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Relations of Epistemic Beliefs With Motivation, Achievement, and Aspirations in Science: Generalizability Across 72 Societies

The proliferation of information and divergent viewpoints in the 21st century requires an educated citizenry with the ability to critically evaluate information and make informed decisions. To meet this demand, adaptive epistemic understandings and beliefs about the nature of knowledge are needed, such as believing that scientific knowledge is evolving (development of knowledge) and needs to be justified through experimentation (justification of knowledge). Our study is the first to use nationally representative samples from 72 societies (PISA2015 database; N= 514,119 students) to examine how scientific epistemic beliefs about development and justification of knowledge in science are associated with students' science motivation, achievement, and career aspirations in the science, technology, engineering, and mathematics (STEM) fields, as well as the cross-national generalizability of these relations. Results showed that (a) students who had more adaptive beliefs about knowledge being changeable and stemming from experimentation were likely to have high science self-efficacy, utility value, and particularly high intrinsic value; (b) epistemic beliefs were more strongly linked to science achievement than were motivational constructs; (c) the positive relation between epistemic beliefs and STEM-related career aspirations was largely explained by motivation and achievement; (d) the pattern of results generalized well across societies. Our findings suggest that epistemic beliefs are substantially positively associated with adolescents' science learning, implying that developing effective interventions that focus on development and justification of knowledge would be fruitful for promoting science educational outcomes.

Educational Impact and Implications

Statement

Holding adaptive epistemic beliefs about the nature of scientific knowledge is critical in distinguishing accurate and useful information from diverse, less trustworthy sources in the digital era. Based on data from more than half a million 15-year-olds from 72 countries/regions, we found that adolescents with more adaptive epistemic beliefs tend to have higher science achievement, feel more self-efficacious, be more intrinsically and extrinsically motivated to engage in science learning, and have higher aspirations to pursue a STEM-related career. Notably, epistemic beliefs are more strongly linked to science achievement than are motivational constructs. Consistent patterns across societies suggest that preparing students for 21st century challenges will require policy initiatives that ensure epistemic cognition is a core component of science education and scientific literacy.

Successfully tackling the world's most pressing challenges, such as COVID-19, Ebola, climate change, and natural disasters, arguably requires broad-based scientific understanding among the global community. People need to critically evaluate the information they get regarding these issues and make informed decisions to protect themselves and their families and participate in policy-making processes as global citizens. However, people can also feel overwhelmed by the volume of scientific information from diverse sources in the digital era. The diversity and sheer amount of information makes it critically important but extremely difficult to distinguish accurate and useful information from dogma and fake news (Greene et al., 2018). In the fields of education and psychology, there is growing research into how to help students critique and produce knowledge more effectively by focusing on epistemic cognition - "how people acquire, understand, justify, change, and use knowledge in formal and informal contexts" (Sandoval et al., 2016, p. 1).

Epistemic cognition comprises not only beliefs about the nature of knowledge but also the practices and other cognitive and metacognitive processes dynamically interacting with those beliefs during knowledge construction and critique (Sinatra, 2016). Among epistemic cognition research, epistemic beliefs have received widespread attention in recent research because how people interact with the knowledge they encounter is greatly influenced by how they perceive it (Cartiff et al., 2020; Greene et al., 2018; Sinatra et al., 2014). This research has revealed that epistemic beliefs are significantly related to students' academic performance (see Greene et al., 2018 for a meta-analytic review) and motivation to learn (e.g., Alpaslan, 2017; Chen & Pajares, 2010; Kizilgunes et al., 2009; Ricco et al., 2010; Tsai et al., 2011; Winberg et al., 2019). However, the strength of these relations substantially varies across studies. For example, Greene et al. (2018)'s meta-analysis of 132 studies revealed a small positive average association between epistemic beliefs and performance ($r = .162$, $p < .001$); however, there was substantive cross-study variability. The substantial heterogeneity of conceptualizations and measures of epistemic beliefs was found to be a major contributor to such variability (see the "Research on Epistemic Beliefs" section for detailed information). Furthermore, most existing epistemic belief research has been conducted in Western, educated, industrialized, rich, and democratic (WEIRD) countries, with few studies done in non-WEIRD countries (Lin et al., 2013).

Thus, the generalizability of findings on the relations between epistemic beliefs and academic performance and motivation remains unclear, which leaves the theoretical and practical relevance of research on epistemic beliefs open to question. Students from different cultures hold different views of knowledge (e.g., Qian & Pan, 2002), and a certain view of knowledge may or may not have the same implications across different cultural contexts (Sandoval et al., 2016). Thus, it is crucial to seek an answer to the question: “Are there universal links between adaptive epistemic beliefs and optimal forms of student learning and regulation?”. Evaluating cross-national generalizability not only promises to advance our understanding of epistemic cognition theory, but also has practical implications regarding the benefits of adaptive epistemic beliefs in daily life and directions for educational intervention in a global context.

