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Do sophisticated epistemic beliefs predict meaningful learning? Findings from a structural equation model of undergraduate biology learning

Silvia Wen-Yu Lee[a], Jyh-Chong Liang[b] and Chin-Chung Tsai[b]

[a]Graduate Institute of Science Education, National Changhua University of Education, Changhua, Taiwan; [b]Graduate Institute of Digital Learning and Education, National Taiwan University of Science and Technology, Taipei, Taiwan

ABSTRACT

This study investigated the relationships among college students' epistemic beliefs in biology (EBB), conceptions of learning biology (COLB), and strategies of learning biology (SLB). EBB includes four dimensions, namely 'multiple-source,' 'uncertainty,' 'development,' and 'justification.' COLB is further divided into 'constructivist' and 'reproductive' conceptions, while SLB represents deep strategies and surface learning strategies. Questionnaire responses were gathered from 303 college students. The results of the confirmatory factor analysis and structural equation modelling showed acceptable model fits. Mediation testing further revealed two paths with complete mediation. In sum, students' epistemic beliefs of 'uncertainty' and 'justification' in biology were statistically significant in explaining the constructivist and reproductive COLB, respectively; and 'uncertainty' was statistically significant in explaining the deep SLB as well. The results of mediation testing further revealed that 'uncertainty' predicted surface strategies through the mediation of 'reproductive' conceptions; and the relationship between 'justification' and deep strategies was mediated by 'constructivist' COLB. This study provides evidence for the essential roles some epistemic beliefs play in predicting students' learning.

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Epistemic belief; conception of learning; learning strategy; biology learning; undergraduate

Introduction

While learning can be a complex phenomenon, research has shown that students' epistemic beliefs can predict their attitudes, self-efficacy, motivation, metacognition, and achievement (e.g. Chen, 2012; Chen & Pajares, 2010; Fulmer, 2014; Lin, Deng, Chai, & Tsai, 2013). A commonly accepted definition of epistemic beliefs refers to learners' beliefs about the nature of knowledge and the nature of knowing (Hofer, 2004; Schommer, 1990). Past studies have also investigated the relationships between epistemic beliefs and conceptions of learning (Liang & Tsai, 2010), and between epistemic beliefs and learning

CONTACT Silvia Wen-Yu Lee silviawyl@cc.ncue.edu.tw Graduate Institute of Science Education, National Changhua University of Education. No.1, Jin-Der Rd., Changhua 500, Taiwan; Jyh-Chong Liang aljc@mail.ntust.edu.tw Graduate Institute of Digital Learning and Education, National Taiwan, University of Science and Technology, Taipei, Taiwan
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strategies (Liang, Lee, & Tsai, 2010; Lin, Liang, & Tsai, 2012a). However, few studies have included epistemic beliefs, conceptions of learning, and learning strategies in the same statistical model to reveal the more complex relationships among all three of these constructs in relation to biology learning. Conceptions of learning refer to a learner's understanding of or beliefs about learning (Chiou, Liang, & Tsai, 2012). Learning strategies have been defined as learners' ways of learning or processing of academic tasks in a situated learning environment (Biggs, 1987). Thus, by using structural equation modelling (SEM), the aim of this study was to verify a proposed structural model including the three constructs. In the following, we first introduce the meanings of the three constructs and their effects on learning. We then review the relationships among these three constructs.

Epistemic beliefs

Although there are disagreements about how to theorise epistemic beliefs, a few studies have provided definitions of the major categories of epistemic beliefs. Each category can be further interpreted as a continuum from 'more' to 'less' sophisticated along epistemic dimensions. Drawn from previous work, Schommer (1990) proposed five dimensions of epistemic beliefs: the structure, certainty and source of knowledge, and the control and speed of knowledge acquisition. These five dimensions were used to develop items in Schommer's (1990) Epistemological Questionnaire, namely 'simple knowledge' (i.e. ranges from 'knowledge structure is simple and discrete' to 'knowledge is complex'), 'certain knowledge' (i.e. ranges from 'knowledge is certain and absolute' to 'knowledge is tentative'), 'omniscient authority' (i.e. ranges from 'knowledge is handed down by authority' to 'knowledge is derived from reason'), 'innate ability' (i.e. ranges from 'the ability to learn is innate' to 'the ability is acquired'), and 'quick learning' (i.e. ranges from 'learning happens quickly' to 'learning is slow'). However, in Schommer's (1990) empirical study, only four factors were identified since 'omniscient authority' did not yield a factor. Also, some researchers (Hofer & Pintrich, 1997) have argued that the last two dimensions of epistemic beliefs proposed by Schommer are more about the nature of learning than the nature of knowing. Hofer and Pintrich (1997) thus replaced the last two dimensions with 'justification' (i.e. evaluation of knowledge claims and dualistic view to multiplistic view) and 'source' (i.e. 'knowledge resides in external authority' to 'knowledge is actively constructed by the knower'). Among the four dimensions of epistemic beliefs, 'uncertainty' of knowledge and 'simplicity' or 'development' of knowledge represent the nature of knowledge, while 'source' of knowing and 'justification' of knowing represent the nature of knowing (Conley, Pintrich, Vekiri, & Harrison, 2004; Hofer, 2000; Hofer & Pintrich, 1997). The four dimensions of epistemic beliefs and their modified versions have become the major constructs used to examine students' epistemic beliefs in different areas of research (e.g. Chen & Pajares, 2010; Deniz, 2011; Hsieh & Tsai, 2014).

Researchers have suggested that successful integration of scientific epistemic beliefs can lead to effective learning (Lising & Elby, 2005). In science education, research has indicated the positive impact of students' epistemic beliefs on conceptual learning, science inquiry, laboratory practices, and so on. (e.g. Ding, 2014; Lising & Elby, 2005; Tsai, 1999). In Murphy and Mason's (2006) study, students who had sophisticated understanding of the changing nature of science were found to be more likely to change their conceptual structures. In online science information searching, epistemic belief activation is related to prior knowledge of the topic and argumentative skills (Mason, Ariasi, & Boldrin, 2011). In other studies related to science information searching, more sophisticated epistemic beliefs are found to be associated with advanced searching skills (Hsieh & Tsai, 2014) and metacognitive searching patterns (Hsu, Tsai, Hou, & Tsai, 2014). Moreover, students' sophisticated epistemic beliefs were found to be associated with an intrinsic motive for learning (Lin et al., 2013), and were associated with positive perspectives on the content to be learnt (Retzbach, Marschall, Rahnke, Otto, & Maier, 2011). In sum, the advanced epistemic beliefs seem to be multidimensional in nature and have positive relationships with learning affect, metacognition, and learning performance.

