'episteme' (knowledge) and 'logos' (theory) (Kitchener, 2002). In science education, researchers often characterise individuals' epistemic views on an empiricist/constructivist continuum (e.g. Tsai, 1998). Constructivist epistemology assumes that 'knowledge is created or constructed by the learner on the basis of certain inherent cognitive characteristics of the individual learner and in relation to existing frameworks of knowledge in memory' (Tsai, 2001, p. 970). On the contrary, empiricist epistemology mainly views that 'scientific knowledge is a discovery of an objective reality external to ourselves and discovered by observing, experimenting or application of a universal scientific method. It also asserts that evidence in science accumulated carefully will produce infallible knowledge' (Tsai, 2006, p. 364).

Based on the above-mentioned, individuals' stances on ontology and the epistemology of science exist in a close relationship and could be broadly categorised as either the traditional or the postmodern stance (e.g. Good & Shymansky, 2001; Loving, 1997; Yore et al., 2004). The traditional stance indicates a realist ontology and empiricist epistemology, while the postmodern stance suggests an idealist ontology and constructivist epistemology. In this study and the following sections, this classification will be used to delineate the students' scientific ontological beliefs and scientific epistemic beliefs. Table 1 also summarises the critical viewpoints of the traditional and postmodern stances.

### Conceptualising ontological beliefs

Ontological beliefs represent the role one's beliefs about the external world of nature plays in one's knowledge of the discipline. Although the term ontological belief has not been frequently explored in educational research, a few researchers have still argued that individuals can hold multiple ontological beliefs about the origin, permanence and changeability of reality and being (Kuhn & Weinstock, 2002), collectively comprising a personal ontology (Olafson, Schraw, & Vander Veldt, 2010). In the domain of science, scientific ontological beliefs may be regarded as the beliefs about 'the ontological status of entities postulated by scientific theories' (Abd-El-Khalick, 2012, p. 359). Chinn and Brewer (1993) have defined scientific ontological beliefs as 'the fundamental categories and properties of the world' (p. 17). They also contended that each individual's deeply-held ontological assumptions, commitments, or beliefs are very resistant to change. In the current study, the notion of scientific ontological beliefs is defined here as the beliefs about the ontological status of entities (i.e. nature and the material world) postulated in scientific theories.

A small number of available empirical studies in science education have managed to approach the issue of students' beliefs about ontology of science and scientific knowledge

**Table 1.** The two stances regarding ontology and epistemology of science used in this study.

| Stance | Classification | Assertions |
|---|---|---|
| Traditional stance | Realist ontology | • There is an existing material world apart from, and independent of, human experiences and human mental activity<br>• Scientific reality is out there and resides in nature waiting to be discovered |
| | Empiricist epistemology | • Scientific knowledge is a discovery of an objective reality external to ourselves and discovered by observing, experimenting or application of a universal scientific method<br>• Evidence in science accumulated carefully will produce infallible knowledge |
| Postmodern stance | Idealist ontology | • Either there is no world outside of human experience or such a world is ideational and constructed by our discourse and theorising as an internally coherent system<br>• Reality (i.e. scientific truth) is socially constructed, subjective, and contingent |
| | Constructivist epistemology | • Scientific knowledge is created or constructed in the context of people's own experiences, beliefs, and cultural value<br>• Emphasise the tentative nature of science knowledge, the theory-laden quality of scientific exploration and the role of conceptual change in the progressive development of scientific understanding |

(Kang, Scharmann, & Noh, 2005; Lucas & Roth, 1996; Reiner & Eilam, 2001; Roth & Lucas, 1997; Sere, 2002; Séré et al., 2001). For example, Roth and Lucas (1997) analysed 23 high school students' written discourse about ontological, epistemological, and sociological claims relating to nature and scientific knowledge in the context of physics. After differentiating the participants' ontological claims, nature and the physical world could be regarded as either an inherent and a-priori structure (i.e. absolute truth) or as having no presumed or inherent structure, depending on how individuals describe the physical world (i.e. invented reality). Séré et al. (2001) also identified two extreme ontological tendencies based on the secondary school and university students' responses regarding the image of science, including 'identity of the real world with its scientific modelling/distance of the real world from its scientific modelling' (p. 504). However, these available dimensions of the ontology of science are usually scattered across different studies and lack a more comprehensive outline. The current study aims to fill this gap by exploring high school students' scientific ontological beliefs by means of the interview method to identify potential dimensions. It is believed that the identified core dimensions may serve as an empirical foundation for future research, and will contribute to an understanding of students' characteristics of science learning.

## Situating epistemic beliefs

Educational psychology research has mainly focused on empirical observations of the epistemology of laypersons called personal epistemology (Briell, Elen, Verschaffel, & Clarebout, 2011). After a scrupulous review, Hofer and Pintrich (1997) proposed the 'epistemological theories' to conceptualise individuals' epistemological beliefs. In their model, they identified two core dimensions, *nature of knowledge* and *nature of knowing*. The former refers to the issues of what constitutes knowledge, how it is known, and whether it can be known with any certainty, whereas the latter relates to how individuals come to know, the beliefs they hold about knowing, and how these epistemological premises influence their thinking and reasoning. Due to the significance of this seminal work, the epistemological theories have been widely employed to guide later works in the line of personal epistemology research.

It should be noted that early personal epistemology research has often characterised individuals' beliefs about knowledge and knowing as 'epistemological beliefs' (e.g. Schommer, 1990). Evolving overtime, personal epistemology researchers have begun to differentiate the two candidate adjectives (i.e. epistemic or epistemological) in this line of research. Mason and Boldrin (2008) further explicated that epistemological beliefs should be conceived in terms of beliefs about the study of epistemology, while epistemic beliefs pertain to the beliefs about knowledge and knowing.

In addition, one of the important issues with respect to personal epistemology research is whether epistemic beliefs are domain-general or domain-specific. A number of researchers have addressed this particular issue (e.g. Buehl & Alexander, 2001; Hofer, 2006) or conducted relevant empirical studies (e.g. Buehl, Alexander, & Murphy, 2002; Greene & Yu, 2014). Investigations of students' scientific epistemic beliefs have received much attention from science education researchers since the last decade (e.g. Conley, Pintrich, Vekiri, & Harrison, 2004; Topcu, 2013; Tsai, Ho, Liang, & Lin, 2011). By and large, the constructs regarding scientific epistemic beliefs which have emerged from the available studies can be broadly referred to as the two main dimensions (i.e. *nature* of knowledge and *nature* of knowing) that are parallel to the model proposed by Hofer and Pintrich (1997). In turn, there is wide recognition that personal epistemic beliefs appear to be both domain-general and domain-specific and may be a developmental trend from the general to the specific epistemic beliefs (Muis, Bendixen, & Haerle, 2006). In other words, individuals may hold their beliefs about knowledge as a whole as well as specific academic knowledge (e.g. science) (Buehl & Alexander, 2001, 2005).