Additionally, epistemic beliefs may be important for students’ career choices. Scientific epistemic beliefs are closely related to critical thinking and reasoning skills that have been emphasized by academic standards in the science curriculum. However, little research has been done on how epistemic beliefs about scientific knowledge are associated with students’ career choices (see Hofer, 2000). For example, do students with more adaptive epistemic beliefs (e.g., beliefs that scientific knowledge is changeable and needs to be justified through experimentation) show higher aspirations to attain STEM jobs?

The aim of this study was to overcome these shortcomings of prior research by testing the relations between students’ epistemic beliefs, motivational constructs, academic performance, and STEM career aspirations and investigating whether these relations generalize across countries/regions. To achieve this aim, we leveraged a large-scale international survey – the Programme for International Students Assessment (PISA) that has been a major basis of international comparisons of countries in terms of students’ motivation and academic achievement. The cycle of PISA 2015 focuses on the domain of *science*. For the first time, epistemic beliefs were included in the survey. Thus, PISA 2015 provides an unprecedented opportunity for researchers to systematically investigate and compare the associations between epistemic beliefs, motivational constructs, and academic outcomes across a broad range of countries and regions. An analysis of the PISA 2015 data provides a robust test of the cross-national generalizability of these associations.

Research on Epistemic Beliefs

Theoretical Framework of Epistemic Beliefs

Epistemic beliefs are individuals' views about the nature, organization, and source of knowledge, e.g., what counts as "true," how the validity of an argument can be established, and whether scientific ideas and theories can change on the basis of new data and evidence (Hofer & Pintrich, 1997). Although numbers of theories and empirical studies on epistemic beliefs have increased exponentially in last years, the conceptualization of epistemic beliefs continues to be subject to debate, with a wide variety of terminologies and methodologies proposed (e.g., Chinn et al. 2011; Hofer & Pintrich, 1997; Muis, 2007). However, a growing consensus has emerged that epistemic beliefs are multidimensional, multilayered, and contextual constructs (Muis et al., 2006; Bråten et al., 2011). Individuals vary on multiple dimensions of beliefs about the nature of knowledge and knowing, which can be organized on a continuum from naïve to sophisticated/adaptive (Bråten et al., 2011; Greene et al., 2008; Hofer & Pintrich, 1997; Schommer, 1990).

Although epistemic beliefs were characterized as a domain-general construct with people's beliefs consistently influencing their functions within and across contexts in the early literature (e.g., King & Kitchener, 1994; Perry, 1970; Hofer and Pintrich (1997), along with numerous other researchers (e.g., Buehl & Alexander, 2001; Kuhn, 2000; Muis et al., 2006), argued that epistemic beliefs could be conceived as context-sensitive and might differ across subject domains. Students who believe knowledge to be complex and dynamic endorse different approaches to justify knowledge in different domains, such as relying on experimentation in science but on authority in history. Domain specificity in responses to epistemic belief measures is well-supported by extant research (e.g., Buehl & Alexander, 2001; Hofer, 2000; Muis et al., 2006). Therefore, in this study, we focus on students' epistemic beliefs in one specific domain (i.e., science).

In the science domain, epistemic beliefs are conceptualized in terms of four core dimensions –justification of knowledge, source of knowledge, development of knowledge, and certainty of knowledge (Chen, 2012; Conley et al. 2004). These dimensions align with the four dimensions in earlier work by Elder (2002) and Hofer (2000). The present study focuses on the justification and development dimensions. Justification is a central question in philosophical epistemology (Pollock & Cruz, 1999) and a core component of almost all dimensional models of epistemic beliefs (e.g., Baxter Magolda, 1992; Hofer, 2000; King & Kitchener, 1994; Kuhn, 2000; Greene et al., 2008). It refers to how individuals use evidence and evaluate claims. An adaptive stance on the justification dimension would consider that claims need to be justified by evidence; the reverse is true for individuals who hold naïve beliefs on justification. In the science domain, justification is primarily concerned with the role of experiments and data use to support arguments, which is similar to the reason factor in Elder (2002).

The development dimension refers to the belief that knowledge is continuously evolving and changing (rather than static). This dimension has a long history in epistemic cognition and nature of science research (e.g., see King & Kitchener, 1994). In the domain of science, individuals with more adaptive stances endorse that scientific knowledge is changeable over time and that ideas and theories are changeable based on new data and evidence (Conley et al., 2004). It is worth noting that the extent of the tentativeness of scientific claims varies across disciplines and contents (Elby & Hammer, 2001; Schizas et al., 2016). Some scientific knowledge (e.g., the earth is spherical) can be relatively stable rather than dynamic. However, it is still reasonable to believe that the developmental view of scientific knowledge tends to be more adaptive (Abd-El-Khalick, 2012; Lederman et al., 2019). Previous research (Schwartz & Lederman, 2008; Wong & Hodson, 2009) found that scientists from different scientific disciplines and areas share largely overlapping understanding of scientific epistemic cognition and hold adaptive beliefs that scientific knowledge is generally dynamic and evolving. Further, epistemic cognition researchers have demonstrated the effectiveness of measuring epistemic beliefs regarding domain-general science through the use of quantitative scales (Greene et al., 2018). In the present study, we relied on the generalized measure of scientific epistemic beliefs provided by the PISA.

