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Investigating structural relationships among upper-secondary school students' beliefs about knowledge, justification for knowing, and Internet-specific justification in the domain of science

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Abstract

In a sample of 455 Taiwanese upper-secondary school students, latent variable structural equation modeling was used to test hypothesized relationships between beliefs about knowledge in science, beliefs about justification for knowing in science, and justification of knowledge claims concerning science encountered on the Internet. Results indicated that participants displayed adaptive beliefs in the tentative and evolving nature of scientific knowledge while their beliefs about justification for knowing in science seemed somewhat less adaptive. Further, their self-reports of Internet-specific justification of knowledge claims suggested that they did not strongly believe that science information posted on the Internet needed to be carefully evaluated. The structural equation modeling indicated that beliefs in the tentative and evolving nature of scientific knowledge had direct positive relationships with beliefs in justification by research-based authority and justification by multiple sources in science, which, in turn, mediated the relationships between beliefs in tentative and evolving knowledge and adaptive beliefs about Internet-specific justification of knowledge claims. Beliefs in the unambiguous, certain nature of scientific knowledge had a direct positive relationship with beliefs in justification by school-based authority (i.e., the science teacher and the science textbook), but beliefs in justification by school-based authority were not related to Internet-specific justification beliefs. We highlight the unique contributions of this study to the field of epistemic belief and science education research, and its theoretical and educational implications are discussed.

KEYWORDS

beliefs about knowledge, epistemic beliefs, Internet-specific justification, justification for knowing, science education

1 | INTRODUCTION

Developing critical and evaluative habits of mind in students has always been a main focus within science education. Accordingly, a number of science education researchers have highlighted that learning in the domain of science requires a critical questioning of scientific claims as well as an evaluation of alternative and competing claims (e.g., Duncan et al., 2018; Duschl & Hamilton, 2011; Linn & Eylon, 2006; Sandoval, 2003; Tabak, 2016; Yang & Tsai, 2010). Also, in recent years, this requirement has been emphasized within several important educational documents. For example, the Organization for Economic Cooperation and Development (OECD) proposed *Education 2030* in which the need to develop competencies that mobilize knowledge, skills, attitudes, and values in meeting environmental, economic, and social challenges was highlighted (OECD, 2018a). The position of the OECD in this regard has informed the construct of global understanding as defined by the Program of International Student Assessment (OECD, 2018b). This construct refers to four cognitive processes including the ability to evaluate information, formulate arguments, and explain complex situations and problems; the ability to identify and analyze multiple perspectives and world views; the ability to understand differences in communication; and the ability to evaluate actions and consequences. Similarly, the US Board of Science Education proposed a *Framework for K–12 Science Education* in which eight practices for K–12 science and engineering curricula were specified (National Research Council, 2012). Among these practices were engaging in argumentation from evidence and obtaining, evaluating, and communicating information. In brief, such educational documents have strengthened the emphasis on developing critical and evaluative habits of mind in students and supported current trends within science education and science education research.

In particular, over the past decades, science education researchers have devoted much attention to students' beliefs and thinking about knowledge and the process of knowing as potential contributors to their scientific reasoning (Elby et al., 2016; Khishfe, 2008; Sinatra & Chinn, 2012; Zeineddin & Abd-El-Khalick, 2010). Also, students' beliefs and thinking about knowledge and the process of knowing have been a major area of investigation within educational psychology and the learning sciences (Greene et al., 2016; Sandoval et al., 2016). Of note is that research within these areas (i.e., science education and educational psychology) has traveled on somewhat different paths despite considerable overlap, however (Elby et al., 2016).

1.1 | Beliefs about knowledge and knowing in science education and educational psychology

Within science education, beliefs and understanding concerning the nature of science (NOS) has been considered an important aspect of science literacy (e.g., Abd-El-Khalick, 2013; Lederman, 2007; Lederman et al., 2002). This work has typically addressed students' views about a wide range of scientific practices or ways of knowing (e.g., experimentation) and scientific outcomes or forms of knowledge (e.g., theories; Lederman, 2007), often probed by means of questionnaires or interviews (e.g., Lederman et al., 2002; Smith & Wenk, 2006). For example, Osborne et al. (2003) highlighted views about science and certainty, scientific methods and critical testing, analysis and interpretation of data, hypothesis and prediction, diversity of scientific thinking, creativity, science and questioning, and cooperation and collaboration as relevant to the NOS. Regarding the potential influences of students' beliefs about science on science learning and science literacy, science education researchers have shown relationships with inquiry learning, argumentation, conceptual understanding, and problem solving in science (e.g., Lindfors et al., 2019; Nussbaum et al., 2008; Stathopoulou & Vosniadou, 2007; Tsai, 1999). Accordingly, a six-item measure of epistemic beliefs about science was included in the 2015 Program for International Student Assessment, with these items targeting the tentativeness of scientific ideas and the importance of gathering evidence from multiple experiments (OECD, 2016). Agreement with such statements on the PISA test later has been shown to positively predict engagement and achievement in science (Karakolidis et al., 2019; She et al., 2019).

Within educational psychology, researchers have mainly been interested in students' domain-specific perspectives on beliefs about knowledge and knowing, without targeting beliefs that are distinctively about a particular discipline (e.g., the NOS) (Elby et al., 2016; Hofer, 2016). Thus, research in this area has typically adapted the same belief measures to different domains (e.g., science), for example, to demonstrate that students' beliefs about knowledge and knowing differ across domains (Sandoval et al., 2016). However, students' scores on domain-specific measures in this latter sense (i.e., when adapted to the domain of science) also have been found to predict their engagement and achievement in science in many studies (Bråten et al., 2011; Greene et al., 2018). This is consistent with the view that beliefs about the NOS and beliefs about knowledge and knowing from the perspective of science are related, which seems to be acknowledged by several science education researchers (e.g., Abd-El-Khalick & Akerson, 2004; Deniz, 2011; Sinatra et al., 2003), yet seldom investigated (see, however, Borgeding & Deniz, 2019; Ozgelen, 2012).

Because beliefs about knowledge and knowing in reference to science have been a burgeoning area of research during the last decades, and because such beliefs seem to be comparable to beliefs about the NOS in predicting science learning and literacy, we followed this line of research in the present study. In particular, because measures used in different studies concerning science have targeted different dimensions of epistemic beliefs, we included measures of these different dimensions in our study to investigate the structural relationships among them.

1.2 | The multidimensionality of epistemic beliefs

A fundamental assumption within a multidimensional view of epistemic beliefs has been that students' beliefs about the nature of knowledge can be distinguished from their beliefs about the nature of knowing (Hofer & Pintrich, 1997). Thus, in the first main category of epistemic beliefs, concerning the nature of knowledge, Hofer and Pintrich (1997) included beliefs about the certainty and simplicity of knowledge. In their view, beliefs about the certainty of knowledge could be defined along a dimension ranging from absolute and unchanging to tentative and evolving, while beliefs about the simplicity of knowledge could be defined along a dimension ranging from an accumulation of facts to highly interrelated concepts. In the second main category of epistemic beliefs, Hofer and Pintrich (1997) included beliefs about the source of knowledge and justification for knowing. While they assumed that beliefs about the source of knowledge ranged from external authority to self as a knower, they assumed that beliefs about justification for knowing ranged from observation and gut feeling through authority to rules of inquiry and the evaluation of multiple sources.

Although research on beliefs about both the nature of knowledge and the nature of knowing has flourished since Hofer and Pintrich (1997) conducted their landmark review of the field, with both categories of beliefs found to be linked to academic achievement (Greene et al., 2018), beliefs about the nature of knowing seem to have received the lion's share of attention during the last decade. This, at least in part, may be due to a revitalization of the multidimensional approach to epistemic belief research by Greene and colleagues (Greene et al., 2008), who highlighted the importance of beliefs about justification for knowing and argued that such beliefs, rather than being defined along one single dimension, should be conceptualized in terms of several different dimensions. In particular, those authors distinguished between one dimension concerning justification of knowledge claims by referring to an external authoritative source and one dimension concerning justification by relying on self as a source (see also Greene et al., 2010).