### *The underlying relationships between ontological beliefs and epistemic beliefs*

Science education researchers have suggested that ontological beliefs and epistemic beliefs should be distinguished and yet may be closely interrelated (e.g. Coll & Taylor, 2001; Sere, 2002; Yore et al., 2004). Levers (2013) indicated that individuals' beliefs about epistemology may be confined to and associated with their ontological beliefs. Researchers have claimed that ontology of science is metaphysical and regarded as more entrenched in a theoretical sense (e.g. Duit & Treagust, 2003; Packer & Goicoechea, 2000). This perspective implies that scientific epistemic beliefs are in a more peripheral and outer position, while scientific ontological beliefs are in a more centred and inner position. Olafson et al. (2010) also stated that 'the two are related because beliefs about how we come to know reality necessarily involve epistemological assumptions' (pp. 244–245).

Several scholars have indicated that individuals' ontological beliefs and epistemic beliefs are two fundamental elements of comprising their own worldviews or belief systems (Matthews, 2009; Schraw, 2013; Schraw & Olafson, 2008). Recent empirical evidence seems to support this assertion to a certain extent. In a series of studies conducted by Olafson et al. (e.g. 2010; Olafson & Schraw, 2006), they developed a four-quadrant scale method and invited teachers to situate themselves on a two-dimensional Cartesian coordinate system with respect to epistemic beliefs and ontological beliefs. One of the interesting findings was the fact that they found a significant positive relation between the participants' ontological and epistemic dimensions. In sum, the issue of whether researchers should distinguish these two kinds of beliefs remains unclear. Moreover, exploring the relationships between them has not gained much attention until recently and has seldom been investigated empirically. Therefore, this study managed to bridge the gaps by providing empirical evidence regarding the underlying relationships.

## Research purpose and questions

By synthesising the aforementioned literature, the current study attempted to explore and identify Taiwanese high school students' scientific ontological and epistemic beliefs in a coherent manner. The corresponding research questions are presented below:

1. By interviewing the Taiwanese high school students who participated in this study, what are their scientific ontological beliefs?
2. By interviewing the Taiwanese high school students who participated in this study, what are their scientific epistemic beliefs?
3. What are the Taiwanese high school students' pattern variations in terms of their stances on scientific ontological and epistemic beliefs?

4 What is the interplay between the Taiwanese high school students' scientific ontological beliefs and epistemic beliefs?

## Method

### Participants

A total of 40 Taiwanese 10th, 11th, and 12th graders (25 males and 15 females) were invited to participate in this study. The students, with an average age of 16.7 years, came from 10 classes in 4 high schools located in northern Taiwan. One of the researchers first made contact with school administrators and class teachers to gain permission to conduct interviews. After permission was granted, volunteer students were invited to participate in this study. The involved participants were informed that the purpose of interviews was to understand their views and ideas about science and were instructed not to prepare for the interviews in advance. Each participating student was interviewed individually by a trained researcher. It should be noted that each student was interviewed twice. Since ontological beliefs are regarded as more entrenched and fundamental, the students' responses with respect to ontology of science were obtained at the first interview. During the first interview, the students responded to 7 questions regarding their scientific ontological beliefs, while in the second interview the students responded to 11 questions regarding their scientific epistemic beliefs. The average length of the first and second interview for each student was approximately 20–30 minutes, respectively.

### Interview protocol

In order to understand the participants' scientific ontological and epistemic beliefs, several rounds of constructing interview questions were carried out. In the beginning, the researchers reviewed the available literature and began to generate interview questions. After establishing the interview protocol, an experienced science education researcher was invited to evaluate the adequacy of the interview questions to ensure content validity. Two experienced high school science teachers as well as 10 high school students were invited to evaluate the appropriateness of the interview questions. The interview protocol (see Appendix) included two main parts. In the first part, seven interview questions regarding scientific ontological beliefs were constructed based on the past relevant studies (e.g. Abd-El-Khalick, 2012; Greene, Azevedo, & Torney-Purta, 2008; Kwak, 2001; Olafson et al., 2010).In addition, as presented in the second part of the protocol, the guiding interview questions for understanding the students' scientific epistemic beliefs were created mainly from relevant studies (e.g. Topcu, 2013; Tsai, 1998, 2002) giving a total of 11 questions.

### Data interpretation and analysis

Each interview was conducted in a semi-structured format based on the interview protocol. All of the individual interviews were audio-recorded. The interviews were then fully transcribed for further analysis. The verbatim transcripts constituted the source of analysing the students' scientific ontological and epistemic beliefs.

**Table 2.** The analysis framework used in this study.

| Belief system | Dimension | Stance |
|---|---|---|
| Scientific ontological beliefs | *Status of nature* | • Traditional: realist ontology (realist) |
| | *Structure of nature* | • Postmodern: idealist ontology (idealist) |
| Scientific epistemic beliefs | *Knowledge* | • Traditional: empiricist epistemology (empiricist) |
| | *Knowing* | • Postmodern: constructivist epistemology (constructivist) |

Each identification number stands for the student's class number and identification number. For instance, the number '31812' means that the interviewee is a student from class 318 and is number 12 in his/her class.

Content analysis was utilised to analyse the students' responses to the interview questions. In general, sentences within messages were used as the basic unit of analysis. Complete paragraphs may be sometimes used as the unit of analysis to maintain the meaning of a given sentence as well (Denzin & Lincoln, 2000). One of the researchers in this study read all of the verbatim transcripts first and developed first-level codes as keywords from each question for summarising segments of data. Relevant text segments were further categorised, with the goal of keeping the codes as representative of the participants' meaning as possible. Segments of data were classified under common codes, and then codes were combined into overarching categories (Creswell, 2008). In addition, as to establish the reliability of the analysis in terms of inter-rater agreement, a trained assistant was asked to analyse the representative sentences from the verbatim transcripts.

After establishing the dimensions for scientific ontological and epistemic beliefs, each student's scientific ontological beliefs and scientific epistemic beliefs were classified, respectively, based on the traditional/postmodern framework as presented in Table 2. For the scientific ontological beliefs, the traditional stance refers to the students' orientations toward realist ontology (realist), while the postmodern stance represents the students' orientations toward idealist ontology (idealist) in the two dimensions (i.e. *status of nature* and *structure of nature*). Similarly, for the scientific epistemic beliefs, the traditional stance suggests the students' orientations toward empiricist epistemology (empiricist), whereas the postmodern stance indicates the students' orientations toward constructivist epistemology (constructivist) in the two dimensions (i.e. *knowledge* and *knowing*). In this study, each student's ontological and epistemic beliefs were coded according to his/her predominant stance expressed in the interview.