There are several other issues and debatable areas related to epistemic beliefs discussed in the literature such as the domain-specific nature of epistemic beliefs and their situated and contextual nature (Hofer, 2016). An increasing number of studies have emphasised the domain-specific nature of epistemic beliefs (Bråten, 2010; Buehl, Alexander, & Murphy, 2002; Hofer, 2006; Lee & Tsai, 2012). For instance, Paulsen and Wells (1998) found that students from applied science disciplines tended to have more naïve epistemic beliefs than students from pure science disciplines. Hofer (2000) found that students believed science knowledge was more 'certain' than psychology knowledge, while in science more than in psychology, students were more likely to consider authority as the source of knowledge. These results highlighted students' different epistemic stances in different disciplines. At a more fine-grained level, epistemic beliefs have also been found to be topic-specific (Schunk & Zimmerman, 2006). Other researchers have argued that epistemic beliefs are situated, and are sensitive to the learning context (Muis, Trevors, & Chevrier, 2016). To address their situated nature, some researchers have focused on documenting epistemic beliefs in action (Mason et al., 2011; Muis, 2008), and have observed students' learning activities, such as problem-solving or information searching activities, in an attempt to capture the moments when the students reflected epistemologically or when their epistemic beliefs were activated in the context. Using another approach, Chinn, Buckland, and Samarapungavan (2011) argued that researchers should consider epistemic aims, one essential but non-belief construct of epistemic cognition, when investigating epistemic beliefs. Epistemic aims are defined as 'goals related to finding things out, understanding them, and forming beliefs' (Chinn et al., 2011, p. 146). Epistemic aims are important because they determine one's behaviour. For instance, Chinn et al. (2011) argued that people who are aiming for justified truth would be more interested in activities such as debates and weighting different evidences. In other words, one might adopt naïve or sophisticated beliefs depending on one's epistemic aims in a particular context.

Conceptions of learning

Conceptions of learning refer to a learner's understanding of or beliefs about learning (Chiou et al., 2012), or can refer to a learner's experience in the learning context (Lin, Liang, & Tsai, 2012b). Säljö (1979) was the first researcher to study conceptions of learning. By interviewing 90 college students, he identified five categories of conceptions of learning, namely (1) increase of knowledge, (2) memorising, (3) acquisition of facts or procedures that can be retained and/or utilised in practice, (4) abstraction of meaning, and (5) interpretative process aimed at the understanding of reality. The aforementioned categories of learning conceptions have been widely researched. Numerous studies following Säljö's work have either revised his learning conception categorisations or extended his work to different contexts or domains (Chiou et al., 2012; Lee, Johanson, & Tsai, 2008; Marton, Dall' Alba, & Beaty, 1993; Tsai, 2004). Various different sets of categories for conceptualising a learner's learning conceptions have been proposed. For example, Marton et al.'s study showed that the conceptions that learning could be qualitatively categorised into six dimensions: (1) changing as a person, (2) seeing something in a different way, (3) understanding, (4) applying, (5) memorising, and (6) increasing one's knowledge. Taking science learning as an example, Lee et al. (2008) distinguished six dimensions of high school students' learning science conceptions describing them as (1) memorising, (2) testing, (3) calculating and practising, (4) increase of knowledge, (5) applying, and (6) understanding and seeing in a new way. To further investigate the domain-specific nature of learning conceptions, Chiou et al. (2012) developed a questionnaire specifically to investigate biology-major college students' conceptions of learning biology (COLB) which included six learning conception dimensions similar to those of Lee et al. (2008). Although the conception of learning categories vary from study to study, they still overlap, at least to some extent.

Some researchers have also been interested in how learners' learning conceptions relate to their learning outcomes, such as their learning self-efficacy and learning strategies, in different educational contexts (Tsai, Ho, Liang, & Lin, 2011). Previous studies have indicated that learning conceptions can be considered as a hierarchical system (Lee et al., 2008; Marton et al., 1993; Tsai, 2004; Tsai et al., 2011). Cano and Cardelle-Elawar (2004) proposed that the first three of the six conceptions of learning in his study (i.e. 'changing as a person,' 'seeing something in a different way,' and 'understanding') be identified as 'constructivist' conceptions; on the other hand, the other three (i.e. 'applying,' 'memorising,' and 'increasing one's knowledge') can be viewed as 'reproductive' conceptions. In Lee et al.'s study (2008), the six learning conceptions were divided into lower level and higher level conceptions of learning science. The lower level conceptions include 'memorising,' 'testing,' and 'calculating and practising,' while the higher level consists of 'increase of knowledge,' 'applying,' and 'understanding and seeing in a new way.' Tsai et al. (2011) further conducted a confirmatory factor analysis to examine the three competing models of high school learners' conceptions of learning science. Their results showed that both the first-order (six dimensions) and second-order models could adequately represent learners' conceptions of learning science. The second-order analysis further revealed two second-order factors. One includes the three conceptions of 'memorising,' 'testing,' and 'calculating and practising,' while the other consists of the conceptions of 'increasing one's knowledge,' 'applying,' and 'understanding and seeing in a new way.' According to the nature of the first-order factors, Tsai et al. (2011) interpreted the first cluster or profile of factors as 'reproductive' learning and the second as 'constructivist' learning.

Researchers have suggested that learners' learning conceptions may predict their learning outcomes. For example, regarding students' different levels of learning conceptions, Tsai et al. (2011) examined the relationships between high school students' learning conceptions and their learning self-efficacy for science. A negative association was found between students' lower level (i.e. 'reproductive') conceptions of learning science and their learning self-efficacy, while a positive association was found between their higher level (i.e. 'constructivist') conceptions of learning science and their learning self-efficacy. In other words, Tsai et al.'s study (2011) revealed that students' higher level conceptions of learning science could foster their learning science self-efficacy. Furthermore, Liang and Tsai (2010) showed that students' conceptions of learning science as preparing for tests (i.e. the conception of 'testing') was negatively related to their interest and confidence in science learning.

Learning strategies

Learning strategies have been defined as learners' ways of learning or processing academic tasks in a situated learning environment (Biggs, 1987). Strategies can be seen as 'potentially conscious and controllable activities' (Pressley & Harris, 2006). The earliest studies of learning strategies may have been those conducted by Marton and Säljö (1976) and Biggs (1994). Biggs and his colleagues' study further indicated that students' learning strategies can be divided into the two major components of surface and deep learning strategies. Chin and Brown's study (2000) pointed out that students' surface strategies are perceived as a demand to be met, and that they tend to learn through rote learning. On the other hand, students' deep strategies are focused on truly understanding the meaning of the learning content. According to Kember, Biggs, and Leung (2004), employing a surface strategy indicates that students utilise memorisation or narrow the scope of their learning, while adopting a deep strategy implies that they employ higher order learning strategies such as relating to previous learning experiences or striving to comprehend more when learning. In a recent study, based on Biggs' presage–process–product model, it has been found that deep learning strategies are associated with meaningful learning behaviours such as making connections and examining logic in text (Clinton, 2014).

Students' learning strategies can be an important predictor of learning performance. From a metacognitive perspective, students are likely to continuously repeat the same learning strategies or transfer the strategies if a positive impact on the students' learning outcomes is produced by adopting such strategies (Belmont, Butterfield, & Ferretti, 1982; Borkowski, Carr, Rellinger, & Pressley, 1990). Empirical studies have found that sophisticated strategies are associated with better learning performance such as better reading comprehension, increase in procedural and declarative knowledge of mathematics problem-solving, or improvement in scientific reasoning or argumentation (Burkell, Schneider, & Pressley, 1990; Clinton, 2014; Kuhn & Udell, 2003). Students' learning strategies also play the role of mediator in their learning. For example, Cheung (2015) found that students' deep learning strategies mediated teachers' teaching, and in turn impacted the students' learning self-efficacy. Finally, empirical studies have also investigated how students develop different learning strategies. For instance, Vos, van der Meijden, and Denessen (2011) explored the impact of constructing a game versus playing an existing educational game on students' learning strategies. They found that constructing a game better facilitated the students' deep learning strategies. Thus, deep learning strategies are not only associated with better learning performance, but can also be further developed through engagement in appropriate learning activities.