Inspired by Greene et al.'s (2008, 2010) work, Ferguson et al. (2012) used verbal protocol analysis in identifying three dimensions of justification for knowing, finding that students reading about a scientific topic tried to justify knowledge claims not only by referring to authority and personal opinion but also by checking multiple information sources for consistency. This trichotomous justification belief framework, consisting of separate dimensions of justification by authority, personal justification, and justification by multiple sources, was further validated in a factor-analytic study by Ferguson et al. (2013). Of note is that in this framework, the two nature of knowing dimensions originally proposed by Hofer and Pintrich (1997), that is, source of knowledge and justification for knowing, are merged because individuals are assumed to justify knowledge claims by relying on different types of sources (viz., an external authoritative source, self as a source, and multiple information sources).

Measured at a domain-specific level in reference to science, the types of justification for knowing figuring in the trichotomous framework have been linked to students' learning, comprehension, and achievement in science in a range of studies (for review, see Greene et al., 2018). In general, personal justification has been found to be negatively and justification by multiple sources has been found to be positively related to the outcome measures (e.g., Brandmo & Bråten, 2018; Bråten et al., 2013; Bråten et al., 2014; Ferguson & Bråten, 2013; Kendeou et al., 2016; Trevors et al., 2017). In several studies, justification by authority has been found to be unrelated to performance (e.g., Brandmo & Bråten, 2018; Bråten et al., 2013; Kendeou et al., 2016). In these studies, justification by authority has referred to school-based as well as research-based authority in the domain of science. However, a study by Bråten and Ferguson (2014) indicated that a positive relationship between justification by authority and science achievement may be restricted to justification by research-based authority.

1.3 | Internet-specific justification beliefs

In the information age, students are not only presented with scientific information in school, that is, from their science teacher and their science textbook. In addition, the Internet has become a major source of information about science. Many science educators are presently concerned about students' critical evaluation of information they encounter on the Internet because such evaluation seems to require the development of more advanced epistemic cognition concerning the justification of knowledge claims (Chinn et al., 2020; Duncan et al., 2018; Sinatra & Lombardi, 2020). Relevant to this issue, Bråten et al. (2019) recently developed and validated a measure targeting different forms of justification when encountering knowledge claims on the Internet. Like the empirical work described in the previous section, this measure was based on the trichotomous justification belief framework of Ferguson et al. (2012, 2013), capturing justification by authority, personal justification, and justification by multiple sources. However, Bråten et al. (2019) argued that because the Internet is a knowledge resource that involves particular ways of presenting knowledge claims and particular ways of knowing, these types of justification need to be addressed in reference to learning within Internet technologies. In addition, the Internet-specific justification inventory that they constructed was designed to capture beliefs about justification for knowing at the level of specific topics or domains, such as natural science. Of note is, however, that rather than focusing on justification by personal view or opinion, as had been common in prior research within the trichotomous framework, Bråten et al. (2019) designed their measure to focus on personal justification in terms of prior knowledge and reasoning.

1.4 | Potential relationships among epistemic belief dimensions

In the current study, we set out to examine the extent to which students' beliefs about justification of knowledge claims concerning science that they encountered on the Internet were predicted by their more general beliefs about justification for knowing in science, measuring general justification beliefs about science as well as Internet-specific justification beliefs about science in terms of justification by authority, personal justification, and justification by multiple sources. In doing this, we also assessed the applicability of more general justification beliefs heavily studied within the trichotomous framework to the more specific context of learning within Internet technologies.

Another unique contribution of the current study is that we investigated students' beliefs about knowledge in the domain of science as predictors of their beliefs about the process of knowing (i.e., about justification for knowing) in the same domain. In previous research on the structure of epistemic beliefs, beliefs about knowledge and beliefs about the process of knowing have been studied at the same structural level, that is, without considering the possibility that beliefs about knowledge may be primary or foundational in relation to more process-oriented beliefs about knowing, such as beliefs concerning the justification of knowledge claims (Buehl, 2008). Because we targeted general justification beliefs about science as well as beliefs about the justification of claims concerning science encountered on the Internet, we were also able to investigate whether any relationships between beliefs about knowledge and Internet-specific justification beliefs were mediated by more general beliefs about justification of knowledge claims in science.

To measure beliefs about the nature of knowledge, we focused on the two knowledge dimensions used to study epistemic beliefs about science by Conley et al. (2004): beliefs about the certainty and development of scientific knowledge. These dimensions have been used to study beliefs about the nature of knowledge concerning science in a range of studies (e.g., Beghetto & Baxter, 2012; Chen & Pajares, 2010; Conley et al., 2004; Mason et al., 2013; Wu & Tsai, 2010; Yang et al., 2019; Yang, Chang, et al., 2016; Yang, Huang, & Tsai, 2016), with findings indicating that stronger beliefs in the certainty of knowledge (e.g., "All questions in science have one right answer") may be maladaptive and stronger beliefs in the development of knowledge (e.g., "Ideas in science sometimes change") may be adaptive in terms of motivation, strategy use, learning, and comprehension in the domain of science. To the best of our knowledge, however, no prior study has examined these two dimensions as potential antecedents of different types of beliefs about justification for knowing in science.

Of note is that compared with Hofer and Pintrich's (1997) two nature of knowledge dimensions, concerning certainty and simplicity, both the certainty and development dimensions described by Conley et al. (2004) seem to be included in the broader certainty construct proposed by Hofer and Pintrich (1997). Likewise, Bråten et al. (2009) found that beliefs about the certainty of knowledge could be separated into one dimension concerning the unambiguous nature of knowledge and one dimension concerning the tentativeness of knowledge. Also, Schraw et al. (2002), in a factor-analytic study, identified two dimensions concerning the certainty of knowledge that represented different constructs,

1.5 | The present study

In summary, the purpose of this study was to investigate whether students' beliefs about the nature of knowledge in science (i.e., the certainty and development of scientific knowledge) may underlie their beliefs about the process of justification for knowing in science (e.g., justification by authority). An additional purpose was to investigate whether students' beliefs about justification in the context of engaging with science on the Internet may be directly related to their beliefs about different ways of justifying knowledge claims in science more generally, and indirectly related to their beliefs about the nature of knowledge in science (i.e., via beliefs about justification for knowing in science). Although the three sets of beliefs have been included in different studies within the domain of science previously, this is the first time the structural relationships among them have been investigated in any one study. As such, this study represents a unique contribution to the research agenda on both epistemic beliefs and science education. Moreover, because these beliefs have been shown to matter in terms of learning and comprehension in the domain of science (see preceding background analysis), the structural relationships among them may have not only theoretical but also instructional implications (see Section 4).

To accomplish these purposes, we developed and tested a model of direct and indirect relationships between beliefs about knowledge in science, beliefs about justification for knowing in science, and beliefs about the justification of knowledge claims about science encountered on the Internet. Our hypothesized model is displayed in Figure 1. The reason that justification for knowing in science included two constructs concerning justification by authority, that is, justification by school-based authority and justification by research-based authority, is that preliminary factor analyses indicated that the six items used to measure justification by authority loaded on two different factors focusing on school-based and research-based authority, respectively. Also, because two of the three items used to measure personal justification did not have sufficient loadings on this factor, the construct of personal justification was not included in justification for knowing in science (see Section 3.1 below). The fit of the hypothesized model to data was tested in a sample of Taiwanese upper-secondary school students. In the following sections, we describe and justify the specific hypotheses represented within this model. Please note that all the hypothesized relationships in the model were expected to hold while controlling for the entire set of variables.