Hence, by means of the framework (Table 2), the students' pattern variations in terms of their scientific ontological and epistemic beliefs in the four dimensions were revealed. Furthermore, to initially understand the relations between the acquired dimensions of the students' scientific ontological and epistemic beliefs, Chi-square tests were performed. The underlying relationships between the students' ontological and epistemic beliefs were also examined by means of Chi-square tests.

## Results

### *Scientific ontological beliefs obtained from the interviews*

Two dimensions, namely '*status of nature*' and '*structure of nature*,' were categorised from the participants' verbatim transcripts. In this study, the students' dominant statements representing the status of nature as reality existing independently of human experience were sorted into the 'status of nature' dimension. Similarly, students' dominant statements illustrating their ontological views on the structure of nature as either inherently organised or as having no presumed structure or order were classified into the 'structure of nature' dimension. Furthermore, the students' ontological beliefs about the two dimensions were further categorised either as 'realist' or 'idealist' stances based on the traditional/postmodern framework.

### *The 'status of nature' dimension of the students' scientific ontological beliefs*

As previously mentioned, students who were classified as 'idealist' regarding the 'status of nature' dimension believed that there is no reality existing outside of human experience. What we observe about the natural world is ideational and is constructed by personal or/and social discourse and theorising. For example, the students stated that:

> 20511: Everybody has his/her own perspective of the natural world. Each perspective comes from how he/she defines the world. Everybody gives meaning to the natural phenomena. The scale of nature is too broad. It is impossible for people to have the same reality about nature.

> 30812: We can never be sure that the reality really exists. Because I think this so-called reality, every second, is changing. How we define reality is dependent upon everyone's view. Science is just a standard and a guide for us to understand the world.

Moreover, students who were categorised as 'realist' regarding the 'status of nature' dimension mainly believed that the material world and its physical entities as a true reality exist independently of human experiences and knowledge. Scientific knowledge represents nature as it really is. For instance, the students answered that:

> 10319: The reality is really there no matter what we do. Scientists, sometimes, are a bit closer to this reality if they find something or come up with a theory to describe the independent reality.

> 30822: I think scientific knowledge is there in nature; it is not invented by scientists. The reality does exist independently because there is a real world apart from what we can sense, although today we haven't acquired the whole picture of this real world yet.

### *The 'structure of nature' dimension of the students' scientific ontological beliefs*

The students labelled as 'idealist' regarding their ontological beliefs about the 'structure of nature' dimension tended to consider that nature itself has no presumed structure or order. For example, they responded that:

> 20506: I do not consider that nature has its own structure or rule. Nature, sometimes, lacks unity and coherence from the perspectives of human beings because of our own limits in terms of our senses.

> 10321: I don't think nature has an organized structure or contains internal rules. These rules are created and defined by humans. Sometimes it may go wrong and lead to a different situation.

Furthermore, students who were labelled as 'realist' regarding their beliefs about the 'structure of nature' dimension mostly believed that nature is inherently structured by laws and a priori to human apperception. For instance, the students replied that:

> 30512: I think each natural phenomenon is well-connected to one another … .Like cycles such as seasons and … . Everyone has to go through birth, aging, sickness and death. That is the rule of nature.

> 20714: Although scientists have found some exceptions, I still think, basically, nature has its own structure like the food chain. For instance, the extinction of any species would affect the balance of the entire biological chain.

For the reliability of the categorisation of the students' scientific ontological beliefs, another independent analyst conducted the categorisation processes. The two coders then assessed their overall inter-rater reliability as being 0.84, suggesting that the results of categorisation were adequately reliable. Later, the two coders resolved the discrepancies between them by discussing case by case, and, in turn, achieved the final agreement. Accordingly, 62.5% ($n = 25$) of the students held a 'realist' stance on the 'status of nature' dimension. On the other hand, the 'idealist' stance was less expressed by the students ($n = 15$). With respect to the 'structure of nature' dimension, one-third of them ($n = 30$) still possessed the 'realist' stance. In other words, the majority of students believed that nature is inherently structured and ordered by laws and rules.

Furthermore, the associations between the students' stances on the 'status of nature' and the 'structure of nature' dimensions were examined via Pearson Chi-square tests. As shown in Table 3, the results reveal that the 'idealist' stance on the 'status of nature' dimension tends to be associated with the 'idealist' stance on the 'structure of nature' dimension ($n = 10$), whereas the 'realist' stance on the 'status of nature' dimension tends to be associated with the 'realist' stance on the 'structure of nature' dimension ($n = 25$) (*Chi-square* = 22.22, *phi* = 0.75, $p < .001$). The above-mentioned results, thus, indicate that the two ontological dimensions are closely associated.

## *Scientific epistemic beliefs obtained from the interviews*

According to the framework of Hofer and Pintrich (1997), epistemic beliefs could be broadly categorised into the two core dimensions of the nature of knowledge and the nature of knowing. In this study, we adapted this framework into the two dimensions, 'knowledge' and 'knowing,' to understand the interviewees' two fundamental scientific epistemic beliefs which were categorised from their verbatim transcripts. In the current

**Table 3.** The associations among the students' beliefs concerning status of nature and structure of nature ($N = 40$).

| | | Structure of nature | | |
|---|---|---|---|---|
| Status of nature | | *Idealist* | *Realist* | Total |
| *Idealist* | *Count* | 10 | 5 | 15 |
| | *Expected count* | 3.8 | 11.3 | |
| | *Adjusted residuals* | 6.3 | −6.3 | |
| *Realist* | *Count* | 0 | 25 | 25 |
| | *Expected count* | 6.3 | 18.8 | |
| | *Adjusted residuals* | −6.3 | 6.3 | |
| Total | *Count* | 10 | 30 | 40 |

*Chi-square* = 22.22, *Phi* = 0.75, $p < .001$.

study, students' interview responses regarding the 'knowledge' and 'knowing' dimensions were categorised either as constructivist or empiricist based on their dominant statements.

### The 'knowledge' dimension of the students' scientific epistemic beliefs

As mentioned above, the students who were categorised as 'constructivist' concerning the 'knowledge' dimension regarded scientific knowledge as subject to change over time, and believed that absolute truth does not exist. Moreover, they believed that scientific knowledge is one of many forms to explain scientific phenomena. For example, these 'constructivist' students stated that:

> 20514: Although the theories postulated by scientists may be sometimes evolved or improved because of time or new technology and skills, I think that scientists would never arrive at the endpoint of their journey of finding the ultimate truth for the physical world. To be more critical, it is possible that the absolute truth never exists. The accepted scientific knowledge or theories today are just based on the consensus of a group of scientists. The abandoned theories may be correct again in the future. Who knows?