Substantively, epistemic understanding of the justification of knowledge through experimentation (justification) and the changing nature of science (development) is emphasized in the science curriculum (Elder, 2002). These two dimensions were found to be the strongest positive predictors of academic performance among 20 different dimensions of epistemic beliefs in a recent meta-analysis (Greene et al., 2018; ES = .228 for justification, ES = .274 for development). This finding is in line with the research strategy used for the PISA 2015 assessment, where only these two dimensions of epistemic beliefs were included. In theory, an individual could view the nature of science as fixed and, at the same time, believe that scientific knowledge is justified by empirical evidence gained from experiments. However, empirical research showed that these two dimensions might not develop independently but tend to be related positively, with the relation getting stronger over time. For example, the two dimensions were moderately correlated among fifth grade students (rs = .47 and .57, Conley et al., 2004) and their sixth-grade counterparts (r = .65, Chen & Pajares, 2010). Based on a Swedish longitudinal sample (from Grades 5 to 11), Winberg et al. (2019) suggested students tend to endorsed these two dimensions in a similar way (r = .985) (also see Tsai et al., 2011 for similar findings).

Theoretical Framework of Motivational Constructs

In the achievement motivation literature, two motivational questions play fundamental roles in explaining students' achievement-related behaviors and performance "Can I do this task?" and "Do I want to do the task and why?" (e.g., Eccles & Wigfield, 2002; Wigfield & Cambria, 2010). The first question is related to students' competence beliefs, which have been captured in various motivation theories (expectancy-value theory, social cognitive theory, academic self-concept theory, and control-value theory) and specific constructs (e.g., expectations of success, self-efficacy, self-concept, and perceived control). PISA2015 assessed competence beliefs by using self-efficacy that is drawn from Bandura's social cognitive theory (Bandura, 1986, 1997). Self-efficacy refers to a belief concerning their ability to perform given academic tasks at designated levels (Bong & Skaalvik, 2003; Marsh et al., 2019; Schunk & Pajares, 2005). Specifically, science self-efficacy refers to future-oriented judgments about one's capability to accomplishing particular goals in a specific context, "where meeting these goals requires scientific abilities, such as explaining phenomena scientifically, evaluating and designing scientific inquiry, or interpreting data and evidence scientifically (OECD, 2016a, p. 136)". This task-specific self-efficacy has demonstrated the strong association with academic achievement (Marsh et al., 2019).

The second motivation question (i.e., "Do I want to do the task and why?") reflects individuals' beliefs in having a value or reason to do a given task (i.e., value beliefs, Eccles & Wigfield, 2002; Ryan & Deci, 2009; Wigfield & Cambria, 2010). Value beliefs are the driving force behind engagement, learning, and choice of coursework and occupation (see Wang et al., 2019 for a review). PISA 2015 distinguishes between two forms of value beliefs to learn science: students learn science because they enjoy it (intrinsic value) and because they perceive learning science to be useful for their future plans (utility value). These two constructs are central in expectancy-value theory (Wigfield and Eccles, 2000). Unlike self- efficacy, intrinsic and utility values are conceptualized as domain-specific (e.g., science, math) rather than the task-specific level. Although self-efficacy and intrinsic and utility values focus on different levels of domain specificity, there is growing evidence that science self-efficacy has a strong influence on science achievement, while science value beliefs have a stronger influence on aspirations and choices in STEM-related activities (e.g., Guo et al., 2019; Larson et al., 2015; Maltese & Tai, 2011; Perez et al., 2014; Robinson et al., 2019; Wang et al., 2017; Wu et al., 2020). Given that self-efficacy and intrinsic and utility values capture two fundamental motivation mechanisms leading to achievement-related behaviors, this study relied on these three motivational constructs and evaluated their relations with epistemic beliefs, achievement, and STEM career aspirations.

Relations between Epistemic Beliefs and Motivational Constructs

Muis (2007) proposed a model of self-regulated learning to establish why and how epistemic beliefs relate to self-regulated learning. In the first phase of learning, an individual constructs a perception of the task, which is influenced by task conditions (i.e., external conditions), such as context and behaviors, and cognitive and affective conditions (i.e., internal conditions), such as an individual’s epistemic beliefs and motivational beliefs related to the specific task. More specifically, Muis (2007) proposed that epistemic beliefs are a key element of task definition and “serve as antecedents to other learning and motivational beliefs” (p. 187). For example, if students believe that scientific knowledge is certain and simple, when given a science problem, they may believe there is only one path to solve the problem, and the answer is unequivocal. These beliefs may lower their interest in engaging in science. Moreover, facing complex problems may reduce these students’ self-efficacy expectations to successfully complete these tasks and make them perceive that learning activities are not useful (e.g., Alpaslan, 2017; Ricco et al., 2010). In contrast, if students believe scientific knowledge is tentative and complex, they may be more likely to use appropriate learning strategies and have greater self-efficacy, enjoyment, and perceived utility of learning, even when an attempt to understand the material does not immediately lead to success. Similarly, if students believe that scientific knowledge is handed down by authority, which is inconsistent with the epistemic nature of scientific knowledge (i.e., the need to justify knowledge through experimentation), then such inconsistency may lead to confusion and frustration during learning, which in turn lowers their self-efficacy and task values in learning science (also see Bråten et al., 2011; Buehl & Alexander, 2005). However, there may also be occasions where more constructivist epistemic beliefs undermine motivational beliefs. For example, when students believe that scientific knowledge is complex and are given a highly challenging task, their self-efficacy expectation for successfully completing that task may decrease. Nevertheless, overall, Muis posited that "the more constructivist students' epistemic beliefs, the higher their levels of motivation (p.187)". This theoretical claim is supported by growing evidence (e.g., Alpaslan, 2017; Bråten & Strømsø, 2005; Buehl & Alexander, 2005; Chen & Pajares, 2010; Hofer, 1999; Muis, 2008, also see below for more detail).