1.5.1 | Hypothesized relationships between beliefs about justification for knowing in science and beliefs about Internet-specific justification

As can be seen in Figure 1, beliefs about justification for knowing in science were hypothesized to directly affect beliefs about the justification of knowledge claims concerning science encountered on the Internet. Specifically, we hypothesized that justification by research-based

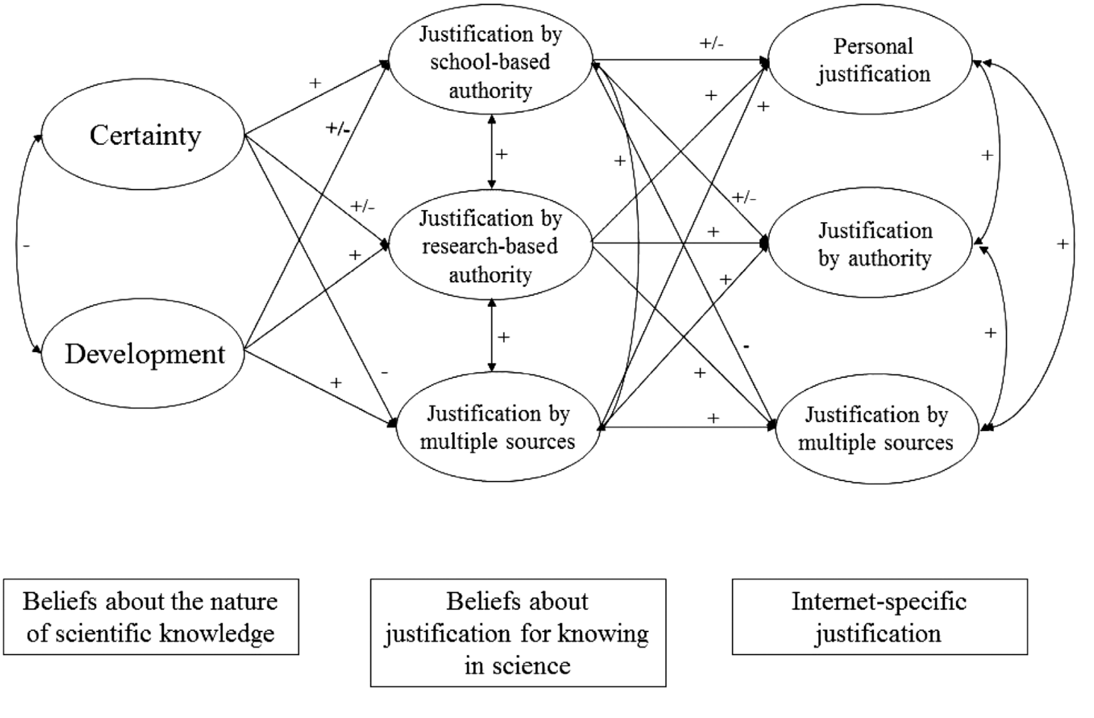

FIGURE 1 The hypothesized model. + = positive effect, − = negative effect, ± = valence not prespecified

authority and justification by multiple sources in science had direct positive effects on Internet-specific personal justification. Presumably, students who rely on research-based authority in the form of scientific investigation and check multiple sources for consistency are also more likely to rely on prior knowledge and reasoning when evaluating knowledge claims encountered on the Internet because they perceive themselves as more competent to do so (e.g., Bråten & Ferguson, 2014; Tsai et al., 2011). Likewise, we hypothesized that justification by research-based authority and justification by multiple sources in science had direct positive effects on Internet-specific justification by authority. Thus, it seems reasonable to assume that students who generally rely on research-based authority and multiple sources in science also put more trust in external expertise when encountering knowledge claims about science on the Internet (e.g., Kammerer et al., 2015; Kammerer et al., 2021; Knight et al., 2017). While we also expected that justification by research-based authority and multiple sources in science would have direct positive effects on checking multiple Internet sources to justify knowledge claims (e.g., Bråten et al., 2011; Kammerer et al., 2021), we expected that justification by school-based authority in science would negatively affect Internet-specific justification by multiple sources. That is, students reporting strong reliance on the science textbook or the science teacher as means of justification might also be less likely to evaluate knowledge claims on the Internet by checking multiple information sources because they think they know the correct answer already (Bråten et al., 2015). We were not able to specify the direction of any direct effects that justification by school-based authority in science might have on Internet-specific personal justification and justification by authority, however. This is because reliance on the science textbook or the science teacher may not necessarily impede students' use of prior knowledge or reasoning when encountering knowledge claims on the Internet; nor may it necessarily promote reliance on external expertise encountered on the Internet (i.e., besides the textbook or the teacher).

1.5.2 | Hypothesized relationships between beliefs about knowledge and beliefs about justification for knowing in science

In turn, we hypothesized that the three justification for knowing in science constructs (i.e., justification by school-based authority, justification by research-based authority, and justification by multiple sources) would be directly affected by students' beliefs about knowledge in science (see Figure 1). Specifically, we hypothesized that beliefs about the certainty of knowledge would positively affect justification by school-based authority and negatively affect justification by multiple sources. Presumably, students who believe there is one unambiguous right answer in science are also more likely to rely on what the science textbook or the science teacher says and, at the same time, less likely to use multiple sources in cross-checking knowledge claims in science (e.g., Bråten et al., 2011; Pieschl et al., 2008). Moreover, with respect to beliefs about the development of scientific knowledge, we hypothesized that this construct would have direct positive effects on both justification by research-based authority and justification by multiple sources. This is because students who view scientific knowledge as tentative and evolving may also be more likely to rely on evidence developed through scientific investigation in justifying knowledge claims, as well as to display an openness to considering multiple perspectives on a scientific issue (e.g., Kendeou et al., 2011; Pieschl et al., 2008). We were not able to specify the directions of any potential effects of certainty beliefs on justification by research-based authority or development beliefs on justification by school-based authority, however. Thus, it is not entirely clear whether beliefs in absolute, certain scientific knowledge would make students more likely to rely on scientific investigation in justifying knowledge claims, or whether beliefs in tentative, evolving knowledge would make them less likely to rely on what the textbook or the teacher says.

1.5.3 | Hypothesized mediated effects

Based on the patterns of direct effects described in the two preceding sections, we also hypothesized that the effects of beliefs about knowledge in science on Internet-specific justification would be mediated by the justification for knowing in science constructs. In particular, we expected that beliefs about the certainty of scientific knowledge would have indirect negative effects on Internet-specific justification by multiple sources, mediated by justification by school-based authority and justification by multiple sources in science, respectively. Moreover, we expected that beliefs about the development of scientific knowledge would have indirect positive effects on all three Internet-specific justification constructs, which were mediated by the justification by research-based authority and justification by multiple sources in science constructs, respectively.

1.5.4 | Hypothesized correlations

Finally, we expected the constructs within each set of beliefs to be correlated (see Figure 1). Specifically, based on prior research (Bråten et al., 2019), we expected the three Internet-specific justification constructs to be positively correlated. Also based on prior research (Conley et al., 2004), we expected beliefs about the certainty and development of scientific knowledge to be negatively correlated. With regard to beliefs about justification for knowing in science, we expected a positive correlation between the two justification by authority constructs (i.e., school-based and research-based), as well as between justification by research-based authority and justification by multiple sources (Bråten & Ferguson, 2014). Justification by school-based authority was expected to be negatively correlated with justification by multiple sources in science.

2 | METHOD

2.1 | Design and methodology

This study used a nonexperimental, correlational design to investigate relationships between beliefs about knowledge in science, beliefs about justification for knowing in science, and beliefs about justification of knowledge claims about science encountered on the Internet, with data on these three types of beliefs collected by means of designated questionnaires (see Section 2.3). Confirmatory factor analyses were used to identify specific beliefs within each type of beliefs (e.g., within beliefs about justification for knowing in science), and structural equation modeling was used to test how well our hypothesized model of direct and indirect relationships between these specific beliefs fit the questionnaire data.

2.2 | Participants

Participants were 455 students (60% female) from eight public upper secondary schools in Taiwan. All students were 16–17 years old and attended the 10th grade of the academic track. In Taiwan, basic education lasts for 12 years and includes elementary school (Grades 1–6), lower secondary school (Grades 7–9), and upper secondary school (Grades 10–12), with admission to upper secondary school based on the results of the Comprehensive Assessment Program. The sample of the current study can be regarded as purposive. That is, we recruited participants by contacting teachers we knew in various schools but to ensure variability with respect to social background and socioeconomic status, we selected schools from four different parts of Taiwan: north, central, south, and east. Moreover, we recruited only students in the academic track because beliefs about knowledge and justification in science presumably would be more salient and pertinent to students in this track than to students enrolled in the vocational track. All participants were born in Taiwan and were native Mandarin speakers.