> 30123: Scientific knowledge is subject to change. The contemporary science is just decided by the dominant scientific community. These scientists discuss, negotiate, and reach agreement on the knowledge and theories. They give reasonable meanings and explanations for the phenomena happening around us.

Moreover, the students whose orientation toward an 'empiricist' stance regarding the 'knowledge' dimension may agree that scientific knowledge is used to represent the real world and absolute truth. Science is based on observations of nature and the physical world. Scientists just need to prove whether their theories are right or wrong by conducting experiments. The purpose of scientific knowledge is to describe the physical world as accurately and precisely as possible. For instance, the students responded that:

> 10902: I believe that scientific knowledge will represent truth eventually when we have a technology breakthrough to observe the phenomena precisely.

> 21522: I think the process of what scientists do is to find the absolute truth about the physical world. That is the one and only answer.

> 30115: The purpose of scientific knowledge is to accurately describe the natural world that surrounds us. One day, scientists will find absolute truth with 100 percent certainty.

### The 'knowing' dimension of the students' scientific epistemic beliefs

The students labelled as having 'constructivist' scientific epistemic beliefs in terms of their beliefs about the 'knowing' dimension tended to consider scientific knowledge as being derived from and related to scientists' intuitive ideas and their own thoughts. The existence of various theories is due to the scientists' different standpoints or perspectives. That is, scientists may weigh and prefer a particular theory to other competing ones, even though they aim to describe the same phenomena. For example, the students answered that:

> 31023: Scientists have their own hypotheses derived from, for example, their ideas, imagination, etc. of a phenomenon. Because of the different interpretations of different scientists, they elaborate their own theories along different paths.

> 10408: Starting from the beginning, scientists' own training processes are varied. They may have different interpretations and inferences of natural phenomena. What they observe about this phenomenon may be just the tip of the iceberg. Consequently, the interaction between what they think and what they observe may lead to different paths of scientific theory.

Moreover, the students whose scientific epistemic beliefs in the 'knowing' dimension featured as 'empiricist' mostly regarded that scientific knowledge originates from and resides in external authorities and is independent of themselves. The ideas of scientists are irrelevant to their work. The way of conducting experiments may sometimes be misleading and they may fail to see the true picture. Besides, scientists are regarded as the reproducers of nature and the physical world. The important priority for them is to discover scientific knowledge from the external world. For instance, the students replied that:

> 31330: Scientists are the people who aim to discover the rules or principles of the natural world. They are still under the regulation of nature. No one can escape it.

> 20521: I think that, if different scientists conduct the same experiment, they would definitely get the same results. If not, there must be something wrong with the procedure. I cannot imagine that the conclusions would be different at all.

For the inter-rater reliability of the classification of the students' scientific epistemic beliefs, another trained analyst was invited to perform the classification processes. In turn, the agreement for the classification of students' scientific epistemic beliefs was 0.86, suggesting that the results were sufficiently reliable. In addition, the disagreements and discrepancies between the researchers were discussed case by case, and final agreement was reached. In all, 60% ($N = 16$) of the students possessed an 'empiricist' stance on scientific epistemic beliefs, while 40% of them embraced a 'constructivist' stance in the 'knowledge' dimension. As for the 'knowing' dimension, most students (70%, $N = 28$) held 'constructivist' scientific epistemic beliefs in this study.

Moreover, concerning the associations between scientific epistemic beliefs about knowledge and knowing, the Pearson Chi-square test results shown in Table 4 indicate that constructivist beliefs about knowledge tend to be related to constructivist beliefs about knowing, while empiricist beliefs about knowledge tend to be associated with empiricist beliefs about knowing (*Chi-square* = 11.43, *Phi* = 0.54, $p < .01$). In other words, it seems that epistemic beliefs about knowledge and knowing are closely associated.

**Table 4.** The associations among the students' beliefs about knowledge and knowing ($N = 40$).

| | | Knowing | | |
|---|---|---|---|---|
| Knowledge | | *Constructivist* | *Empiricist* | Total |
| *Constructivist* | *Count* | 16 | 0 | 16 |
| | *Expected count* | 11.2 | 4.8 | |
| | *Adjusted residuals* | 4.8 | −4.8 | |
| *Empiricist* | *Count* | 12 | 12 | 24 |
| | *Expected count* | 16.8 | 7.2 | |
| | *Adjusted residuals* | −4.8 | 4.8 | |
| Total | *Count* | 28 | 12 | 40 |

*Chi-square* = 11.43, *Phi* = 0.54, $p < .01$.

### The pattern variations of the students' ontological and epistemic beliefs

Each interviewee was categorised into four stances, including two dimensions for scientific ontological beliefs in terms of idealist or realist stances (i.e. status of nature and structure of nature) and two for scientific epistemic beliefs in terms of constructivist or empiricist stances. Thus, Table 5 depicts the pattern variations among the four dimensions.

As shown, 12 among 40 students expressed consistent 'realist/empiricist' stances across the four dimensions, indicating that these students possess coherent traditional belief systems in terms of scientific ontological and epistemic beliefs. Likewise, 10 students demonstrated consistent 'idealist/constructivist' beliefs across the four dimensions, suggesting that these students demonstrate coherent postmodern belief systems. Therefore, more than a half of the students ($n = 22$) expressed coherent belief systems across the dimensions of scientific ontological and epistemic beliefs.

Besides, six students (i.e. 'realist/constructivist') displayed consistent traditional stances within the two ontological dimensions (i.e. realist) and congruent postmodern stances within the two epistemic dimensions (i.e. constructivist). Seven of 40 students (realist/mixed) exhibited congruent ontological beliefs as realist, while they showed inconsistent stances in terms of their epistemic beliefs (i.e. knowledge: empiricist; knowing: constructivist). There are another five students (mixed/mixed) who revealed mixed beliefs in both ontological dimensions (status of nature: idealist, structure of nature: realist) and epistemic dimensions (knowledge: empiricist, knowing: constructivist).

In summary, the results entail that, first, over half of the students demonstrated congruent stances across and within the two belief systems, either as traditional (i.e. realist/empiricist) or postmodern (i.e. idealist/constructivist) stances. It is worth noting that, when the stances within each belief system were congruent yet inconsonant across the two systems, the students tended to hold a postmodern stance of epistemic beliefs and a traditional stance of ontological beliefs (i.e. realist/constructivist). In other words, their epistemic beliefs were more sophisticated than their ontological beliefs.