In science education, some previous studies have utilised questionnaires to investigate different domains or subject areas regarding how students learn and which strategies they employ while learning (Li, Liang, & Tsai, 2013; Lin, Liang, & Tsai, 2012b). Li et al.'s study

(2013) on chemistry learning revealed that students learning by transforming conceptions tended to utilise deep learning strategies. In addition, research has also extended to the exploration of the role of students' learning strategies to learning physics (Lin, Liang, & Tsai, 2012a; Lin, Liang, & Tsai, 2012b). Lin et al. (2012) investigated the differences between students' strategies of learning physiology in Internet-based and traditional learning environments. The results indicated that students in the Internet-based instruction physiology class expressed deeper learning strategies than those in the traditional class. In our current study, we also utilised a questionnaire to survey a large sample of students in order to examine the relationships between learning strategies and other constructs.

Relationships among epistemic beliefs, conceptions of learning, and learning strategies

Past studies have revealed the direct and indirect roles of epistemic beliefs in students' conceptions of learning and in their learning strategies. Studies using correlational analyses and SEM have found that the beliefs of 'multiple-source,' 'sophisticated understanding of development,' and 'knowledge is uncertain' were negatively correlated with students' lower level (i.e. reproductive) conceptions of learning (i.e. 'memorising,' 'testing,' and 'calculating and practising') (Liang & Tsai, 2010; Tsai et al., 2011). Sophisticated beliefs in 'development' and 'justification' were nonetheless positive predictors of students' higher level (i.e. constructivist) conceptions of learning (i.e. 'increasing one's knowledge,' 'application,' 'understanding,' and 'seeing in a new way') (Liang & Tsai, 2010; Tsai et al., 2011). In some other studies, students' learning strategies were also able to be explained by their epistemic beliefs. For instance, through correlational studies, Lin, Liang, and Tsai (2012a) found a tendency that the sophisticated beliefs of 'uncertainty,' 'development,' and 'justification' were positively correlated to deep learning strategies, and the sophisticated beliefs of the four dimensions of epistemic beliefs in biology (EBB) were negatively correlated to surface learning strategies. Kizilgunes, Tekkaya, and Sungur (2009) developed a path model that predicts students' learning (i.e. tendency towards meaningful learning or rote learning) by epistemic beliefs and through the mediation of motivation. They also found that students' beliefs in external authorities (i.e. 'source') led directly to rote learning, while sophisticated beliefs of 'uncertainty,' 'development,' and 'justification' played a direct role in meaningful learning.

In a few studies, the relationships between students' conceptions of learning and their strategies for learning have been examined. Students with higher level (i.e. constructivist) conceptions of learning tend to use deep strategies for learning biology, while those with lower level (i.e. reproductive) conceptions are more likely to adopt surface strategies while learning biology (Chiou et al., 2012). In another study, Chiou and Liang (2012) further verified the model that conceptions of learning science can predict learning strategies, and then learning strategies can predict self-efficacy. In these two studies, similar relationships between conceptions of learning and learning strategies were found.

Research purpose

Recently, models that involve epistemic beliefs and two or more other constructs or outcomes to better explain the complexity of learning have been established in a growing number of studies (Bahcivan, 2014; Kizilgunes et al., 2009; Ozkal, Tekkaya, Cakiroglu, & Sungur, 2009; Tsai et al., 2011). However, few studies have included epistemic beliefs, conceptions of learning, and learning strategies in the same statistical model. Although some relationships between epistemic beliefs and conceptions of learning or learning strategies have been observed in past studies, it is important to further verify this more complete model. Additionally, the rationale of the current study is supported by the domain-specific perspective of epistemic beliefs. In this study, we followed the domain-specific perspective and thus surveyed students' epistemic beliefs regarding biology, rather than their general epistemic beliefs. As past studies have suggested that epistemic beliefs of biology are different from those of other science disciplines (e.g. Lee & Tsai, 2012; Tsai, 2006), it is essential to establish a unique model in the context of biology learning. Based on our research aims, and to align our work with previous studies, we chose the survey method and SEM as the research methods.

Therefore, as shown in Figure 1, epistemic beliefs are hypothesised in this study as playing a direct role in students' conceptions of learning and in their learning strategies. We hypothesised that all epistemic beliefs play a positive role in constructivist conceptions of learning, and have negative effects on reproductive conceptions of learning. We also hypothesised that epistemic beliefs have positive relationships with deep learning strategies and negative relationships with surface learning strategies. Also, based on the findings of the aforementioned studies, epistemic beliefs are assumed to predict learning strategies through the mediation of conceptions of learning. Thus, constructivist conceptions of learning were hypothesised as having positive relationships with deep learning strategies and negative relationships with surface learning strategies. On the contrary, reproductive conceptions of learning were hypothesised as having negative relationships

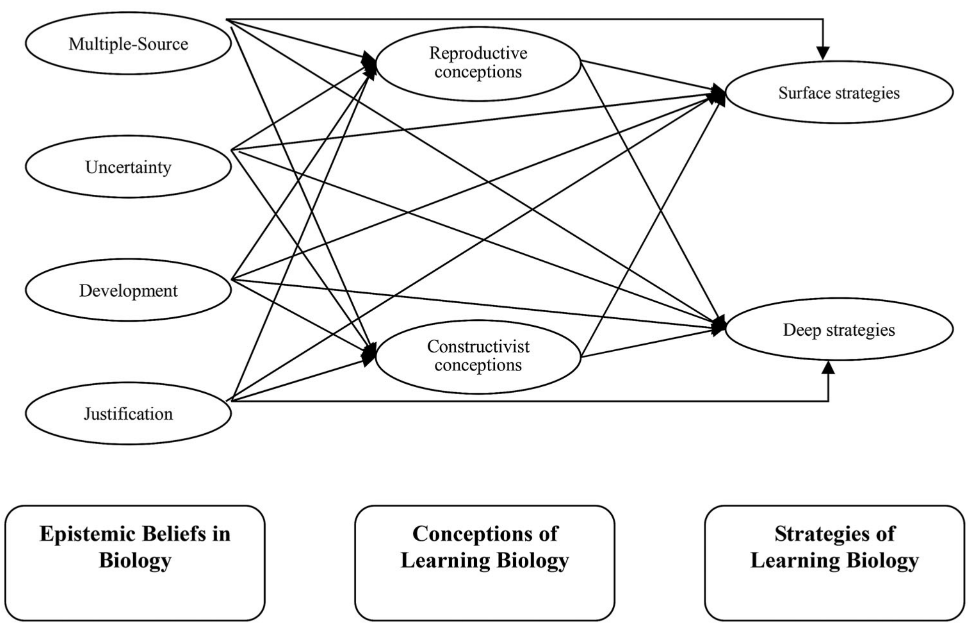

Figure 1. A hypothetical model of the relationships among EBB, conceptions of learning biology, and SLB. * $P < .05$, ** $P < .01$, *** $P < .001$.

with deep learning strategies but positive relationships with surface learning strategies. In order to verify this hypothetical model, we posed the following research questions:

1. What is the validity of the questionnaires for measuring the three constructs (i.e. students' EBB, COLB, and strategies of learning biology (SLB))?
2. What are the correlations among the three constructs?
3. To what extent do epistemic beliefs predict students' learning strategies through the mediation of conceptions of learning?