2.3 | Instrumentation

2.3.1 | Beliefs about the nature of scientific knowledge

To measure beliefs about the nature of scientific knowledge, we used two dimensions from a 26-item questionnaire developed by Conley et al. (2004) to investigate epistemic beliefs in the domain of science. This measure has been validated in much prior research (e.g., Chen & Pajares, 2010; Mason et al., 2013), also including Taiwanese students (e.g., Wu & Tsai, 2010; Yang et al., 2019; Yang, Chang, et al., 2016). The two dimensions that we used concerned beliefs about the certainty of knowledge and beliefs about the development of knowledge. The six items included in the certainty of knowledge dimension focused on beliefs in the existence of unambiguous, correct answers in science, with higher scores on this dimension representing the belief that scientific knowledge consists of true, certain knowledge. The six items included in the development of knowledge dimension focused on beliefs in the evolving and changing nature of scientific knowledge, with higher scores on this dimension representing the belief that knowledge in science is continuously changing.

All 12 items used to measure these two dimensions were rated on a 5-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (5). Reliability estimates for participants' scores on each dimension are shown in Table 1. All items are included in Appendix A.

2.3.2 | Beliefs about justification for knowing in science

To measure beliefs about justification for knowing in science, we used the Justification for Knowing Questionnaire (JFK-Q) developed by Bråten, Ferguson, and colleagues (Bråten et al., 2013; Ferguson et al., 2013). This measure was developed to capture three dimensions concerning justification in the domain of science, that is, justification by authority, personal justification, and justification by multiple sources. The JFK-Q has been validated in a number of previous studies (e.g., Brandmo & Bråten, 2018; Trevors et al., 2017), most of them using the 14-item version resulting from a factor-analytic study by Ferguson et al. (2013). In this version, which we also used in the current study, justification by authority is measured by six items concerning students' reliance on external authority in the form of the science teacher, the science textbook, and scientific investigation.[i] Thus, higher scores on this dimension represent the belief that knowledge claims in science can be justified by referring to an authoritative external source. The three items used to measure personal justification focus on justification for knowing in science on the basis of one's own personal views or opinions, with higher scores indicating a reliance on subjective, internal means of justification. The five items used to measure justification by multiple sources focus on justification for knowing in science by checking and corroborating information across various sources of information. Higher scores on this dimension thus represent the belief that knowledge claims in science gain credibility through consistency among multiple external sources.

All 14 items on the JFK-Q items were rated on a 5-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (5). Reliability estimates for participants' scores on each of the dimensions identified in the present sample and used in subsequent statistical analyses are shown in Table 1. All items included in these dimensions are shown in Appendix B.

2.3.3 | Internet-specific justification of knowledge claims

We used the 12-item Internet-Specific Epistemic Justification Inventory (ISEJ) developed by Bråten et al. (2019) to measure beliefs about justification of knowledge claims about science encountered on the Internet, with this inventory also developed to capture beliefs concerning justification by authority, personal justification, and justification by multiple sources. Importantly, all the items targeted justification of knowledge claims when using the Internet as a knowledge resource. Moreover, compared with the JFK-Q, the personal justification dimension concerned reliance on prior knowledge and reasoning rather than personal views or opinions. Thus, in the ISEJ, personal justification concerned students' reliance on their own cognitive resources (i.e., knowledge and reasoning), whereas in the JFK-Q, personal justification mainly concerned students' reliance on their own impressions and preferences regardless of their knowledge base. Finally, compared with the JFK-Q, the justification by authority dimension concerned attention to the competency and expertise of the author of Internet-based information rather than reliance on the science teacher, the science textbook, and scientific investigation. The inventory was validated in two prior studies in which the content domain was specified as education (Bråten et al., 2019) or science (Kammerer et al., 2021).

Thus, the four items used to measure justification by authority focused on justification of knowledge claims encountered on the Internet by referring to the expertise of the author. Higher scores on this dimension can be considered to represent a form of outsourcing of judgments concerning knowledge claims about science encountered on the Internet. The four items used to measure personal justification focused on evaluation of Internet-based knowledge claims by means of prior knowledge activation and reasoning, with higher scores representing confidence in one's own ability to evaluate knowledge claims on the Internet. Finally, the four items used to measure justification by multiple sources focused on evaluation of knowledge claims encountered on the Internet by checking several information sources and comparing information across websites. Higher scores on this dimension thus represent the belief that consistency across multiple external sources are required to establish the credibility of Internet-based knowledge claims about science.

All 12 items on the ISEJ were rated on a 5-point Likert scale ranging from *strongly disagree* (1) to *strongly agree* (5). Reliability estimates for participants' scores on each dimension are shown in Table 1. All items are included in Appendix C.

2.4 | Procedure

The teachers group administered the measures in their ordinary classrooms. The measures were administered on paper and participants spent approximately 20 minutes completing them. After having completed a brief demographic survey, they completed the items targeting beliefs about scientific knowledge (i.e., certainty and development), the JFK-Q, and the ISEJ in this order. All the materials were in Mandarin. The Mandarin translation of the original English version of the measure of beliefs about scientific knowledge has been used and validated in a range of published studies (e.g., Yang et al., 2019; Yang, Chang, et al., 2016; Yang, Huang, & Tsai, 2016). The existing translation was therefore used in this study without any modifications. Both the JFK-Q and the ISEJ were translated from English to Mandarin by one of the authors, who is proficient in both English and Mandarin. Afterward, the translated versions were reviewed by two independent experts, one science education researcher, and one high-school science teacher, to ensure the accuracy and validity of the translated versions. Participants were informed that participation was voluntary, that the data would be treated anonymously, and that their responses would not affect their grades. The study was approved by the Ministry of Science and Technology in Taiwan.

2.5 | Analytic approach

First, we evaluated all item scores with respect to their distributions and psychometric properties. Then, we performed confirmatory factor analyses (CFA) with Mplus 7 (Muthén & Muthén, 2012) to examine the dimensional structure of the scores on each of the three questionnaires. Finally, we performed latent variable structural equation modeling (SEM) with Mplus 7 to test our hypothesized model. To assess the overall fit of a model to the data, we used chi-square statistics, the comparative fit index (CFI), the root mean square error of approximation (RMSEA), and the standardized root mean square residual (SRMR). After reviewing the literature on cut-off criteria for goodness of fit (Hu & Bentler, 1999; Marsh et al., 2004) and considering sample size and model complexity in addition to criteria adopted in related studies (Brandmo & Bråten, 2018; Bråten et al., 2019), we evaluated tested models based on the following criteria: CFI $\geqq$ 0.90, RMSEA $\leqq$ 0.08, and SRMR $\leqq$ 0.09 indicated an acceptable model fit, whereas CFI $\geqq$ 0.95, RMSEA $\leqq$ 0.05, and SRMR $\leqq$ 0.06 indicated a good model fit.

3 | RESULTS

3.1 | Preliminary analyses

Although most item scores were normally distributed, analyses of kurtosis showed that a few items used to measure beliefs about knowledge in science were tail heavy (e.g., #7 and 8 in Appendix A had kurtosis values of 3.38 and 2.00, respectively). To deal with such minor deviations from normality, we decided to use robust statistics (i.e., robust maximum likelihood) in all subsequent statistical analyses.

A two-factor CFA model of beliefs about knowledge in science, in which six items were included in the certainty of knowledge factor and six items were included in the development of knowledge factor, resulted in an acceptable fit to the data, with $\chi^2[53] = 148$, $p < 0.001$; CFI = 0.94; RMSEA = 0.063, 90% CI [0.051–0.075]; SRMR = 0.055. Although two of the items (#1 and 2 in Appendix A) included in the certainty factor had low loadings ($\sim$ 0.50), we decided to use this model based on results obtained in prior research and the overall fit of the model.