### The interplay between the students' ontological beliefs about the status of nature and their epistemic beliefs

As previously mentioned, this study categorised the students' scientific ontological beliefs into idealist and realist stances and their scientific epistemic beliefs into constructivist and empiricist stances. As a result, in order to find the underlying relations between the ontological and epistemic beliefs, the cross-tabulation of the students' identifications regarding their ontological beliefs about the status of nature and their epistemic beliefs about knowledge and knowing were calculated using the Pearson Chi-square test; the results are shown

**Table 5.** The pattern variations between the students' scientific ontological and epistemic beliefs.

| Scientific ontological beliefs | | Scientific epistemic beliefs | | |
|---|---|---|---|---|
| Status of nature | Structure of nature | Knowledge | Knowing | *N* |
| Realist | Realist | Empiricist | Empiricist | 12 |
| Idealist | Idealist | Constructivist | Constructivist | 10 |
| Realist | Realist | Constructivist | Constructivist | 6 |
| Realist | Realist | Empiricist | Constructivist | 7 |
| Idealist | Realist | Empiricist | Constructivist | 5 |

in Table 6. Overall, the associations among beliefs about the 'status of nature' and 'knowledge' and 'knowing' are significant (for the knowledge dimension: *Chi-square* = 7.11, *Phi* = 0.42, $p < .01$; for the knowing dimension: *Chi-square* = 10.29, *Phi* = 0.51, $p < .01$), representing significant relations. To be more specific, the students possessing idealist scientific ontological beliefs in the 'status of nature' dimension tended to have constructivist scientific epistemic beliefs about the 'knowledge' and 'knowing' dimensions. In addition, it seemed that the students holding a realist stance regarding the 'status of nature' dimension were more likely to embrace the empiricist stance in the two epistemic dimensions, including 'knowledge' and 'knowing.'

### *The interplay between the students' ontological beliefs about the structure of nature and their epistemic beliefs*

Similarly, the cross-tabulation of the students' classifications concerning the scientific ontological beliefs in the dimension of the 'structure of nature' and their scientific epistemic beliefs about the 'knowledge' and 'knowing' dimensions are shown in Table 7. The upper part shows the results of the ontological beliefs regarding the 'structure of nature' and epistemic beliefs in the 'knowledge' dimension, while the lower one indicates the results of the ontological beliefs regarding the 'structure of nature' and epistemic beliefs in the 'knowing' dimension. In general, the associations identified by the Pearson Chi-square test among beliefs about the 'structure of nature' and about 'knowledge' and 'knowing' are significant (for the 'knowledge' dimension: *Chi-square* = 20.00, *Phi* = 0.71, $p < .001$; for the 'knowing' dimension: *Chi-square* = 10.29, *Phi* = 0.51, $p < .01$). The results also indicate significant relations between the 'structure of nature' dimension of scientific ontological beliefs and the 'knowledge' and 'knowing' dimensions of scientific epistemic beliefs. To be more specific, the students possessing idealist scientific ontological beliefs in the 'status of nature' dimension tended to have constructivist scientific epistemic beliefs about the 'knowledge' and 'knowing' dimensions. Moreover, the students endorsing

**Table 6.** The association among the students' ontological beliefs regarding the status of nature and epistemic beliefs about knowledge and knowing.

| | | *Status of nature* | | |
|---|---|---|---|---|
| | | Idealist | Realist | Total |
| *Knowledge* | | | | |
| Constructivist | *Count* | 10 | 6 | 16 |
| | *Expected count* | 6.0 | 10.0 | |
| | *Adjusted residuals* | 2.7 | −2.7 | |
| Empiricist | *Count* | 5 | 19 | 24 |
| | *Expected count* | 9.0 | 15.0 | |
| | *Adjusted residuals* | −2.7 | 2.7 | |
| Total | *Count* | 15 | 25 | |
| *Knowing* | | | | |
| Constructivist | *Count* | 15 | 13 | 28 |
| | *Expected count* | 10 .5 | 17.5 | |
| | *Adjusted residuals* | 3.2 | −3.2 | |
| Empiricist | *Count* | 0 | 12 | 12 |
| | *Expected count* | 4.5 | 7.5 | |
| | *Adjusted residuals* | −3.2 | 3.2 | |
| Total | *Count* | 15 | 25 | 40 |

Notes: Knowledge: *Chi-square* = 7.11, *Phi* = 0.42, $p < .01$. Knowing: *Chi-square* = 10.29, *Phi* = 0.51, $p < .01$.

**Table 7.** The association among the students' ontological beliefs about the structure of nature and epistemic beliefs about knowledge and knowing.

| | | Structure of nature | | |
|---|---|---|---|---|
| | | Idealist | Realist | Total |
| *Knowledge* | | | | |
| Constructivist | *Count* | 10 | 6 | 16 |
| | *Expected count* | 4.0 | 12.0 | |
| | *Adjusted residuals* | 4.5 | −4.5 | |
| Empiricist | *Count* | 0 | 24 | 24 |
| | *Expected count* | 6.0 | 18.0 | |
| | *Adjusted residuals* | −4.5 | 4.5 | |
| Total | *Count* | 10 | 30 | |
| *Knowing* | | | | |
| Constructivist | *Count* | 15 | 13 | 28 |
| | *Expected count* | 10.5 | 17.5 | |
| | *Adjusted residuals* | 3.2 | −3.2 | |
| Empiricist | *Count* | 0 | 12 | 12 |
| | *Expected count* | 4.5 | 7.5 | |
| | *Adjusted residuals* | −3.2 | 3.2 | |
| Total | *Count* | 15 | 25 | |

Notes: Knowledge: *Chi-square* = 20.00, *Phi* = 0.71, $p < .001$. Knowing: *Chi-square* = 10.29, *Phi* = 0.51, $p < .01$.

a realist stance in this dimension are also prone to hold empiricist stances in the 'knowledge' and 'knowing' dimensions.

## Discussion and implications

This study is one of the pioneering works exploring students' scientific ontological beliefs by adopting the qualitative interview method. Two dimensions regarding students' scientific ontological beliefs, including the Status of nature and the Structure of nature were unravelled. The two dimensions, on the one hand, emerged from the students' interview data. On the other hand, they paralleled some previous empirical studies (e.g. Greene et al., 2008; Roth & Lucas, 1997; Sere, 2002). Nevertheless, it is contended here that other ontological dimensions may exist, suggesting that additional work may be imperative for researchers. In addition, this study also explored the associations between the two dimensions. The results also provide evidence that the two dimensions are closely associated. Both of the dimensions are related to the issue of nature and the natural world at an ontological level, so it is reasonable that there may be some relations between them.