Methodology

Participants

The participants in this study included 303 college undergraduate students from 10 different colleges or universities in Taiwan. There were 137 female and 161 male students. Five students did not return the questionnaires, which resulted in missing data. All of the students in this study were majoring in biology-related disciplines, including life science, biological science, and biological technology. Prior to the study, all students had taken a series of biology-related courses either in senior high school or in college. The students' ages ranged from 18 to 31 (with 13 missing age data), with an average age of 20.48. All of the research participants were recruited on campus and were asked to complete the questionnaires in the classroom. The three questionnaires were filled out at the same time.

Instruments

The current study utilised three separate questionnaires – the Epistemic Belief for Biology (EBB) questionnaire, the COLB questionnaire, and the SLB questionnaire. The EBB questionnaire was originally developed by Conley et al. (2004) to measure students' epistemic beliefs in science, and was then modified by Lin, Liang, and Tsai (2012a) specifically for biology research. The EBB consists of four dimensions: 'multiple-source,' 'uncertainty,' 'development,' and 'justification.' The original questionnaire included 26 items, presented on a seven-point Likert scale. A higher score indicates that the student is more likely to agree with the sophisticated epistemic beliefs. In Conley et al.'s (2004) study, the reliability of the four factors ranged from .57 to .82. The work by Lin, Liang, and Tsai (2012a) further validated the biological version of the questions and yielded four reliable factors for surveying undergraduate students' EBB. The definition of each dimension is described as follows (Conley et al., 2004):

1. *Multiple-source*: this dimension represents the belief that external authorities are not the only source of knowledge. Sample item: 'Everybody has to believe what biologists say' (scored in reverse).
2. *Uncertainty*: this dimension refers to the belief that biology knowledge is uncertain and tentative. Sample item: 'Biology knowledge is always true' (scored in reverse).
3. *Development*: this dimension refers to the belief that biology knowledge is evolving and changing. Sample item: 'The ideas in biology books sometimes change.'

4. *Justification*: this dimension concerns the importance of experimentation in biology and how students justify biological knowledge. Sample item: 'One important part of biology is doing experiments to come up with new ideas about how things work.'

For students' conceptions of learning, we adopted the COLB questionnaire from Chiou et al. (2012). The questionnaire includes six dimensions and uses a seven-point Likert scale, ranging from strongly disagree to strongly agree. The items in this survey were first developed to understand students' conceptions of learning science based on a phenomenographic study by Tsai (2004). A few follow-up studies further modified and validated the questionnaire (Chiou & Liang, 2012; Lee et al., 2008; Liang & Tsai, 2010). In order to survey students' domain-specific conceptions of learning, Chiou et al. (2012) modified the questionnaire for biology learning. As suggested by the results of previous studies (Chiou et al., 2012; Tsai et al., 2011), the six dimensions were further grouped into two levels. The reproductive-oriented conceptions include 'memorising,' 'testing,' and 'calculating and practising,' while the constructivist-oriented conceptions consist of 'increasing one's knowledge,' 'applying,' and 'understanding and seeing in a new way.' Through factor analysis and confirmatory factor analysis, researchers have shown that the items were highly reliable and demonstrated a good model fit (e.g. Chiou et al., 2012; Lee et al., 2008; Tsai et al., 2011). Each dimension includes five to seven items. The definition of each factor is listed below (Chiou et al., 2012).

Memorising: Learning biology is conceptualised as the memorisation of definitions, formulae, laws, and special terms. Sample item: 'Learning biology means memorising the definitions, formula, and laws found in biology textbooks.'

Testing: Learning biology is to pass the examinations or to achieve high scores in biology tests. Sample item: 'Learning biology means getting high scores on examinations.'

Calculating and practising: Learning biology is viewed as a series of calculating, practising tutorial problems, and manipulating formulae and numbers. Sample item: 'Learning biology means constantly practising calculations and solving problems.'

Increasing one's knowledge: An increase in knowledge is seen as the main feature of learning biology. Sample item: 'Learning biology means acquiring knowledge that I did not know before.'

Applying: The purpose of learning biology is the application of received knowledge. Sample item: 'Learning biology means learning how to apply knowledge and skills that I already know to unknown problems.'

Understanding and seeing in a new way: A true understanding is viewed as a major feature of learning biology; also, biology learning is characterised in terms of getting a new perspective. Sample item: 'Learning biology means expanding my own views.'

The SLB questionnaire was modified from the Approaches to Learning Biology (ALB; Chiou et al., 2012) questionnaire and included two dimensions, 'surface strategies' and 'deep strategies.' The items in the ALB were first developed by Kember et al. (2004) and were then validated by Lee et al. (2008) and Liang et al. (2010) for probing Taiwanese high school and undergraduate students' learning strategies in science. Chiou et al. (2012) further modified the item for biology learning at the college level. Repeatedly, these past studies have shown that the items possess high validity and reliability. In the current study, we only utilised the two dimensions related to learning strategies in the structural model. Each dimension included six items, rated on a seven-point Likert scale. The two dimensions are defined as follows:

Deep strategies: students use a meaningful way to learn biology, such as making connections and extracting key points. Sample item: 'I try to relate what I have learnt in biology to what I learn in other subjects.'

Surface strategies: students use rote strategies to learn biology, such as unreflective memorisation. Sample item: 'I see no point in learning material which is not likely to be in the examination.'

Data analysis

In previous studies, the EBB, COLB, and SLB questionnaires were validated by exploratory factor analysis for biology-major students (Chiou et al., 2012; Lin, Liang, & Tsai, 2012a). Thus, in the current study, a single Confirmatory Factor Analysis (CFA) with all of the items and dimensions of the three questionnaires (EBB, COLB, and SLB) included in one model was performed to clarify the reliability and validity of all of the questionnaires. To simplify the relationships among these dimensions for advanced analysis with other questionnaires (i.e. EBB and SLB), in this study, we further reframed the COLB dimensions in terms of reproductive COLB and constructivist COLB, as proposed by Tsai et al. (2011). Thus, both first-order and second-order CFA analyses were conducted. The convergent validity of the proposed model was judged based on the following three criteria: (1) all of the item factor loadings should be higher than .6; (2) the values of the composite reliabilities (CR) should exceed .8; and (3) the values of average variance extracted (AVE) should exceed .5 (Chiu, Hsu, & Wang, 2006; Fornell & Larcker, 1981; Hair, Black, Babin, & Anderson, 2010). Based on these criteria, items were deleted. Taking the 'testing' dimension of the conception learning, for example, the original questionnaire included seven items, four of which were deleted (items T2, T3, T6, and T7). The original items for the 'testing' dimension are as follows:

T1. Learning biology means getting high scores on examinations.
T2. Learning biology means giving the correct answers while testing.
T3. If there were no tests, I would not learn biology.
T4. There are no benefits to learning biology other than getting high scores on examinations. In fact, I can get along well without knowing many scientific facts.
T5. The major purpose of learning biology is to get more familiar with test materials.
T6. I learn biology so that I can do well on biology-related tests.
T7. There is a close relationship between learning biology and taking tests.