With respect to justification for knowing, a three-factor CFA model based on solutions obtained in prior factor analytic studies of the JFK-Q with Norwegian secondary school students (Bråten et al., 2014; Ferguson et al., 2013), in which six items were included in the justification by authority factor, three items were included in the personal justification factor, and five items were included in the justification by multiple sources factor, did not result in an acceptable fit to the data, with $\chi^2[74] = 411$, $p < 0.001$; CFI = 0.81; RMSEA = 0.100, 90% CI [0.091–0.110]; SRMR = 0.11. Two of the items included in justification by authority had loadings below 0.50 and two of the items included in personal justification had loadings below 0.40, suggesting that the latter factor was not viable in this sample. Based on an examination of the content of the items and their inter-correlations, as well as the modification indices provided by the Mplus, we therefore re-specified and re-evaluated the model without the three personal justification items. In this model, the justification by authority factor was split in two, with four items included in a factor termed justification by school-based authority and two items included in a factor termed justification by research-based authority. The items included in justification by school-based authority focused on justification through reliance on the science teacher and the science textbook and the items included in justification by research-based authority focused on justification through reliance on scientific investigation. In addition we included the five items focusing on justification by multiple sources. The CFA of this model including 11 items resulted in an acceptable fit to the data, with $\chi^2[41] = 136$, $p < 0.001$; CFI = 0.94; RMSEA = 0.071, 90% CI [0.058–0.085]; SRMR = 0.067.

Finally, with respect to Internet-specific justification, we tested a three-factor CFA model consistent with the results of a previous validation study of the ISEJ with Norwegian teacher education students (Bråten et al., 2019), in which four items were included in each of the three factors (i.e., justification by authority, personal justification, and justification by multiple sources). This model had an acceptable fit to the data, with $\chi^2[51] = 179$, $p < 0.001$; CFI = 0.94; RMSEA = 0.074, 90% CI [0.063–0.086]; SRMR = 0.046. Moreover, all items had loadings above 0.75 except for two items (#4 and 12 in Appendix C) that had loadings of 0.66. However, the modification indices suggested two cases of statistically significant and substantial correlations between residuals (item #1 with #9 and item #3 with #11; see Appendix C), implying that these items may have common variance outside the specified model. Because there were some similarities in wordings between the two pairs of items, correlating these residuals seemed appropriate from a methodological as well as a substantial point of view. We therefore re-specified the model by including these two correlations between residuals, resulting in an improved measurement model that fit the data well, $\chi^2[49] = 112$, $p < 0.001$; CFI = 0.97; RMSEA = 0.053, 90% CI [0.040–0.066]; and SRMR = 0.040.[ii]

Table 1 shows descriptive information (means and standard deviation), reliabilities, and zero-order correlations for all constructs used in testing the hypothesized model. As can be seen, the means for the constructs of certainty and development of knowledge suggested that participants tended to believe that scientific knowledge is tentative and evolving rather than

TABLE 1 Descriptive statistics, reliabilities, and zero order-correlations for all constructs

		1	2	3	4	5	6	7	8
1	Certainty of knowledge	–							
2	Development of knowledge	−0.490***	–						
3	Justification by school-based authority	0.526***	−0.196***	–					
4	Justification by research-based authority	0.160	0.225**	0.479***	–				
5	Justification by multiple sources	−0.308***	0.614***	−0.174**	0.272**	–			
6	Internet-specific personal justification	−0.218**	0.402***	−0.098	0.317***	0.599***	–		
7	Internet-specific justification by authority	−0.039	0.241***	0.064	0.270***	0.375***	0.762***	–	
8	Internet-specific justification by multiple sources	−0.189**	0.347***	−0.129*	0.225**	0.520***	0.882***	0.773***	–
	Reliability (Cronbach's α)[a]	0.77	0.91	0.89	0.74	0.80	0.83	0.84	0.88
	M	2.03	4.23	2.39	3.19	3.66	3.53	3.21	3.41
	SD	0.57	0.57	0.73	0.72	0.58	0.64	0.70	0.71

[a]Cronbach's α and McDonald's ω were identical for all constructs except Justification by research-based authority, for which McDonald's ω was slightly higher (0.76).

[a]*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

certain and fixed. In comparison, participants' beliefs about the process of knowing (i.e., justification) in science seemed to be somewhat less adaptive, especially with respect to justification by research-based authority. Also, their Internet-specific justification beliefs suggested that they did not consider it highly important to justify knowledge claims encountered on the Internet by means of internal and external sources. The correlational analysis indicated relationships between beliefs about the nature of knowledge and beliefs about the process of knowing in science, as well as between beliefs about the process of knowing in general and beliefs about the process of knowing on the Internet in particular. For example, beliefs in certain knowledge were negatively and beliefs in developing knowledge were positively related to beliefs in justification by multiple sources. In turn, beliefs in the need to justify knowledge claims in science by multiple sources were strongly related to beliefs in Internet-specific personal justification and justification by multiple sources.

3.2 | Hypothesized model testing

The testing of the hypothesized model resulted in an acceptable fit to the data, with χ^2 [536] = 936, $p < 0.001$; CFI = 0.94; RMSEA = 0.040, 90% CI [0.036–0.045]; SRMR = 0.055. Figure 2 shows that, as expected, both justification by research-based authority and justification by multiple sources in science had direct positive relationships with Internet-specific personal justification (viz., $\beta = 0.24$, $p < 0.01$, and $\beta = 0.52$, $p < 0.001$) as well as with Internet-specific justification by multiple sources (viz., $\beta = 0.16$, $p < 0.05$, and $\beta = 0.46$, $p < 0.001$). Also as expected, justification by multiple sources in science had a direct positive relationship with Internet-specific justification by authority ($\beta = 0.34$, $p < 0.001$). Although the direct relationship between justification by research-based authority in science and Internet-specific justification by authority was not statistically significant ($\beta = 0.15$, *ns*.), the valence of this relationship was in the expected direction. With respect to justification by school-based authority in science, there was no statistically significant direct relationship between this construct and any of the Internet-specific justification constructs. Of note is that its relationship with Internet-specific justification by multiple sources was in the expected (i.e., negative) direction ($\beta = -0.13$, *ns*.), however.

In turn, the constructs concerning justification for knowing in science were directly related to the constructs concerning the nature of scientific knowledge. As expected, beliefs about the certainty of scientific knowledge had a direct positive relationship with justification by school-based authority ($\beta = 0.57$, $p < 0.001$) and beliefs about the development of scientific knowledge had direct positive relationships with both justification by research-based authority ($\beta = 0.40$, $p < 0.001$) and justification by multiple sources in science ($\beta = 0.61$, $p < 0.001$). However,

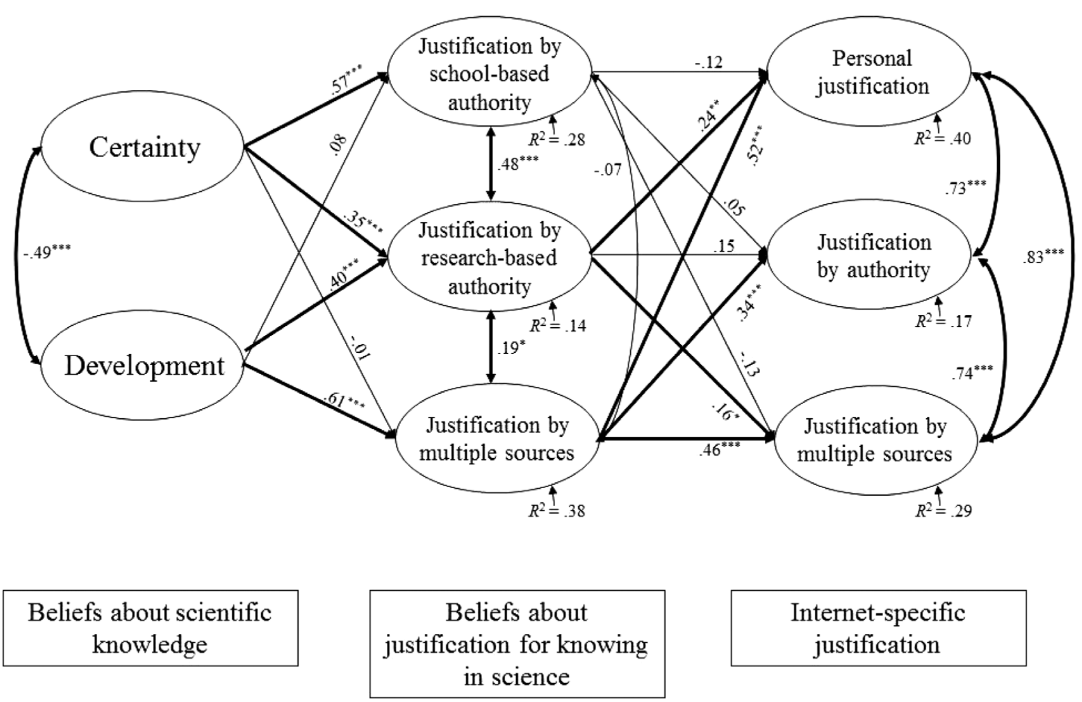

FIGURE 2 The resulting model for beliefs about knowledge and justification for knowing constructs with standardized path coefficients and explained variance for dependent variables. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