It is worth noting that more than half of the interviewees still possessed realist ontological beliefs in the two dimensions. Unlike epistemology of science, students may implicitly shape their scientific epistemic beliefs perpetrated by the text and with their experience of school science (Conley et al., 2004). The issues related to the ontology of science may be rarely brought up in formal science education, especially in Taiwan. Although recent science education reforms emphasising constructivism in Taiwan have been implemented and introduced into science classrooms, many school science teachers in Taiwan may still focus on transmitting content knowledge on an epistemological level for preparing for national examinations (Lin, Lee, & Tsai, 2014). Although developing students' scientific ontological beliefs is of great importance in science education, Roth and Lucas (1997) stated that 'abandoning the claim that nature is inherently ordered in favour of another one according to which nature is chaotic, ordered only through human efforts, appears to be a radical step and counterintuitive with our everyday experience' (p. 174). This dilemma and related issues should be paid more attention to by science educators in the future.

In addition, most students believed that scientific knowledge is derived from and related to scientists' intuitive ideas and reasoning about the physical world. The results may indicate that the students tended to consider scientific knowledge from an empiricist perspective. On the contrary, in the 'knowing' dimension, most of the students held constructivist beliefs. Since the last decade, Taiwan has launched several curriculum reforms, and the idea of constructivism has been a critical component in science education. Yet, students may still regard scientific knowledge as facts or as representing truth. Based on the results, it seems that students may more easily embrace the constructivist beliefs about knowing in science. Conley et al. (2004) suggested that students' epistemic thinking could be cultivated in the domain of science in terms of the scientists' work and the use of evidence related to the 'knowing' dimension of epistemic beliefs. These experiences may initially form students' basic epistemic beliefs in the 'knowing' dimension. Thus, in formal school science, students may more easily perceive the processes of science rather than the characteristics of scientific knowledge. Kang et al. (2005) also suggested that high school students may still regard scientific theories, models, and knowledge merely as representations of real-world objects/events, suggesting that students may still have inappropriate impressions of scientific knowledge. Yet, these claims should be verified further in the future.

In general, students' ontological and epistemic beliefs are quite consistent. However, when incongruence occurs within each belief system, it seems that students may more easily embrace the constructivist beliefs about knowing and the realist beliefs about the status of nature. As previously mentioned, students may more easily perceive the processes of science rather than the characteristics of scientific knowledge in school science (Conley et al., 2004). Moreover, compared to the 'status of nature' dimension, the 'structure of nature' dimension may be more metaphysical. For example, Roth and Lucas (1997) analysed 23 university students' written and oral discourses about ontology, epistemology, and sociology of science. They found that it would be very difficult for students to abandon the claim that nature is inherently ordered, indicating that the idealist beliefs regarding the status of science are quite counter-intuitive and contrary to their everyday experience.

Moreover, five patterns were revealed in terms of the classification of students' ontological and epistemic beliefs in this study. That is, based on the framework of traditional and postmodern stances proposed by researchers (e.g. Loving, 1997; Yore et al., 2004), these patterns are realist/empiricist, realist/mixed, realist/constructivist, mixed/mixed, and idealist/constructivist. The traditional stance is the realist/empiricist pattern, while the postmodern stance is the idealist/constructivist pattern. Both patterns not only showed congruent beliefs within the two beliefs (i.e. ontological and epistemic beliefs) but also across the two beliefs. The realist/mixed and realist/constructivist patterns, in general, also illustrated congruent beliefs within each of the belief systems. To be more specific, the realist/mixed pattern only shows congruent beliefs in terms of the two dimensions of ontological beliefs, whereas the realist/constructivist pattern portrayed congruent beliefs within both beliefs. In addition, the mixed/mixed pattern revealed in congruent beliefs within and across the two belief systems. Based on the pattern variations found in this study, it is assumed that the maturation of ontological beliefs could be more complicated and difficult than epistemic beliefs. Three out of the five patterns still revealed a congruent realist ontological belief, even though a coherent constructivist epistemic belief has formed. This finding may indicate that students' ontological beliefs are metaphysical, entrenched, and resistant to change (Levers, 2013; Packer & Goicoechea, 2000). More studies could be conducted in the future to consolidate this interpretation.

Furthermore, after analysing the students' interview responses, this study found that their scientific ontological beliefs and scientific epistemic beliefs were closely associated. That is, the students who endorsed idealist ontological beliefs were prone to endorse constructivist epistemic beliefs. Olafson et al. (2010) found that, when teachers reported a more sophisticated ontological worldview (i.e. relativism), they tended to endorse a more availing epistemic worldview (i.e. relativism). In other words, it is very likely that individuals tend to be consistent in their epistemological and ontological views. In the current study, similar findings were revealed in the domain of science and for a sample of students. The findings of this study not only shed light on this line of research but also provide strong evidence that students' scientific ontological beliefs and epistemic beliefs are closely related.

As previously mentioned, when the stances within each belief system were congruent yet inconsonant across the two belief systems, the students' epistemic beliefs were more sophisticated than their ontological beliefs. This result may imply that, to promote the sophistication of students' scientific ontological beliefs, the maturation of the students' scientific epistemic beliefs may serve as the essential step and a viable way. Researchers (e.g. Mason, Boldrin, & Ariasi, 2010; Tsai, 2004, 2008) have advocated the benefits of using Internet-based learning environments to facilitate learners' epistemic development. For example, Tsai (2004) claimed that a well-designed Internet-based learning environment that conforms to the so-called constructivist-oriented instruction can be an epistemic tool to change or reshape learners' epistemic beliefs. In his later study (Tsai, 2008), an inquiry-based instruction in science with the assistance of Internet resources was implemented with a group of Taiwanese high school students. The results indicated that the participants' epistemic beliefs in science were considerably enhanced, echoing the above-mentioned points of view. Mason et al. (2010) also explicated that Internet-based learning environments allow learners to actively explore those open-ended, ill-structured controversial issues that contain different opinions, contradictory claims, or competing arguments. Learners have to carefully scrutinise the source, structure, or credibility of Internet information and resources with their epistemic thinking. Thus, when they are epistemically active, the sophistication of their epistemic beliefs may be achieved and facilitated. In sum, it is claimed here that the use of proper technology-enhanced learning can be regarded as a potential vehicle to foster not only learners' epistemic beliefs but also their ontological beliefs since the two belief systems are related according to the results of this study. Science education researchers and educators are encouraged to make more endeavours in this regard and verify the above-mentioned implications.

This study identified two potential dimensions of scientific ontological beliefs. This preliminary result could help science educators to better understand students' scientific ontological beliefs. Ontological beliefs about science may influence and form their specific perspectives about learning and assessment (Olafson et al., 2010). It is helpful for science educators to identify students' 'ontological barriers' as indicated by Venville, Gribble, and Donovan (2005) based on the two dimensions revealed by this study. In a theoretical sense, science education researchers have regarded ontological beliefs are often resistant to change. Yet, Slotta and Chi (2006) have provided evidence that students' ontological beliefs could be trained by receiving direct trainings by instructing them with relevant ontology, suggesting that 'explicit' ontological training may be an effective way to promote students' ontological beliefs. Yet, it should be noted that science teachers rarely attain to this issue. More endeavours should be employed in this regard.