With regards to the relations between epistemic beliefs and motivational constructs, empirical studies show that students with more adaptive beliefs about knowledge justification and development in science tend to have higher science self-efficacy and place more value on science, even after controlling other dimensions of epistemic beliefs (e.g., Alpaslan, 2017; Chen & Pajares, 2010; Ricco et al., 2010; Tsai et al., 2011). However, studies juxtaposing self-efficacy and value beliefs and comparing their associations with epistemic beliefs are largely lacking, with two exceptions.

Alpaslan (2017) linked epistemic beliefs to science self- efficacy and a single, combined score for value beliefs. Both the justification and the development dimensions of epistemic beliefs were positively associated with task value but not self-efficacy. In contrast, relations of these two dimensions with both self-efficacy and value beliefs were significant and of similar magnitude in Ricco et al.'s (2010) study. Besides the inconsistent findings, these two studies have not incorporated multiple components of value beliefs (e.g., intrinsic value and utility value) and thus miss out on the opportunity to gain a more in-depth insight into the associations between epistemic beliefs and motivational processes.

Relations Among Epistemic Beliefs, Motivational Constructs, and Science Achievement

Along with other epistemic belief researchers (Hofer & Pintrich, 1997; Schommer- Aikins et al., 2005), Muis (2007) posited that motivational constructs are more proximal predictors of achievement-related outcomes than epistemic beliefs. Thus, the influence of epistemic beliefs on performance is posited to be partially mediated through motivational constructs. For instance, individuals believing knowledge to be absolute or unchanging may experience more confusion and frustration and less enjoyment, which in turn may lead to worse performance than individuals believing knowledge to be tentative and evolving. However, we note that the effects on motivation are just one way in which epistemic beliefs influence learning. Other possible ways may go through the selection of metacognitive and self-regulation strategies (e.g., planning, monitoring, critical thinking) and through setting standards for performance (Bråten et al., 2011; Muis, 2007). Empirical studies have found that epistemic beliefs are more strongly associated with motivational constructs than with achievement, and that the effect of epistemic beliefs on achievement is significantly reduced after controlling for motivation (e.g., Alpaslan, 2017; Alpaslan et al., 2016; Chen & Pajares, 2010; Kizilgunes et al., 2009). These findings support the theoretical proposition that the relation between epistemic beliefs and achievement is partially mediated through motivation (Hofer & Pintrich, 1997; Muis, 2007; Schommer-Aikins et al., 2005).

Relations between Epistemic Beliefs, Motivational Constructs, and Aspirations in STEM-Related Fields

As mentioned above, self-efficacy and particularly task value are found useful to predict achievement-related behaviors, such as educational and career aspirations in STEM- related fields (e.g., Guo et al., 2015; Simpkins et al., 2006). Nevertheless, the link between epistemic beliefs and educational and career aspirations has received scant attention in the epistemic belief literature. There is, to our knowledge, only one study that examined this issue. Trautwein and Lüdtke (2007) adapted a domain-general (rather than domain-specific) epistemic belief instrument and found that viewing knowledge as more certain was likely to motivate students to aspire a career in STEM-related fields. However, in this study, the justification and development dimensions, which are critical aspects in domain of science, were not included. Given these critical limitations in the previous research, the relation between scientific epistemic beliefs and aspirations in STEM-related fields is unclear and needs further investigation.

Inconsistency and Generalizability of Findings in Research on Epistemic Beliefs

Given the lack of agreed-upon operationalizations of epistemic beliefs in the existing literature, a variety of conceptualization and measures have been created and used to capture epistemic beliefs (Greene et al., 2018; Hofer & Pintrich 1997). In a recent meta-analysis, the use of different instruments was a significant moderator for the relation between epistemic beliefs and achievement (Greene et al., 2018). Among the 20 instruments used in the studies integrated in this analysis, 11 instruments yielded positive relations with substantial variability, whereas non-significant effect sizes were found for nine instruments. Besides the substantial differences in conceptualizations and measures of epistemic beliefs, another reason that may lead to the inconsistent findings is the cross-national differences. For example, based on the same instrument (Conley et al., 2004) and participants from the same grade level, Chen and Pajares (2010) found American students' epistemic beliefs were positively correlated with their self-efficacy, while the pattern of results was weak and even not significant for their Italian counterparts (Mason et al., 2013).