contrary to our expectation, beliefs about the certainty of scientific knowledge did not have any direct negative relationship with justification by multiple sources in science. Of note is also that beliefs about the certainty of scientific knowledge had a direct positive relationship with justification by research-based authority ($\beta = 0.35$, $p < 0.001$), and that justification by school-based authority was not related to beliefs about the development of scientific knowledge. Taken together, the two nature of knowledge constructs explained 28, 14, and 38% of the variance in justification by school-based authority, justification by research-based authority, and justification by multiple sources, respectively.

In addition to the direct relationships described above, all seven correlations between the epistemic belief constructs that were included in the hypothesized model were found to be in the expected directions, and all but one (the correlation between justification by school-based authority and justification by multiple sources in science) were statistically significantly different from zero (see Figure 2).

Finally, we tested the mediated effects of beliefs about scientific knowledge on the Internet-specific justification constructs by means of the "indirect" command available in the Mplus software. As expected, beliefs about the development of scientific knowledge had indirect positive relationships with Internet-specific personal justification ($\beta = 0.09$, $p < 0.05$) and Internet-specific justification by multiple sources ($\beta = 0.07$, $p < 0.05$) mediated by justification by research-based authority, and with all three Internet-specific justification constructs mediated by justification by multiple sources in science ($\beta = 0.31$, $p < 0.001$, for Internet-specific personal justification; $\beta = 0.21$, $p < 0.001$, for Internet-specific justification by authority; and $\beta = 0.28$, $p < 0.001$, for Internet-specific justification by multiple sources). However, contrary to our expectations, beliefs about the development of scientific knowledge did not have any indirect positive relationship with Internet-specific justification by authority mediated by justification by research-based authority, and beliefs about the certainty of knowledge did not have any indirect negative relationships with Internet-specific justification by multiple sources mediated by justification by school-based authority and justification by multiple sources in science, respectively. Instead, beliefs about the certainty of knowledge had an indirect positive relationship with Internet-specific personal justification mediated by justification by research-based authority ($\beta = 0.08$, $p < 0.01$). Statistically significant mediated relationships are summarized in Table 2.[iii] Of course, these indirect relationships also need to be interpreted in the multivariate context of our study, meaning that they are controlled or adjusted by the other variables and relationships that we included in the model. The model explained 40, 17, and 29% of the variance in Internet-specific personal justification, Internet-specific justification by authority, and Internet-specific justification by multiple sources, respectively.

4 | DISCUSSION

Although epistemic beliefs have been conceptualized as falling in two main categories, concerning beliefs about the nature of knowledge and beliefs about the process of knowing, for more than two decades (Hofer & Pintrich, 1997), prior research on the structural relationship between these categories is essentially lacking. In the current study, we therefore used latent variable structural equation modeling to investigate potential effects of beliefs about the nature of knowledge on beliefs about justification for knowing, as well as whether more general beliefs about justification for knowing mediated any effects of beliefs about knowledge on beliefs about justification in the specific context of learning within Internet technologies. As science

TABLE 2 An overview of the mediated effects

Predictor	Mediator	Outcome	Effect
Certainty of knowledge →	Research-based authority →	Internet personal justification	$\beta = 0.08$, $p < 0.01$
Development of knowledge →	Research-based authority →	Internet personal justification	$\beta = 0.09$, $p < 0.05$
Development of knowledge →	Research-based authority →	Internet justification by multiple sources	$\beta = 0.07$, $p < 0.05$
Development of Knowledge →	Justification by multiple sources →	Internet personal justification	$\beta = 0.31$, $p < 0.001$
Development of knowledge →	Justification by multiple sources →	Internet justification by authority	$\beta = 0.21$, $p < 0.001$
Development of knowledge →	Justification by multiple sources →	Internet justification by multiple sources	$\beta = 0.28$, $p < 0.001$

education researchers, we were particularly interested in students' beliefs about the nature of knowledge and the process of knowing in science. Accordingly, we adapted all belief measures that we used to the domain of science. The results of our investigation largely supported the assumptions regarding direct and mediated effects.

4.1 | Relationships between justification for knowing in science and beliefs about Internet-specific justification

With respect to Internet-specific justification, justification through prior knowledge activation and reasoning, justification through reliance on expert authors, and justification through the corroboration of information across various websites were all predicted by more general beliefs about justification by research-based authority and justification by multiple sources in science. Interestingly, Internet specific justification was not predicted by justification by school-based authority, however.

Thus, according to these findings, justification by research-based but not school-based authority may positively predict adaptive beliefs about justification of knowledge claims concerning science that students encounter on the Internet. In their recent meta-analysis, Greene et al. (2018) reported that an undifferentiated justification by authority construct did not seem to matter much in terms of academic achievement, suggesting that "items or measures that treat authority as a monolithic, good or bad source of knowledge are unlikely to result in accurate estimates of how people actually evaluate and use sources of testimony" (p. 1101). Also, Bråten and Ferguson's (2014) findings are consistent with the notion that a more differentiated conceptualization of justification by authority is required, suggesting that adaptive justification beliefs in the domain of science may be restricted to reliance on scientific investigation or methodology. Our findings bring additional nuances to this theoretical discussion by suggesting that the uncritical trust in the science teacher and the science textbook that students often display (e.g., Bråten et al., 2015; Paxton, 2002) does not bode well for their critical evaluation of knowledge claims on the Internet by means of resources both internal and external to the self. In terms of educational implications, the view that emphasizing the importance of scientific investigation and scientific methodology in science education rather than rewarding uncritical adoption and reproduction of what the teacher or the textbook says seems to be consistent with the findings of the current study (Duncan et al., 2018; Duschl & Hamilton, 2011; National Research Council, 2012).

4.2 | Relationships between beliefs about knowledge and beliefs about justification for knowing in science

With respect to the relationships between beliefs about the nature of knowledge and the process of knowing, our assumptions regarding the positive effects of beliefs about the development of knowledge on justification by research-based authority and justification by multiple sources in science were supported. Theoretically, these findings are consistent with the view that beliefs in the tentative and evolving rather than stable, once-and-for-all nature of scientific knowledge may underlie beliefs in scientific investigation as an appropriate process for justifying knowledge claims (Bråten et al., 2011). In addition, they indicate that beliefs in tentative knowledge may underlie beliefs in the importance of cross-checking and corroborating knowledge claims across various external sources, for example, to identify the most updated information relevant to a particular claim (Bråten et al., 2011). Whereas beliefs about the development of knowledge did not predict seemingly less adaptive beliefs in school-based authority, such beliefs were positively related to the certainty of knowledge construct. Thus, our findings highlight an interesting and potentially important distinction between two beliefs about knowledge constructs that typically have been merged under “certainty of knowledge” in multidimensional approaches to epistemic beliefs (e.g., Hofer, 2004; Hofer & Pintrich, 1997; Schommer, 1990). As was the case with justification by authority, then, a differentiated certainty of knowledge construct may provide new information about the structural relationships among epistemic belief constructs. Interestingly, beliefs in the existence of unambiguous, absolute correct answers in science, in particular, seem to form a psychological basis for seeking such answers in information provided by the science teacher and the science textbook.