Several issues could be explored in the future based on the results of this study. First, whether ontological and epistemic orientations should involve several developmental stages or various systems of beliefs has been widely discussed in the literature. Although recent research (e.g. Greene et al., 2008; Greene & Yu, 2014) may suggest the two beliefs appear to be an integration of both developmental and multi-dimensional perspectives, more studies should be conducted in the future. In addition, since the practice of science may be culture-sensitive as documented in the science education literature (e.g. Abd-El-Khalick, 2012), it is possible that the two beliefs may be shaped by different cultures in other countries. Another issue stems from the fact that the results of this study were mainly discussed from the participants' formal science experiences. How their informal or everyday experiences beyond school science influence the formation of different orientations may be also imperative to explore further in the future.

Since this study is one of the initial explorations on students' scientific ontological and epistemic beliefs, only two stances (traditional/postmodern) were adopted. It is likely that some other intermediate stances (e.g. mixed) may be existed in the ontological and epistemic dimensions found in this study. Future studies could refine the framework adopted in this study and attain a more informative picture regarding students' ontological and epistemic beliefs as well as the intertwined relationships between the two beliefs. Moreover, the congruence between each belief system only suggests a more sophisticated stance per se as indicated in the literature. This study did not explore how the students' ontological and epistemic beliefs interact with other learning features such as academic achievement, approaches to learning, or conceptions of learning. A recent study (Lee, Liang, & Tsai, 2016) also suggests that students with sophisticated beliefs are not necessarily associated with meaningful learning. More studies are warranted to investigate in this regard.

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## References

Abd-El-Khalick, F. (2012). Examining the sources for our understandings about science: Enduring conflations and critical issues in research on nature of science in science education. *International Journal of Science Education*, *34*, 353–374.

Briell, J., Elen, J. E., Verschaffel, L., & Clarebout, G. (2011). Personal epistemology: Nomenclature, conceptualizations, and measurement. In J. Elen, E. Stahl, R. Bromme, & G. Clarebout (Eds.), *Links between beliefs and cognitive flexibility* (pp. 7–36). New York, NY: Springer.

Buehl, M. M., & Alexander, P. A. (2001). Beliefs about academic knowledge. *Educational Psychology Review*, *13*, 385–418.

Buehl, M. M., & Alexander, P. A. (2005). Motivation and performance differences in students' domain-specific epistemological belief profiles. *American Educational Research Journal*, *42*, 697–726.

Buehl, M. M., Alexander, P. A., & Murphy, P. K. (2002). Beliefs about schooled knowledge: Domain specific or domain general? *Contemporary Educational Psychology*, *27*, 415–449.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research*, *63*, 1–49.

Coll, R. K., & Taylor, N. (2001). Using constructivism to inform tertiary chemistry pedagogy. *Chemistry Education Research and Practice in Europe*, *2*, 215–226.

Conley, A. M., Pintrich, P. R., Vekiri, I., & Harrison, D. (2004). Changes in epistemological beliefs in elementary science students. *Contemporary Educational Psychology*, *29*, 186–204.

Creswell, J. W. (2008). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (3rd ed.). Columbus, OH: Merrill Prentice Hall.

Denzin, N. K., & Lincoln, Y. S. (2000). *Handbook of qualitative research* (2nd ed.). Thousand Oaks, CA: Sage.

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education*, *25*, 671–688.

Duschl, R. (1990). *Restructuring science education: The importance of theories and their development*. New York, NY: Teacher's College Press.

Friedrichsen, P., Van Driel, J., & Abell, S. (2011). Taking a closer look at science teaching orientations. *Science Education*, *95*, 358–376.

Good, R., & Shymansky, J. (2001). Nature-of-science literacy in benchmarks and standards: Post-modern/relativist or modern/realist? *Science & Education*, *10*, 173–185.

Greene, J. A., Azevedo, R., & Torney-Purta, J. (2008). Modeling epistemic and ontological cognition: Philosophical perspectives and methodological directions. *Educational Psychologist*, *43*, 142–160.

Greene, J. A., & Yu, S. (2014). Modeling and measuring epistemic cognition: A qualitative re-investigation. *Contemporary Educational Psychology*, *39*, 12–28.

Hofer, B. K. (2004). Exploring the dimensions of personal epistemology in differing classroom contexts: Student interpretations during the first year of college. *Contemporary Educational Psychology*, *29*, 129–163.

Hofer, B. K. (2006). Domain specificity of personal epistemology: Resolved questions, persistent issues, new models. *International Journal of Educational Research*, *45*, 85–95.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*, 88–140.

Kang, S., Scharmann, L. C., & Noh, T. (2005). Examining students' views on the nature of science: Results from Korean 6th, 8th, and 10th graders. *Science Education*, *89*, 314–334.

Kitchener, R. (2002). Folk epistemology: An introduction. *New Ideas in Psychology*, *20*, 89–105.

Kuhn, D., & Weinstock, M. (2002). What is epistemological thinking and why does it matter? In B. Hofer & P. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 121–144). Mahwah, NJ: Lawrence Erlbaum.

Kwak, Y. (2001). *Profile change in preservice science teacher's epistemological and ontological beliefs about constructivist learning: Implications for science teaching and learning* (*Unpublished doctoral dissertation*). The Ohio State University, Columbus.

Lee, S. W.-Y., Liang, J.-C., & Tsai, C.-C. (2016). Do sophisticated epistemic beliefs predict meaningful learning? Findings from a structural equation model of undergraduate biology learning. *International Journal of Science Education*, *38*, 2327–2345.

Levers, M.-J. D. (2013). Philosophical paradigms, grounded theory, and perspectives on emergence. *SAGE Open*, *3*, 1–6.

Lin, T.-J., Lee, M.-H., & Tsai, C.-C. (2014). The commonalities and dissonances between high-school students' and their science teachers' conceptions of science learning and conceptions of science assessment: A Taiwanese sample study. *International Journal of Science Education*, *36*, 382–405.

Lincoln, Y. S., & Guba, E. G. (2000). Paradigmatic controversies, contradictions, and emerging confluences. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed., pp. 163-188). Thousand Oaks, CA: Sage.

Loving, C. (1997). From the summit of truth to its slippery slopes: Science education's journey through positivist-postmodern territory. *American Educational Research Journal*, *34*, 421–452.

Lucas, K. B., & Roth, W. M. (1996). The nature of scientific knowledge and student learning: Two longitudinal case studies. *Research in Science Education*, *26*, 103–127.