Additionally, although epistemic beliefs have been the subject of extensive research for many years in Western countries, less has been done in non-Western countries (see Lin et al., 2013 for more discussion). Given that students from different cultural backgrounds might view knowledge in different ways (Qian & Pan, 2002), it is imperative to examine whether the proposed relations in the epistemic belief framework from Western theorists are generalizable across different countries/regions based on the same epistemic belief measure.

Cross-national comparisons provide researchers with a heuristic basis to test the external validity and generalizability of their measures, theories, and models (Marsh et al., 2020). In doing so, researchers typically rely on meta-analytic approach or traditional cross- national approach (i.e., cross-national comparisons in single studies). However, there is, to our knowledge, only one meta-analytic study (Greene et al., 2018) and few cross-national studies on the relations of epistemic beliefs with student learning outcomes in the current literature. To the extent that a strong theoretical model generalizes well to heterogeneous samples drawn from a diverse set of countries, there is strong support for the external validity and the robustness of the interpretations based on the theory. Therefore, it is essential to scrutinize the cross-national generalizability of the nomological net of epistemic belief framework.

The Present Investigation

There is exponentially growing research on epistemic beliefs over the last years, since epistemic beliefs are posited to be a key antecedent of achievement motivation and achievement-related behaviors (e.g., Greene et al., 2018; Hofer & Pintrich, 1997; Muis, 2007). Although previous studies provide some support for these theoretical claims, they lacked nationally representative samples and relied on different conceptualizations and instruments of epistemic beliefs, which makes the cross-national generalizability of theoretical predictions open to question. The present study is unique in that it uses data based on large-scale nationally representative samples from 72 countries/regions and a validated epistemic belief instrument to test the cross-national generalizability of relations between scientific epistemic beliefs, motivational constructs, achievement, and STEM career aspirations. It is worth noting that our approach has many advantages over meta-analysis and traditional cross-national research as these approaches suffer from the heterogeneity of participants, measures, research designs, and publication bias involved in the analysis (Marsh et al., 2020, see discussion for more detail).

Because our research is cross-sectional, we avoid the implication of the causal ordering based on the correlates between scientific epistemic beliefs, motivational constructs, achievement, and STEM career aspirations. Indeed the motivational constructs and outcome variables can be a precursor of epistemic beliefs, a consequence of epistemic beliefs, or reciprocally related to epistemic beliefs (e.g., Chen et al., 2014; Muis, 2007). Nevertheless, it is reasonable to assume that some covariates (e.g., gender, grade level, socioeconomic status, and science instruction) influence epistemic beliefs and that it is useful to determine how they relate to these beliefs and outcome variables. Extant literature has revealed that students' gender, grade level, and family socioeconomic status (SES) are associated with their epistemic beliefs (e.g., Belenky et al., 1986; Chen, 2012; Conley et al., 2004; Schommer, 1990). For example, based on profile analysis, Chen (2012) found that girls and students in higher grade level were more likely to show a profile including adaptive epistemic beliefs. The impacts of these background variables on science motivation, achievement, and career aspirations have also been well-documented in previous research (e.g., Guo et al., 2019; Marsh et al., 2020; OECD, 2016b). Additionally, science instruction, such as inquiry-based instruction and teacher-directed instruction, has been found to influence students' epistemic beliefs, science motivation, and achievement-related outcomes (Areepattamannil et al., 2020; Chen et al., 2014; OECD, 2017). Hence, the omission of instructional practices would make the examination of the relations between epistemic beliefs, motivation, achievement, and career aspirations potentially misleading. Therefore, in the present study, we focused on the associations between epistemic beliefs and motivational constructs, and the joint relations of epistemic beliefs and motivational constructs with science achievement and STEM aspirations, controlling for plausible covariates including gender, year grade, and socioeconomic status as well as science instruction.

We aimed to answer four overarching research questions. For each research question, specific hypotheses and empirical analysis questions were as follows.

Research Questions 1: How Are Epistemic Beliefs Associated with Motivational Constructs in Science?

Hypothesis 1 (H1)

We expect that epistemic beliefs are positively correlated with self-efficacy, intrinsic value, and utility value (e.g., Alpaslan, 2017; Chen & Pajares, 2010; Ricco et al., 2010; Tsai et al., 2011). Given limited research juxtaposing both self-efficacy and multiple value components when investigating relations with epistemic beliefs, it is unclear whether the relations vary in strength across these different motivational constructs. For example, are epistemic beliefs more strongly associated with intrinsic value than with self-efficacy and utility value? As such, we leave this as an exploratory research question.

Research Questions 2: How Are Epistemic Beliefs and Motivation Associated with Science Achievement?