According to our findings, strong beliefs in the existence of unambiguous correct answers in science may also positively predict beliefs in justification by research-based authority, however, possibly because such certain answers are sought in scientific research as well. Since beliefs in research-based authority are also positively predicted by beliefs in tentative and evolving scientific knowledge, this raises the question of whether learners with strong beliefs in one correct answer and learners with strong beliefs in tentative knowledge actually may interpret and use the results of scientific research somewhat differently. That is, whereas learners with strong beliefs in certain knowledge may seek closed answers in scientific research, learners with strong beliefs in tentative knowledge may be attracted to science because they seek to understand how knowledge develops through the process of scientific investigation. Further research is needed to clarify this question, however.

4.3 | Indirect relationships

Regarding the indirect relationships, beliefs about the development of scientific knowledge, as expected, also had indirect positive relationships with presumably adaptive beliefs about Internet-specific justification (i.e., personal justification, justification by authority, and justification by multiple sources). These relationships were mediated by beliefs about research-based authority and justification by multiple sources in science. Such mediated relationships underscore the potential importance of beliefs in tentative and evolving scientific knowledge for critical reading and learning of scientific information on the Internet. Taken together, the direct and indirect relationships between beliefs about the development of scientific knowledge and other constructs also suggest that the tentative and evolving nature of scientific knowledge should be emphasized in science education. Students typically believe that knowledge in the domain of science is more stable and unconditional than is knowledge in other domains (Muis et al., 2006), possibly because of the way science is taught in school. Trying to counteract this tendency by emphasizing and illustrating how scientific knowledge is continuously changing seems to be an important aspect of science education, however (see Section 4.4).

Our expectation that beliefs in the certainty of knowledge would have indirect negative effects on Internet-specific justification by multiple sources was not supported. Instead, beliefs in certain knowledge were found to have a positive mediated relationship with Internet-specific personal justification via justification by research-based authority. Previously, we raised the question of whether learners high in certainty beliefs might approach scientific research in order to find closed answers to scientific issues. If that is the case, the indirect relationship between certainty beliefs and Internet-specific personal justification might also have a different character than the indirect relationship between beliefs about development and that construct, for example signaling the use of personal resources to retrieve definite answers to scientific issues on the Internet.

4.4 | Implications for science education

Prior science education research has indicated that students' epistemic beliefs in the domain of science matter in terms of their conceptual learning and understanding and their scientific reasoning and argumentation (e.g., Chang et al., 2020; Ku et al., 2014; Lindfors et al., 2019; Mason et al., 2013; Mason & Scirica, 2006; Noroozi, 2018; Nussbaum et al., 2008; She et al., 2019; Stathopoulou & Vosniadou, 2007; Wu & Tsai, 2010; Yang et al., 2019). Accordingly, ongoing movements within science education emphasize the importance of developing critical and evaluative thinking among students (National Research Council, 2012; OECD, 2018a, 2018b), which seems to require adaptive epistemic beliefs about the nature of knowledge and the process of knowing in science (Duncan et al., 2018; Elby et al., 2016; Sinatra & Chinn, 2012; Yang & Tsai, 2010; Zeineddin & Abd-El-Khalick, 2010). Regarding learning about science on the Internet, in particular, this study suggested that a critical and evaluative approach may be supported by more general beliefs about justification by research-based authority and multiple sources in science. And, because our findings also suggested that acknowledging the developmental nature of scientific knowledge may be underlying such beliefs, it seems important to devote sufficient time in science classrooms to analyzing and discussing changes in scientific theories or models over time, focusing on the perspectives, problems, and data that have been driving such changes. This kind of historical analysis can address both local and global issues involving the application of science and technology, hopefully leading to more adaptive beliefs regarding not only knowledge but also justification in science. Of note is that such historical analysis requires science teachers who have deep and integrated understandings of the NOS (Abd-El-Khalick, 2013). Moreover, science educators may profitably use new cases of scientific discoveries to illustrate the developmental nature of scientific knowledge and how such developments are tied to scientific investigation (i.e., justification by research-based authority) and corroboration across multiple sources of evidence (i.e., justification by multiple sources). In turn, such adaptive beliefs about justification for knowing in science may facilitate beliefs about justification that students need as they engage with scientific information on the Internet.

That said, this study also indicated that adaptive beliefs in Internet-specific justification through prior knowledge activation and reasoning, reliance on expert authors, and corroboration of information across various websites were less developed in the participating upper-secondary academic track students than desirable. This is a matter of concern, given that the multifarious sources that students encounter or search for on the Internet more often than not present scientific information that must be weighed, vetted, and critically evaluated (Strømsø & Kammerer, 2016). Finding ways to scaffold a higher degree of epistemic vigilance in critically evaluating claims about science on the Internet should therefore be an important agenda for science education and science education research (Sinatra & Lombardi, 2020). In accordance with the dimensions of Internet-based justification beliefs highlighted in the present study, such scaffolding should not only try to promote evaluation of source expertise and source credibility, but also harness students' cognitive resources (i.e., prior knowledge and reasoning skills) in judging the plausibility of multiple, often conflicting views about scientific issues (Sinatra & Lombardi, 2020).

Recently, science education researchers, in large scale studies, successfully classroom-tested an approach scaffolding students' evaluation of alternative explanations of scientific phenomena by critically evaluating how those explanations fit available evidence (Lombardi, Bailey, et al., 2018; Lombardi, Bickel, et al., 2018). This approach used diagrammatic representations of alternative explanations and different lines of evidence, in accordance with how prior science education research has used model-based inquiry tasks in which students evaluate and re-evaluate models based on evidence (e.g., Krajcik et al., 2008; Pluta et al., 2011). It is still an open question to what extent such science-classroom based approaches may facilitate students' evaluation and justification of alternative claims concerning science during Internet search, however. Therefore, a next step would be to adapt them to and test them in ecologically valid contexts of retrieving, processing, evaluating, and using diverse Internet sources for science inquiry purposes. In doing this, students could also be asked to reflect on their beliefs about knowledge and knowing in science more generally (i.e., outside the specific context of the Internet).

In particular, this concerns students' beliefs about tentative knowledge and justification by research-based authority and multiple sources in science, given that such beliefs according to our findings indirectly and directly may contribute to adaptive justification on the Internet. Specifically, bringing such beliefs to bear on the process of learning within Internet technologies may help students be open to alternative explanations because they realize the tentativeness of scientific knowledge, yet seek to narrow down the alternatives by comparing their plausibility based on judgments of “scientificness” and consistency across multiple sources (Bråten et al., 2011; Thomm & Bromme, 2012). Presumably, students will have to be explicitly prompted or asked to reflect on such beliefs when using the Internet to realize their applicability in this specific context, with this increasing the likelihood that they actually will think and reason with their beliefs in trying to justify knowledge claims (Chinn et al., 2014; Sinatra & Lombardi, 2020). For example, science teachers could engage students in meta-epistemic discourse about their beliefs concerning justification for knowing in the context of authentic scientific inquiry, with the goal of developing shared commitment to beliefs in adaptive processes of justification (Barzilai & Chinn, 2018; Chinn et al., 2020). As part of this discourse, students may discuss why justification by research-based authority and justification by multiple sources can be considered reliable processes in both offline and online contexts, as evidenced by their own collective science inquiries under guidance of the teacher (cf., Chinn et al., 2020).

However, while students also encounter an abundance of claims concerning science when using the Internet outside school, next to nothing is currently known about how they bring adaptive beliefs about knowledge and justification for knowing in science that are developed in schooled contexts to bear on their evaluation and justification of claims in an unschooled online context, if at all (Breakstone et al., 2018). Needless to say, this is an important challenge for science education research to try to better understand and for science education to try to address.

4.5 | Limitations

There are several limitations to the current study, of course. First, the structural equation modeling that we used to analyze our data does not allow us to draw any firm conclusions regarding causality. Although the causal model that we tested fit the data quite well, longitudinal or experimental designs are needed to discover causal relationships between the constructs that we included. Thus, as it now stands, we cannot be sure about the direction of the effects or rule out the existence of bidirectional relationships between these constructs.