The reason for the deletion of the items may be related to the large number of total items. The three questionnaires originally included 70 items in total. This large number of items might increase students' reading load far more than other studies in which only one or two questionnaires were used. Thus, the quality of the responses may be less stable than we expected.

Although many items were deleted, each dimension still includes 3–4 items. Three items per factor is acceptable for CFA analysis (Hair et al., 2010). All of the remaining items are listed in Appendix A.

To further understand the relationships among the dimensions of these three questionnaires, correlation analysis and SEM were performed. The SEM analysis was conducted with the SPSS Amos software, version 20. Finally, the mediating roles of students' COLB (i.e. reproductive COLB and constructivist COLB) in the relationship between their EBB and SLB were examined in this study. The bootstrap procedure in the AMOS software was used to analyse the direct relationship (with or without a mediator), the indirect relationship, and the mediation type. The effects of mediation are examined only when the direct effects between students' EBB and SLB are statistically significant.

Results

Verification of the validity and structure of the three questionnaires

Based on the aforementioned criteria, a total of 42 items were retained in the final version (i.e. 13 items for EBB, 21 items for COLB, and 8 times for SLB). Appendix A shows the results of the confirmatory factor analysis for the three questionnaires in one model as well as the descriptive statistics for each variable. Three to four items remained for each dimension. The reliability (Cronbach's alpha) coefficients for all of these dimensions ranged from .83 to .93, the composite reliability (CR) coefficients exceeded .8 (.81–.93), and the AVE exceeded .5 (.52–.77). In addition, all of the factor loadings of the measured items were statistically significant and higher than .6. The goodness of fit of the structure, Chi-square = 1251.63, $P < .001$, degree of freedom = 785, GFI = .84, AGFI = .82, IFI = .95, TLI = .94, CFI = .95, RMSEA = .044, and SRMR = .072 were obtained, and indicated a sufficient fit (Burkell et al., 1990), thus confirming the convergent and construct validity of this model for these three questionnaires.

Correlational relationships among different dimensions

The correlations among the dimensions of these three questionnaires, EBB, COLB, and SLB, are revealed in Table 1. In general, the students' COLB were correlated with their EBB. Furthermore, their reproductive COLB, such as the dimensions of 'memorising,' 'testing,' and 'calculating and practising,' negatively correlated with all of the dimensions in their EBB, except for the correlations between the dimensions of 'memorising' and 'development,' and between 'memorising' and 'justification.' On the contrary, the constructivist COLB, namely the dimensions of 'increase one's knowledge,' 'application,'

Table 1. The correlations among the dimensions of the EBB, COLB, and SLB.

	Multiple-source	Uncertainty	Development	Justification	Surface strategy	Deep strategy
Memorising	−.32**	−.35**	.09	.08	.38**	−.04
Testing	−.35**	−.54**	−.21**	−.21**	.60**	−.30**
CP	−.32**	−.57**	−.24**	−.23**	.52**	−.22**
IK	.05	.21**	.47**	.55**	−.16**	.43**
Application	.01	.08	.32**	.43**	−.17**	.52**
US	.08	.26**	.50**	.56**	−.27**	.60**
Surface strategy	−.29**	−.47**	−.14*	−.13*	–	–
Deep strategy	.04	.10	.33**	.41**	–	–

Notes: *$P < .05$, ** $P < .01$; CP: calculating and practising; IK: increase one's knowledge; US: understanding and seeing in a new way.

and 'understanding and seeing in a new way,' were positively correlated with the 'uncertainty,' 'development,' and 'justification' dimensions of their EBB, except for the relationship between 'application' and 'uncertainty.' However, the correlations between the constructivist COLB and 'multiple-source' were not statistically significant.

On the other hand, the statistics showed that students' learning biology strategies significantly correlated with both their COLB and their EBB, in general. More specifically, their surface SLB positively correlated with their reproductive COLB, and also negatively correlated with both their constructivist COLB and their EBB. Moreover, in contrast to the surface SLB, students' deep strategies negatively correlated with their reproductive COLB (except for the dimension of 'memorising'), and positively correlated with their constructivist COLB and two dimensions of EBB (i.e. 'development' and 'justification'). However, the correlations between their deep SLB and their EBB in terms of 'multiple-source' and 'uncertainty' were not statistically significant.

The structural relationships among students' epistemic beliefs, conceptions of learning, and learning strategies

Figure 2 shows the structural relationships among the three questionnaires: EBB, COLB, and SLB. The path with no statistical significance is omitted. The fit indices reveal that the model adequately explains the data (Chi-square = 1270.50, $P < .001$, degree of freedom = 787, GFI = .84, AGFI = .81, IFI = .95, TLI = .94, CFI = .95, RMSEA = .045, and SRMR = .072) (Jöreskog & Sörbom, 1993). According to Figure 2, 'uncertainty' is the significantly negative dimension for explaining the variation in reproductive COLB (path coefficient =

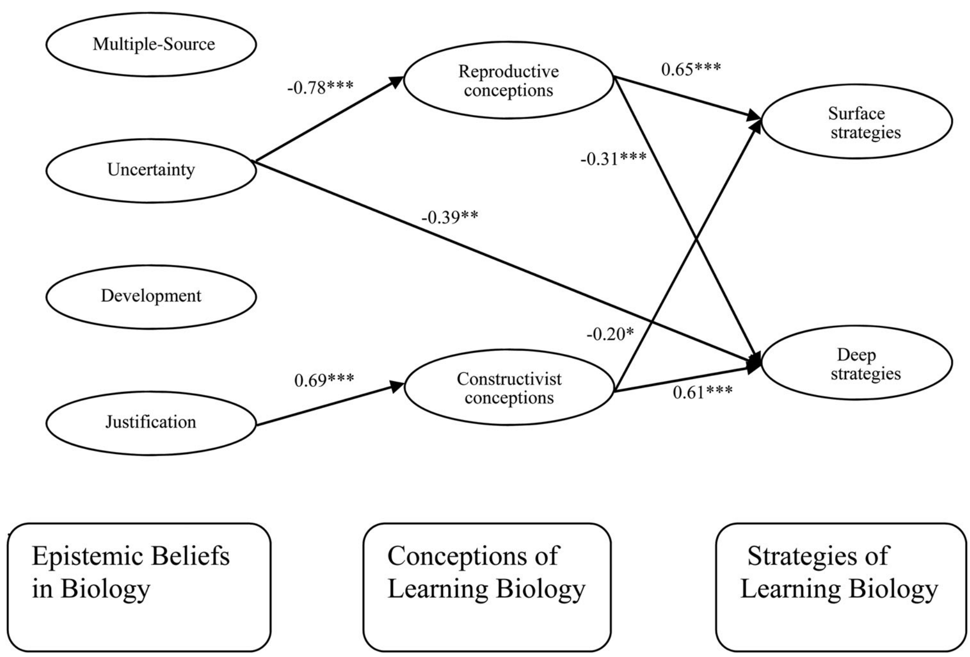

Figure 2. The structural equation model of the relationships among EBB, conceptions of learning biology, and SLB.