Hypothesis 2 (H2)

We expect that epistemic beliefs and motivational constructs (particularly self-efficacy) are positive predictors of science achievement (e.g., Eccles & Wigfield, 2002; Greene et al., 2018; Guo et al., 2017). More specifically, it is hypothesized that motivational constructs are more predictive of science achievement, given that achievement is assumed to be a more proximal outcome for motivational constructs than for epistemic beliefs (Hofer & Pintrich, 1997; Muis, 2007; Schommer-Aikins et al., 2005) (H2). Moreover, we expect that when epistemic beliefs and motivational constructs are simultaneously considered as predictors, then the positive relations of epistemic beliefs with achievement will be substantially reduced, because the effect of epistemic beliefs on achievement is at least partially mediated through motivational constructs (e.g., Alpaslan, 2017; Alpaslan et al., 2016; Chen & Pajares, 2010).

Research Questions 3: How Are Epistemic Beliefs Associated with STEM Career Aspirations?

Hypothesis 3 (H3)

There is extensive evidence showing that high motivational constructs (particularly intrinsic and utility value) in science are positively related to students' aspirations to engage in STEM-related fields (e.g., Guo et al., 2019; Robinson et al., 2019; Wu et al., 2020). Given that epistemic beliefs are positively related to motivational constructs, we expect that scientific epistemic beliefs are associated with STEM career aspirations, even though the relation between epistemic beliefs and career aspirations has been rarely studied yet. Again, this hypothesized relation will be substantially reduced when motivational constructs are further included.

Research Questions 4: Do the Hypothesized Associations Generalize Across Cultures?

We leave as an open research question whether the hypothesized associations will generalize across the 72 countries and regions. Given that students are exposed to substantially different cultural and educational contexts across countries and regions, analyzing this question provides a strong test of the generalizability of findings on these associations.

Method

Participants

The present study used data from the Programme for International Student Assessment (PISA) 2015, which assessed 15-year-old students from 73 countries/regions in terms of their science, mathematics, and reading achievement. PISA employed a two-stage sampling approach, which ensures that the samples were nationally representative for all participating countries/regions (OECD, 2017). In addition to the tests, students were asked to complete a contextual questionnaire assessing various aspects of their motivation, personal demographics, family background, and school life. We considered data from 72[1] countries/regions whose data on students' epistemic beliefs, motivational factors, and science achievement were available in the PISA2015 database. As a result, a total of 514,119 students were involved in the main analysis.

Measures

Scientific Epistemic Beliefs

The PISA 2015 student questionnaire included two scales to measure epistemic beliefs: justification of knowledge and development of knowledge. Three items were used to measure justification of knowledge (i.e., “A good way to know if something is true is to do an experiment”; “Good answers are based on evidence from many different experiments”; and “It is good to try experiments more than once to make sure of your findings”), while another three items were employed to measure the development of knowledge (i.e., “Idea in <broad science> sometimes change”; “Sometimes <broad science> scientists change their minds about what is true in science”; and “The ideas in <broad science> science books sometimes change”). All six epistemic belief items were based on 4-point Likert scales ranging from 1 (*strongly disagree*) to 4 (*strongly agree*). All answers were recoded to ensure high scores indicating adaptive understanding of the underlying constructs.

The preliminary analysis showed that the two-factor confirmatory factor analysis (CFA) resulted in a high correlation between these two dimensions (r = .83). This finding is aligned with the results from previous studies (e.g., r = .95 in Winberg et al., 2019; r = .81 in Tsai et al., 2011) and suggests that students tend to perceive these two epistemic beliefs in a similar way in the science domain. Moreover, in the original PISA analyses (OECD, 2017), these two epistemic constructs have already been combined and validated extensively, and demonstrated excellence in measuring students’ epistemic beliefs with strong reliability (Cronbach's alpha α = .875; OECD, 2017; also see Supplemental Materials [SMs]). Therefore, epistemic beliefs were treated as a unidimensional construct in the present study. As such, the weighted likelihood estimates (WLE) score provided by the PISA2015 organizers were employed to measure epistemic beliefs.

Science Motivational Constructs

The measures of motivational constructs were also selected from the PISA2015 student questionnaire. The PISA science self-efficacy scale was employed to represent expectancy, which consists of eight items to measure how confident students are in performing eight different tasks (e.g., "explain why earthquakes occur more frequently in some areas than in others"). The answers were based on 4-point Likert scales ranging from 1 (*I could do this easily*) to 4 (*I couldn't do this*).

A scale of enjoyment and interest in science containing five items (e.g., "I generally have fun when I am learning <broad science> topics") was used to represent intrinsic science value, and a scale of instrumental motivation that comprises four items (e.g., "Many things I learn in my <school science> subject(s) will help me to get a job") was applied to assess utility value. Note that intrinsic value and epistemic beliefs target students' attitudes and beliefs towards science as a broad subject, while utility value tends to capture students' perceived usefulness of learning science at school for their future plans. Thus, the term "broad science" was employed for assessing students' scientific epistemic beliefs and intrinsic value and "school science" was used for measuring their science utility value[2]. The scales of both intrinsic value and utility value were based on 4-point Likert scales ranging from 1 (*strongly disagree*) to 4 (*strongly agree*). All answers on the three motivational scales were recoded to ensure high scores indicating positive orientations on the underlying constructs. The three motivational constructs demonstrated satisfactory reliability across societies (α range from .867 to .917; also see Table S1 in SMs for specific items). Again, the three motivational constructs were measured using the WLE scores provided by the PISA organizers.