Mason, L., & Boldrin, A. (2008). Epistemic metacognition in the context of information searching on the Web. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs: Epistemological studies across diverse cultures* (pp. 377–404). New York, NY: Springer.

Mason, L., Boldrin, A., & Ariasi, N. (2010). Searching the Web to learn about a controversial topic: Are students epistemically active? *Instructional Science*, *38*, 607–633.

Matthews, M. R. (2009). Science, worldviews and education: An introduction. *Science & Education*, *18*, 641–666.

Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review*, *18*, 3–54.

Nola, R. (2004). Pendula, models, constructivism and reality. *Science & Education*, *13*, 349–377.

Olafson, L., & Schraw, G. (2006). Teachers' beliefs and practices within and across domains. *International Journal of Educational Research*, *45*, 71–84.

Olafson, L., Schraw, G., & Vander Veldt, M. (2010). Consistency and development of teachers' epistemological and ontological world views. *Learning Environments Research*, *13*, 243–266.

Packer, M. J., & Goicoechea, J. (2000). Sociocultural and constructivist theories of learning: Ontology, not just epistemology. *Educational Psychologist*, *35*, 227–241.

Reiner, M., & Eilam, B. (2001). Conceptual classroom environment – A system view of learning. *International Journal of Science Education*, *23*, 551–568.

Roth, W.-M., & Lucas, K. (1997). From "truth" to "invented reality": A discourse analysis of high school physics students' talk about scientific knowledge. *Journal of Research in Science Teaching*, *34*, 145–179.

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology*, *82*, 498–504.

Schraw, G. (2013). *Conceptual integration and measurement of epistemological and ontological beliefs in educational research*. ISRN Education. Retrieved from http://www.hindawi.com/isrn/education/aip/327680/

Schraw, G. J., & Olafson, L. J. (2008). Assessing teachers' epistemological and ontological world-views. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs. Epistemological studies across diverse cultures*, (pp. 25–41). New York, NY: Springer.

Sere, M.-G. (2002). Towards renewed research questions from the outcomes of the European project *Labwork in Science Education*. *Science Education*, *86*, 624–644.

Séré, M.-G., Fernandez-Gonzalez, M., Gallegos, J. A., Gonzalez-Garcia, F., De Manuel, E., Perales, F. J., & Leach, J. (2001). Images of science linked to labwork: A survey of secondary school and university students. *Research in Science Education*, *31*, 499–523.

Slotta, J. D., & Chi, M. T. H. (2006). Helping students understand challenging topics in science through ontology training. *Cognition and Instruction*, *24*, 261–289.
Staver, J. R. (1998). Constructivism: Sound theory for explicating the practice of science and science teaching. *Journal of Research in Science Teaching*, *35*, 501–520.
Taber, K. S. (2006). Beyond constructivism: The progressive research programme into learning science. *Studies in Science Education*, *42*, 125–184.
Topcu, M. S. (2013). Preservice teachers' epistemological beliefs in Physics, Chemistry, and Biology: A mixed study. *International Journal of Science and Mathematics Education*, *11*, 433–458.
Tsai, C.-C. (1998). An analysis of scientific epistemological beliefs and learning orientations of Taiwanese eighth graders. *Science Education*, *82*, 473–489.
Tsai, C.-C. (2001). A review and discussion of epistemological commitments, metacognition, and critical thinking with suggestions on their enhancement in Internet-assisted chemistry classrooms. *Journal of Chemical Education*, *78*, 970–974.
Tsai, C.-C. (2002). Nested epistemologies: Science teachers' beliefs of teaching, learning and science. *International Journal of Science Education*, *24*, 771–783.
Tsai, C.-C. (2004). Beyond cognitive and metacognitive tools: The use of the Internet as an "epistemological" tool for instruction. *British Journal of Educational Technology*, *35*, 525–536.
Tsai, C.-C. (2006). Reinterpreting and reconstructing science: Teachers' view changes toward the nature of science by courses of science education. *Teaching and Teacher Education*, *22*, 363–375.
Tsai, C.-C. (2008). The use of Internet-based instruction for the development of epistemological beliefs: A case study in Taiwan. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs: Epistemological studies across diverse cultures* (pp. 273–285). Dordrecht: Springer.
Tsai, C.-C., Ho, H. N., Liang, J.-C., & Lin, H.-M. (2011). Scientific epistemic beliefs, conceptions of learning science and self-efficacy of learning science among high school students. *Learning and Instruction*, *21*, 757–769.
Venville, G., Gribble, S. J., & Donovan, J. (2005). An exploration of young children's understandings of genetics concepts from ontological and epistemological perspectives. *Science Education*, *89*, 614–633.
Yore, L. D., Hand, B. M., & Florence, M. K. (2004). Scientists' views of science, models of writing, and science writing practices. *Journal of Research in Science Teaching*, *41*, 338–369.

## Appendix. The interview protocol of this study

**Part A: scientific ontological beliefs**

O1. What role does nature play in giving shape to the knowledge that is constructed?

O2. Do you think there is an inherent and a priori structure to nature?

O3. Is there an external world (a real nature) that, in some way, influences how knowledge is constructed? And if there is, how does it exert its influence?

O4. Does the natural world in some way constrain or influence how/what scientists believe about it?

O5. In your view, what is the difference between the real objects of science and the theoretical objects of science?

O6. In your view, do you think that what scientific theory or knowledge describes or hypothesizes truly exists?

O7. In your view, which of these two positions is similar to your own perception of the world? Why?

A: The material world as a real structure exists independently of our knowledge of their existence. Therefore, theories refer to real features of the world and science has discovered a human-independent world, including the world of observable entities such as electrons, viruses, and tectonic plates.

B: The world (reality, real objects) does not exist independently of minds. Either there is no world outside of human experience, or such a world is all ideational and is constructed or constituted by our own theorizing.

**Part B: scientific epistemic beliefs**

E1. If someone asks you 'What is science?,' what will you tell them?

E2. What are the main characteristics of scientific knowledge?

E3. What are the differences between scientific knowledge and other knowledge?

E4. What do you think about the claim that, in science, most concepts/principles have one clear meaning and most problems have only one right answer? Why do you think that?

E5. In your opinion, what are the purposes of the existence of scientific knowledge/theories?

E6. What are the reasons, in your opinion, why scientists pursue or acquire scientific knowledge?

E7. What kinds of ideas do scientists have? Do scientists do anything with their ideas? What do they do with them and how do they do it?

E8. Where do scientists get their ideas? What are the sources?

E9. After scientists have developed a theory, does the theory ever change? Why (when, how) or why not?

E10. Do you think the development of scientific concepts is a logical process or a creative process? Why do you think that?

E11. Some astrophysicists believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all the scientists are looking at the same experiments and data?