−.78, $P < .001$), whereas 'justification' is the significantly positive dimension explaining the variation in constructivist COLB (path coefficient = .69, $P < .001$). In addition, both students' reproductive and constructivist COLB have statistically significant relationships with both their surface and deep SLB. The reproductive COLB are the significantly positive dimension for explaining the variation in surface strategies (path coefficient = .65, $P < .001$) and the significantly negative dimension explaining the variation in deep strategies (path coefficient = −.31, $P < .001$). On the other hand, the constructivist COLB are the significantly negative dimension explaining the variation in surface SLB (path coefficient = −.20, $P < .05$) and the significantly positive dimension explaining the variation in deep SLB (path coefficient = .61, $P < .001$). As a result, only 'uncertainty' has a negative relationship with students' deep SLB (path coefficient = −.39, $P < .01$). All of the aforementioned dimensions are statistically significant.

Testing of mediation

The standard regression weights of the direct model with or without a mediator, the indirect model, and the mediation types are presented in Table 2. In the direct model without a mediator, students' beliefs of 'uncertainty' and 'justification' directly related to their surface and deep SLB, respectively ($\beta = -.64$–.65, $P < .001$), with statistical significance. Regarding the direct model with mediators, statistically significant relationships were found only between students' 'justification' of their EBB and their deep learning strategies ($\beta = .33$, $P < .05$), as well as students' 'uncertainty' of their EBB and their surface learning strategies ($\beta = -.33$, $P < .05$). However, in the indirect model, statistical significance only exists for the relationship between students' 'uncertainty' of EBB and their surface learning strategies with reproductive COLB as a mediator ($\beta = -.50$, $P < .01$), and in the relationship between 'justification' of EBB and their deep learning strategies with constructivist COLB as a mediator ($\beta = .41$, $P < .01$).

In this study, we hypothesised that students' epistemic beliefs predict COLB and predict SLB. We further assumed that students' COLB played a mediating role between their EBB and SLB. The SEM analysis and mediation testing suggested some relationships between EBB and COLB and between EBB and SLB and further showed two paths with complete mediation. In sum, students' epistemic beliefs of 'uncertainty' and 'justification' in biology were statistically significant in explaining the constructivist and reproductive COLB,

Table 2. Testing students' conceptions of learning biology as mediators between their epistemic beliefs and learning strategies.

Tested relationship	Direct model without mediator	Direct model with mediator	Indirect model	Result
Uncertainty → Reproductive COLB → Surface strategy	−.64***	−.15	−.50**	Complete mediation
Justification → Reproductive COLB → Deep strategy	.65***	.33*	−.04	Direct relationship (no mediation)
Uncertainty → Constructivist COLB → Surface strategy	−.64***	−.31*	.03	Direct relationship (no mediation)
Justification → Constructivist COLB → Deep strategy	.65***	.21	.41**	Complete mediation

*$P < .05$.
**$P < .01$.
***$P < .001$.

respectively; and 'uncertainty' was statistically significant in explaining the 'deep strategies' of learning biology as well. The results of mediation testing further revealed that 'uncertainty' predicted 'surface strategies' through the mediation of 'reproductive' conceptions; and the relationships between 'justification' and 'deep strategies' were mediated by 'constructivist' COLB.

Discussion and implications

Two pathways of learning biology were predicted by the students' epistemic beliefs, and were mediated by their COLB. One path suggested that students who justified their knowing with evidence tended to conceptualise learning from a constructivist orientation and thus focused on learning that maximised their understanding. This result is supported by previous findings that 'justification' serves as a positive predictor of students' learning conceptions and of their deep or meaningful learning strategies (Kizilgunes et al., 2009; Liang & Tsai, 2010; Lin, Liang, & Tsai, 2012a). One teaching implication derived from this finding is to continuously help students develop sophisticated epistemic beliefs of 'justification.' Nonetheless, researchers have stated that science classes, when overly focused on experimentation during the inquiry process, fail to show students how new knowledge is generated, justified, and evaluated by scientists (Duschl & Osborne, 2002). Teaching strategies such as engaging students in argumentation activities and explanation-driven inquiry are suggested by researchers to activate students' epistemic beliefs of justification in biology (Bråten, Ferguson, Strømsø, & Anmarkrud, 2014; Jiménez-Aleixandre, 2014; Sampson & Schleigh, 2013; Sandoval & Reiser, 2004).

The other path revealed that students who believed that biological knowledge was certain tended to adopt the conception that learning was about 'testing' and 'memorising,' and consequently utilised surface learning strategies. This finding is consistent with our prediction based on previous research (e.g. Kizilgunes et al., 2009; Liang et al., 2010). The third major result from the study suggests that the belief of uncertainty negatively predicts the use of deeper strategies for learning biology. This 'mismatch' challenges the more traditional assumption about epistemic sophistication, and sheds some light on the argument that sophisticated epistemic beliefs are not necessarily associated with productive learning (Elby & Hammer, 2001). Elby and Hammer argued that, for instance, the belief of certain knowledge may be more productive for students learning Newton's laws of motion than believing that knowledge is uncertain. In Taiwan, biology learning still focuses more on declarative knowledge and less on inquiry. Although we found that some college students in Taiwan do realise the uncertain nature of biology, especially when it is compared to the physical sciences (Lee & Tsai, 2012; Tsai, 1998, 2006), they might find that the use of surface strategies is effective in coping with their assignments and assessments when 'productivity' is taken into consideration. Similar to Elby and Hammer's argument, Tsai et al. (2011) found that some students who believed that science is uncertain actually developed a lower level of self-efficacy due to lower performance in school. An important implication of this finding is to help college instructors be more familiar with the uncertain nature of science and more comfortable responding to students' beliefs of uncertainty (Greene, Sandoval, & Bråten, 2016). Consequently, instructors may be more willing to create a learning environment that is more encouraging of the belief in uncertainty. Another implication is to revise the questionnaire to be more inclusive of contextual information, as is discussed later.

The relationships between conceptions of learning and strategies of learning were completely consistent with our hypotheses as well as with previous research. However, some of the proposed relationships between epistemic beliefs and conceptions of learning, and between epistemic beliefs and learning strategies, were not observed. As a matter of fact, 'multiple-source' and 'development' predicted neither conceptions of learning nor learning strategies. There may be other mediators that we have overlooked in the current study. As other researchers have suggested, the discipline, the particular knowledge under discussion, and the intended use of the knowledge (i.e. epistemic aim) are important contextual information that might relate to students' epistemic beliefs (Chinn et al., 2011; Elby & Hammer, 2001; Elby, Macrander, & Hammer, 2016). Therefore, in order to increase the explanatory power of the model of how epistemic beliefs are related to learning, in future studies, the aforementioned variables are potential factors to be examined.

Finally, although we built the hypothesised model based on empirical findings and the theoretical assumptions in the literature, there are some limitations to the current study. First, we did not have information of the kind of biology learning the students had experienced. Because our study focused on verifying a theorised model, as a trade-off, we did not use qualitative or mixed methods. The latter two methods are better for capturing the nuances of contextual information. In future studies, one possible solution to this challenge is to provide a particular learning context for the questionnaire, such as undertaking a survey of a particular course or of a particular learning environment (Elby & Hammer, 2001; Ozkal et al., 2009). In addition to epistemic goals, other constructs such as students' learning environment perceptions (e.g. Ozkal et al., 2009) could possibly be a valuable addition to the structural equation model. Another possible future direction is to include outcome variables in the model. Yet, this research direction remains challenging. For instance, it is difficult to develop a standardised test for measuring academic outcomes at the college level, especially when sampling from different universities and recruiting students from different years of study. This is a challenge that needs to be overcome in future research.