Science Achievement

Students' science achievement was measured by their performance on the PISA2015 scientific literacy test. Scientific literacy here refers to "not just knowledge of the concepts and theories of science but also knowledge of the common procedures and practices associated with scientific inquiry and how these enable science to advance" (OECD, 2016a, p. 18). The scientific literacy test assesses an individual's competencies to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically (OECD, 2016a). To save time and effort for students, a balanced incomplete block design was used to assess student science achievement, in which each student only answered a subset of the overall set of science test questions. Since each pair of subtests shared overlapping questions, students' science scores were analyzed by fitting a graded response Rasch model to ensure the between-person comparability of resulting scientific literacy scores (OECD, 2017).

Ten plausible values for scientific literacy scores were produced to estimate students' science performance. Plausible values are derived from multiple imputations of proficiency level scores based on information from the test items and are employed to produce more accurate estimates of group proficiency than would be produced through an aggregated point estimate (OECD, 2017). All the ten plausible values provided by PISA2015 were considered in the present analysis (see Data Analysis section for more detail). PISA tests were specifically designed to ensure cross-national comparability within each round as well as comparability across cycles of the PISA assessments (see OECD, 2017 for details).

STEM Career Aspirations

STEM career aspirations refer to the career expectations whose realization requires further study of STEM-related subjects beyond compulsory education, especially in tertiary education (OECD, 2016b). STEM career aspirations were measured by one open-ended item asking students, "What kind of job do you expect to have when you are about 30 years old?". Students' answers were classified based on the International Standard Classification of Occupations, 2008 edition (ISCO-08, International Labour Office, 2012); the resulting scores are available in the PISA 2015 database. Note that such single-item measure on adolescents' occupational aspirations has been widely used in empirical studies (Han, 2015; OECD, 2016b; Sikora, 2019). A dummy variable was produced to represent whether students aspired to work in STEM fields (0 = Non-STEM field; 1 = STEM field) using the coding strategy described in the PISA report (see Table S2; also see p. 283 in OECD, 2016b).

To conduct cross-national comparisons, a prerequisite is to guarantee that the developed scales measure the same constructs in different cultural contexts. PISA2015 employed a linking item response theory approach to "ensure measurement invariance through the invariance of item parameters across cycles and across participating countries" (OECD, 2017, p. 34). In particular, internal consistency was calculated for each scale in each country. Also, the invariance of item parameters across countries and across languages within a country were analyzed for each item and scale (OECD, 2017). All latent scales detailed above showed strong internal consistency (see above and Table 1). The WLE scores of these latent scales provided by the PISA2015 have demonstrated validity and invariance across countries and are adequate for cross-national comparison (see OECD, 2017, for more details). ***National-Level Moderators***

To examine the cross-national generalizability of the results, three national-level variables were included as moderators in the analysis: Human Development Index (HDI), religiosity, and Gender Gap Index (GGI). HDI represents national social-economic development level, which is calculated by measures of the quality of national living conditions, including health, financial status, life expectancy, and education (United Nations Development Programme, 2016). HDI was retrieved from the 2015 Global Development Reports (http://hdr.undp.org/en/data) and used in the analysis.

National religiosity refers to the degree to which people in a particular society value the importance of religion; the religiosity data were derived from Stoet and Geary (2017). They combined the questions of "How important is religion?" (from the World

Values Survey; 4-point Likert scale) and "How religious are you" (from the European Social Survey; 11-point Likert scale), given that these two questions were found to be highly correlated and measure the same concepts (see Stoet & Geary, 2017 for detailed description).

The GGI, published by the World Economic Forum, measures the extent to which females in a particular country fall behind their male counterparts on 14 key indicators (e.g., life expectancy, tertiary enrolment ratio, and income). The GGI data derived from World Economic Forum (2015) were employed in the analysis.

Individual-Level Covariates

Three individual-level covariates were included in the analysis based on the previous literature (e.g., Guo et al., 2015) and their roles in explaining students' science achievement and STEM aspirations: student gender, grade level, and family socioeconomic status (SES). Gender was coded as 0 (females) or 1 (male). A derived variable, student International grade (ST001D01T), that is available in the PISA dataset was used to define student grade level. SES was indicated by parents' highest education, parent highest occupation, and home possessions (see OECD, 2017, for details).