Further, the lack of process and performance data is a limitation of this study. In particular, it seems important to investigate students' beliefs about the nature of scientific knowledge not only in relation to their beliefs about justification for knowing but also in relation to how they actually try to justify knowledge claims in science, including in the specific context of learning within Internet technologies. Additionally, the outcomes of their efforts to justify knowledge claims in science by means of internal and external resources should be addressed in future research.

Finally, the generalizability of the structural relationships that we observed in the current study should be probed in other populations and at different educational levels. Moreover, the model that we developed and tested could be tested in other cultural contexts.

5 | CONCLUSION

The current study contributes to science education research and science education in several ways. Thus, it provides unique insights into the relationships among beliefs about scientific knowledge, beliefs about justification for knowing in science, and beliefs about justification for knowing when students engage with scientific information on the Internet. In particular, its focus on different types of beliefs concerning justification for knowing in science and Internet-specific justification extends previous science education research, in which a multidimensional approach to justification beliefs seems to have been underfocused thus far. Also, this research in unique in relation to other research on Internet-specific epistemic beliefs and learning within Internet technologies due to its focus on different types of justification beliefs that may be adaptive when engaging with scientific information on the Internet. Last but not least, our research provides unique insights into how such beliefs may be predicted by other epistemic belief dimensions, and, as such, it also offers suggestions for how they can be facilitated in the context of science education.

Specifically, our findings indicated that adaptive beliefs about Internet-specific justification were predicted by more general beliefs about justification by research-based authority and multiple sources in science, but not by justification by school-based authority. In turn, beliefs about justification by research-based authority and multiple sources were predicted by beliefs in the tentative and evolving nature of scientific knowledge, which were indirectly related to Internet-specific justification. This identified network of direct and indirect relationships among beliefs in tentative scientific knowledge, beliefs in justification by research-based authority and multiple sources in science, and Internet-specific justification seems highly relevant to science education and science education research. Basically, it reiterates the call to teach science not as a catalogue of certain facts known to the teacher and the textbook, from which it may be transmitted to the students, but, rather, as an unfolding process based on scientific investigation and multiple sources of evidence (National Research Council, 2012; OECD, 2018a, 2018b). In the context of the present study, this approach is particularly important because it may facilitate the construction of beliefs that can help students traverse the information wilderness of the Internet with heightened epistemic vigilance. Accordingly, as part of trying to promote critical evaluation and justification of knowledge claims from online sources about scientific issues by means of internal as well as external resources, students could also be asked to reflect on and discuss their beliefs about knowledge and knowing in science more generally in order to counteract a widespread tendency to evaluate online information in a superficial and perfunctory way (Breakstone et al., 2018; Sinatra & Lombardi, 2020). Thus far, however, little is known about whether and how science education that targets the critical evaluation of alternative explanations, for example through model-based inquiry approaches (e.g., Krajcik et al., 2008; Lombardi, Bailey, et al., 2018; Pluta et al., 2011), may transfer to the context of learning within Internet technologies, not to speak of unschooled contexts in which students encounter strong claims about controversial scientific issues on a daily basis. Future science education research and practice should therefore try to bridge these contexts by investigating and seeking to promote connections between beliefs constructed in different schooled and unschooled contexts, including the context of reading about scientific issues on the Internet outside school.

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ENDNOTES

[i] The reason that references to both the science textbook and scientific investigation were included in justification by authority is that students may perceive inquiry activities performed in school (e.g., activities presented in the textbook) and scientific activities performed by scientists outside school (i.e., scientific investigation/scientific research) as different. Thus, by including references to both in this dimension, the construct might be

covered more broadly. The fact that items referring to the textbook and to scientific investigation/scientific research loaded on two different factors (termed justification by school-based authority and justification by research-based authority, respectively) seems to confirm that the textbook and scientific investigation were perceived as two different sources of authority among participants in this study (see Section 3.1).

[ii] We also randomly resampled half of the data and tested the measurement models with that subsample. The fit estimates were similar to those obtained with the total sample, with $\chi^2[53] = 106$, $p < 0.001$; CFI = 0.94; RMSEA = 0.066; and SRMR = 0.063 for beliefs about knowledge in science; $\chi^2[41] = 82$, $p < 0.001$; CFI = 0.95; RMSEA = 0.066; and SRMR = 0.062 for justification for knowing in science; and $\chi^2[49] = 87$, $p < 0.001$; CFI = 0.96; RMSEA = 0.058; and SRMR = 0.054 for Internet-specific justification. Besides, all three models showed high stability in terms of the estimated factor loadings, scores, and variances when compared with the models based on the total sample.

[iii] As part of the testing of mediated effects, we also tested an alternative model including direct effects of the nature of knowledge constructs on the Internet-specific justification constructs. This alternative model did not improve model fit and none of these direct relationships was statistically significant, indicating that the relationships between the nature of knowledge constructs and Internet-specific justification were fully mediated by the justification for knowing in science constructs.

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APPENDIX A.: BELIEFS ABOUT THE NATURE OF SCIENTIFIC KNOWLEDGE

Certainty	
#1	All questions in science have one right answer.
#2	The most important part of doing science is coming up with the right answer.
#3	Scientists pretty much know everything about science; there is not much more to know.
#4	Scientific knowledge is always true.
#5	Once scientists have a result from an experiment, that is the only answer.
#6	Scientists always agree about what is true in science.
Development	
#7	Some ideas in science today are different than what scientists used to think.
#8	The ideas in science books sometimes change.
#9	There are some questions that even scientists cannot answer.
#10	Ideas in science sometimes change.
#11	New discoveries can change what scientists think is true.
#12	Sometimes scientists change their minds about what is true in science.

APPENDIX B.: BELIEFS ABOUT JUSTIFICATION FOR KNOWING IN SCIENCE

Justification by school-based authority	
#1	If a natural science teacher says something is correct, then I believe it.
#2	I believe that everything I learn in natural science class is correct.
#3	Things that are written in natural science textbooks are correct.
#4	If a scientist says that something is a fact, then I believe it.
Justification by research-based authority	
#5	When I read something about natural science that is based on scientific investigations, then I believe that it is correct.
#6	I believe in claims that are based on scientific research.
Justification by multiple sources	
#7	To be able to trust knowledge claims in natural science texts, I have to check various knowledge sources.
#8	To detect incorrect claims in texts about natural science, it is important to check several information sources.
#9	I can never be sure about a claim in natural science until I have checked it with at least one other source.
#10	Just one source is never enough to decide what is right in natural science.
#11	To decide whether something I read about natural science is correct, I have to check whether it is in accordance with other things I have read or heard about natural science.

APPENDIX C.: INTERNET-SPECIFIC JUSTIFICATION

Personal justification	
#1	When I find information about a scientific issue on the Internet, I evaluate whether this information is consistent with my own understanding of the topic.
#2	To check whether information about a scientific issue I find on the Internet is reliable, I evaluate it in relation to my own knowledge of this topic.
#3	I evaluate whether information I find about a scientific issue on the Internet seems logical.
#4	When I read about a scientific issue on the Internet, I evaluate whether this information is consistent with what I already know about this topic.
Justification by authority	
#5	When I read something about a scientific issue on the Internet, I evaluate whether this information is written by an expert.
#6	To determine whether information I find about a scientific issue on the Internet is trustworthy, I evaluate whether the author has sufficient knowledge of the topic.
#7	When I find information about a scientific issue on the Internet, I check whether it comes from an expert source.
#8	To evaluate whether information I find about a scientific issue on the Internet is reliable, I try to determine whether it is written by a person with a high level of competence in the area.
Justification by multiple sources	
#9	I evaluate claims I find about a scientific issue on the Internet by checking several information sources on the same topic.
#10	When I read something about a scientific issue on the Internet, I compare several websites that deal with this topic.
#11	To evaluate whether information I find on the Internet about a scientific issue is reliable, I check whether it is consistent with information on other websites.
#12	To determine whether information I find about a scientific issue on the Internet is trustworthy, I compare information from multiple sources.