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References

Bahcivan, E. (2014). Examining relationships among Turkish preservice science teachers' conceptions of teaching and learning, scientific epistemological beliefs and science teaching efficacy beliefs. *Journal of Baltic Science Education*, *13*(6), 870–882.

Belmont, J. M., Butterfield, E. C., & Ferretti, R. P. (1982). To secure transfer of training: Instruct self-management skills. In D. K. Detterman & R. J. Sternberg (Eds.), *How and how much can intelligence be increased?* (pp. 147–154). Norwood, NJ: Ablex.
Biggs, J. B. (1987). *Student approaches to learning and studying. Research monograph*. Hawthorn: Australian Council for Educational Research.
Biggs, J. B. (1994). Approaches to learning: Nature and measurement of. *The International Encyclopedia of Education*, *1*, 319–322.
Borkowski, J. G., Carr, M., Rellinger, E. A., & Pressley, M. (1990). Self-regulated strategy use: Interdependence of metacognition, attributions, and self-esteem. In B. F. Jones (Ed.), *Dimensions of thinking: Review of research* (pp. 53–92). Hilldale, NJ: Lawrence Erlbaum Associates.
Bråten, I. (2010). Personal epistemology in education: Concepts, issues, and implications. In Penelope Peterson, Eva Baker, & B. McGaw (Eds.), *International encyclopedia of education* (3rd ed., pp. 211–217). Oxford: Elsevier Science Limited.
Bråten, I., Ferguson, L. E., Strømsø, H. I., & Anmarkrud, Ø. (2014). Students working with multiple conflicting documents on a scientific issue: Relations between epistemic cognition while reading and sourcing and argumentation in essays. *British Journal of Educational Psychology*, *84*(1), 58–85. doi:10.1111/bjep.12005
Buehl, M. M., Alexander, P. A., & Murphy, P. K. (2002). Beliefs about schooled knowledge: Domain specific or domain general? *Contemporary Educational Psychology*, *27*(3), 415–449. doi:10.1006/ceps.2001.1103
Burkell, J., Schneider, B., & Pressley, M. (1990). Mathematics. In M. Pressley & Associates (Eds.), *Cognitive strategy instruction that really improves children's academic performance* (pp. 147–177). Cambridge, MA: Brookline Books.
Cano, F., & Cardelle-Elawar, M. (2004). An integrated analysis of secondary school students' conceptions and beliefs about learning. *European Journal of Psychology of Education*, *19*(2), 167–187. doi:10.1007/BF03173230
Chen, J. A. (2012). Implicit theories, epistemic beliefs, and science motivation: A person-centered approach. *Learning and Individual Differences*, *22*(6), 724–735. doi:10.1016/j.lindif.2012.07.013
Chen, J. A., & Pajares, F. (2010). Implicit theories of ability of Grade 6 science students: Relation to epistemological beliefs and academic motivation and achievement in science. *Contemporary Educational Psychology*, *35*(1), 75–87. doi:10.1016/j.cedpsych.2009.10.003
Cheung, D. (2015). The combined effects of classroom teaching and learning strategy use on students' chemistry self-efficacy. *Research in Science Education*, *45*(1), 101–116. doi:10.1007/s11165014-9415-0
Chin, C., & Brown, D. E. (2000). Learning in science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching*, *37*(2), 109–138. doi:10.1002/(SICI)1098-2736(200002)37:2<109::AID-TEA3>3.0.CO;2-7
Chinn, C. A., Buckland, L. A., & Samarapungavan, A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist*, *46*(3), 141–167.
Chiou, G.-L., & Liang, J.-C. (2012). Exploring the structure of science self-efficacy: A model built on high school students' conceptions of learning and approaches to learning in science. *The Asia-Pacific Education Researcher*, *21*(1), 83–91.
Chiou, G.-L., Liang, J.-C., & Tsai, C.-C. (2012). Undergraduate students' conceptions of and approaches to learning in biology: A study of their structural models and gender differences. *International Journal of Science Education*, *34*(2), 167–195. doi:10.1080/09500693.2011.558131
Chiu, C. M., Hsu, M. H., & Wang, E. T. (2006). Understanding knowledge sharing in virtual communities: An integration of social capital and social cognitive theories. *Decision Support Systems*, *42*(3), 1872–1888.
Clinton, V. (2014). The relationship between students' preferred approaches to learning and behaviors during learning: An examination of the process stage of the 3P model. *Instructional Science*, *42*, 817–837.

Conley, A. M., Pintrich, P. R., Vekiri, I., & Harrison, D. (2004). Changes in epistemological beliefs in elementary science students. *Contemporary Educational Psychology*, *29*(2), 186–204. doi:10.1016/j.cedpsych.2009.10.003

Deniz, H. (2011). Searching for components of conceptual ecology that mediate development of epistemological beliefs in science. *Journal of Science Education and Technology*, *20*(6), 743–749. doi:10.1007/s10956-010-9267-y

Ding, L. (2014). Verification of causal influences of reasoning skills and epistemology on physics conceptual learning. *Physical Review Special Topics Physics Education Research*, *10*, 023101–023105. doi:10.1103/PhysRevSTPER.10.023101

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*(1), 39–72.

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education*, *85*(5), 554–567.

Elby, A., Macrander, C., & Hammer, D. (2016). Epistemic cognition in science. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 113–127). New York, NY: Routledge.

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, *18*, 39–50.

Fulmer, G. W. (2014). Undergraduates' attitudes toward science and their epistemological beliefs: Positive effects of certainty and authority beliefs. *Journal of Science Education and Technology*, *23*(1), 198–206. doi:10.1007/s10956-013-9463-7

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016). An introduction to epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 1–15). New York: NY: Routledge.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis*. Upper Saddle River, NJ: Prentice Hall.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology*, *25*(4), 378–405. doi:10.1006/ceps.1999.1026

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*(2), 129–163. doi:10.1016/j.cedpsych.2004.01.002

Hofer, B. K. (2006). Domain specificity of personal epistemology: Resolved questions, persistent issues, new models. *International Journal of Educational Research*, *45*(1–2), 85–95.

Hofer, B. K. (2016). Epistemic cognition as a psychological construct: Advancements and challenges. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 19–38). New York: NY: Routledge.

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*(1), 88–140.

Hsieh, Y.-H., & Tsai, C.-C. (2014). Students' scientific epistemic beliefs, online evaluative standards, and online searching strategies for science information: The moderating role of cognitive load experience. *Journal of Science Education and Technology*, *23*(3), 299–308. doi:10.1007/s10956-013-9464-6

Hsu, C.-Y., Tsai, M.-J., Hou, H.-T., & Tsai, C.-C. (2014). Epistemic beliefs, online search strategies, and behavioral patterns while exploring socioscientific issues. *Journal of Science Education and Technology*, *23*(3), 471–480. doi:10.1007/s10956-013-9477-1

Jiménez-Aleixandre, M. P. (2014). Determinism and underdetermination in genetics: Implications for students' engagement in argumentation and epistemic practices. *Science & Education*, *23*(2), 465–484. doi:10.1007/s11191-012-9561-6

Jöreskog, K., & Sörbom, D. (1993). *LISREL 8: Structural equation modeling with the SIMPLIS command language*. Chicago, IL: Scientific Software International Inc.

Kember, D., Biggs, J., & Leung, D. Y. P. (2004). Examining the multidimensionality of approaches to learning through the development of a revised version of the learning process questionnaire. *British Journal of Educational Psychology*, *74*(2), 261–279. doi:10.1348/000709904773839879

Kizilgunes, B., Tekkaya, C., & Sungur, S. (2009). Modeling the relations among students' epistemological beliefs, motivation, learning approach, and achievement. *The Journal of Educational Research*, *102*(4), 243–256. doi:10.3200/JOER.102.4.243-256
Kuhn, D., & Udell, W. (2003). The development of argument skills. *Child Development*, *74*, 1245–1260.
Lee, M.-H., Johanson, R. E., & Tsai, C.-C. (2008). Exploring Taiwanese high school students' conceptions of and approaches to learning science through a structural equation modeling analysis. *Science Education*, *92*(2), 191–220. doi:10.1002/sce.20245
Lee, S. W.-Y., & Tsai, C.-C. (2012). Students' domain-specific scientific epistemological beliefs: A comparison between biology and physics. *The Asia-Pacific Education Researcher*, *21*(2), 215–229.
Li, W.-T., Liang, J.-C., & Tsai, C.-C. (2013). Relational analysis of college chemistry-major students' conceptions of and approaches to learning chemistry. *Chemistry Education Research and Practice*, *14*(4), 555–565. doi:10.1039/C3RP00034F
Liang, J.-C., Lee, M.-H., & Tsai, C.-C. (2010). The relations between scientific epistemological beliefs and approaches to learning science among science-major undergraduates in Taiwan. *The Asia-Pacific Education Researcher*, *19*(1), 43–59.
Liang, J.-C., & Tsai, C.-C. (2010). Relational analysis of college science-major students' epistemological beliefs toward science and conceptions of learning science. *International Journal of Science Education*, *32*(17), 2273–2289. doi:10.1080/09500690903397796
Lin, T.-J., Deng, F., Chai, C. S., & Tsai, C.-C. (2013). High school students' scientific epistemological beliefs, motivation in learning science, and their relationships: A comparative study within the Chinese culture. *International Journal of Educational Development*, *33*(1), 37–47. doi:10.1016/j.ijedudev.2012.01.007
Lin, Y.-C., Liang, J.-C., & Tsai, C.-C. (2012a). The relationships between epistemic beliefs in biology and approaches to learning biology among biology-major university students in Taiwan. *Journal of Science Education and Technology*, *21*(6), 796–807. doi:10.1007/s10956-012-9367-y
Lin, Y.-H., Liang, J.-C., & Tsai, C.-C. (2012b). Effects of different forms of physiology instruction on the development of students' conceptions of and approaches to science learning. *AJP: Advances in Physiology Education*, *36*(1), 42–47. doi:10.1152/advan.00118.2011
Lising, L., & Elby, A. (2005). The impact of epistemology on learning: A case study from introductory physics. *American Journal of Physics*, *73*(4), 372–382. doi:10.1119/1.1848115
Marton, F., Dall' Alba, G., & Beaty, E. (1993). Conceptions of learning. *International Journal of Educational Research*, *19*, 277–300.
Marton, F., & Säljö, R. (1976). On qualitative differences in learning: I – outcome and process. *British Journal of Educational Psychology*, *46*(1), 4–11. doi:10.1111/j.2044-8279.1976.tb02980.x
Mason, L., Ariasi, N., & Boldrin, A. (2011). Epistemic beliefs in action: Spontaneous reflections about knowledge and knowing during online information searching and their influence on learning. *Learning and Instruction*, *21*(1), 137–151. doi:10.1016/j.learninstruc.2010.01.001
Muis, K. R. (2008). Epistemic profiles and self-regulated learning: Examining relations in the context of mathematics problem solving. *Contemporary Educational Psychology*, *33*(2), 177–208.
Muis, K. R., Trevors, G., & Chevrier, M. (2016). Epistemic climate for epistemic change. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 331–358). New York, NY: Routledge.
Murphy, P. K., & Mason, L. (2006). Changing knowledge and beliefs. In P. A. Alexander & P. H. Winne (Eds.), *Handbook of educational psychology* (pp. 305–324). Mahwah, NJ: Lawrence Erlbaum Associates.
Ozkal, K., Tekkaya, C., Cakiroglu, J., & Sungur, S. (2009). A conceptual model of relationships among constructivist learning environment perceptions, epistemological beliefs, and learning approaches. *Learning and Individual Differences*, *19*(1), 71–79. doi:10.1016/j.lindif.2008.05.005
Paulsen, M. B., & Wells, C. T. (1998). Domain differences in the epistemological beliefs of college students. *Research in Higher Education*, *39*(4), 365–384. doi:10.1023/A:1018785219220
Pressley, M., & Harris, K. R. (2006). Cognitive strategies instruction: From basic research to classroom instruction. In P. A. Alexander & P. H. Winne (Eds.), *Handbook of educational psychology* (pp. 265–286). Mahwah, NJ: Lawrence Erlbaum Associates.

Retzbach, A., Marschall, J., Rahnke, M., Otto, L., & Maier, M. (2011). Public understanding of science and the perception of nanotechnology: The roles of interest in science, methodological knowledge, epistemological beliefs, and beliefs about science. *Journal of Nanoparticle Research*, *13*(12), 6231–6244. doi:10.1007/s11051-011-0582-x

Säljö, R. (1979). *Learning in the learner's perspective. I. Some common-sense conceptions*. Sweden: Institute of Education, University of Göteborg.

Sampson, V., & Schleigh, S. (2013). *Scientific argumentation in biology: 30 classroom activities*. Arlington, VA: National Science Teachers Association – NSTA Press.

Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education*, *88*(3), 345–372. doi:10.1002/sce.10130

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology*, *82*(3), 498–504. doi:10.1037/0022-0663.82.3.498

Schunk, D. H., & Zimmerman, B. J. (2006). Competence and control beliefs: Distinguishing the means and ends. In P. A. Alexander & P. H. Winne (Eds.), *Handbook of educational psychology* (pp. 349–367). Mahwah, NJ: Lawrence Erlbaum Associates.

Tsai, C.-C. (1998). An analysis of scientific epistemological beliefs and learning orientations of Taiwanese eighth graders. *Science Education*, *82*(4), 473–489.

Tsai, C.-C. (1999). "Laboratory exercises help me memorize the scientific truths": A study of eighth graders' scientific epistemological views and learning in laboratory activities. *Science Education*, *83*(6), 654–674.

Tsai, C.-C. (2004). Conceptions of learning science among high school students in Taiwan: A phenomenographic analysis. *International Journal of Science Education*, *26*(14), 1733–1750. doi:10.1080/0950069042000230776

Tsai, C.-C. (2006). Biological knowledge is more tentative than physics knowledge: Taiwan high school adolescents' views about the nature of biology and physics. *Adolescence*, *41*(164), 691–703.

Tsai, C.-C., Ho, H. N. J., 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*(6), 757–769. doi:10.1016/j.learninstruc.2011.05.002

Vos, N., van der Meijden, H., & Denessen, E. (2011). Effects of constructing versus playing an educational game on student motivation and deep learning strategy use. *Computers & Education*, *56*(1), 127–137.