For science instruction, we also considered the two relevant scales as covariates in the supplemental analyses to check whether the relations between epistemic beliefs, motivation, achievement, and career aspirations changed after further controlling for both instructional variables. Inquiry-based instruction was measured by nine items regarding the frequency with which students experienced particular instructional practices in science classes (e.g., "students spend time in the laboratory doing practical experiments"), which was answered by students on 4-point Likert scales ranging from 1 (*in all lessons*) to 4 (*never or hardly ever*). A scale of teacher-direct instruction containing four items (e.g., "The teacher explains scientific ideas") was also reported by students based on 4-point Likert scales ranging from 1 (*never or almost never*) to 4 (*every lesson or almost every lesson*). All responses on the both instructional scales were recoded to ensure high score indicating high frequency on the constructs. The WLE scores of both instructional constructs provided by the PISA organizers, were utilized in this study.

Data Analysis

Multilevel mixed-effect models were conducted with the HLM statistical package (Version 7.0; Raudenbush & Bryk, 2002) to accommodate the two-level nested structure of the data (students nested within countries). Specifically, hierarchical linear models (HLMs) were conducted to answer research questions 1 and 2; multilevel generalized linear models (GLMs) with a logit link function were built to answer research question 3, with the dependent variable (i.e., STEM aspirations) included as a dummy variable. Notably, random effects regarding the country-level residual variance of epistemic beliefs and motivational factors in the HLMs and GLMs also contributed to answering research question 4. The corresponding random intercept models were reported in supplemental materials (Tables S3- S5).

Before the main analysis, we used multiple imputation to handle the missing data on the included variables (missings were 11.1% for epistemic beliefs; 11.1% for self-efficacy; 8.7% for intrinsic value; 10.3% for utility value; 15.9% for STEM career aspirations; 1.3% for student grade level; 2.1% for family SES). 10 datasets were imputed, aligned with the availability of 10 plausible values for science achievement in the PISA2015 dataset. Each plausible value was randomly assigned to one imputed dataset. We conducted all analyses for each imputed dataset separately and then combined the results using Rubin's (1987) method, after using the appropriate survey weights. All continuous variables were standardized ($M = 0$, $SD = 1$) across the whole sample.

Results

Correlations among Variables

The correlations of epistemic beliefs with the three motivational constructs, science achievement, and STEM aspirations were low to moderate based on the entire sample (Table 1). Epistemic beliefs were more highly correlated with intrinsic value (r = .279) than with self-efficacy (r = .135) and utility value (r = .115). In relation to achievement-related outcomes, epistemic beliefs were more positively correlated with science achievement (r= .258) than with STEM aspirations (r = .093). The correlations between the three motivational constructs and between these beliefs and the outcomes were also low to moderate (r = .007 to .349), which attests to the discriminant validity of the motivation and achievement-related outcomes.

Associations among Epistemic Beliefs and Motivational Constructs in Science

In order to evaluate the relations among epistemic beliefs and motivational factors in science, we conducted HLMs where epistemic beliefs were used to predict science motivational constructs with and without controlling covariates (i.e., student gender, grade level, and SES). In line with H1, epistemic beliefs were positively related to all three motivational constructs in science: self-efficacy (β = .152, SE = .009), intrinsic value (β= .316, SE = .008), and utility value (β = .127, SE = .008) (see Models 1a, 2a, and 3a in Table 2). The results indicate that students with more adaptive epistemic beliefs tend to possess higher self-efficacy, intrinsic value, and utility value. Specifically, intrinsic value had the strongest association with epistemic beliefs – more than double the effects for self-efficacy and utility value. The relations between epistemic beliefs and motivational construct remained similar after controlling for the three individual-level covariates (i.e., student gender, grade level, and SES): self-efficacy (β = .135, SE = .008), intrinsic value (β = .313, SE = .008), and utility value (β = .128, SE = .008) (see Models

1b, 2b, and 3b in Table 2). The results of the corresponding random intercept models were similar to these results (see Table S3 in SMs).

Association between Epistemic Beliefs and Science Achievement

Next, we regressed science achievement on epistemic beliefs and the three motivation constructs. As expected, epistemic beliefs had a positive association (*β* = .316, SE = .014) with science achievement (see Tables 3 and S4). After including the three covariates, the pattern remained similar (*β* = .259, SE = .013). After further controlling science self-efficacy, intrinsic value, and utility value, the effect of epistemic beliefs showed only a small reduction (to *β* = .205, SE = .010). Epistemic beliefs were a stronger predictor of achievement than intrinsic value (*β* = .141, SE =.007), self-efficacy (*β* = .076, SE =.008), and utility value (*β* =-.040, SE =.006). Thus, the findings are only partially consistent with our hypothesis (H2), in that epistemic beliefs are a positive predictor of science achievement; meanwhile, it contrasts our expectation and indicates that epistemic beliefs are a more prominent predictor of science achievement than are the three motivational constructs.

Association between Epistemic Beliefs and STEM Career Aspirations

We conducted multilevel GLMs with a logit link function to determine how epistemic beliefs and motivational constructs predict student STEM career aspirations after controlling for student gender, grade, and family SES. With epistemic beliefs as the only predictor, Model 5a (see Tables 4 & S5) showed that epistemic beliefs positively predicted STEM aspirations (*β* = .261, SE = .015; OR = 1.229). In terms of odds ratios (OR), students who were 1 Standard Deviation (*SD*) above the mean in epistemic beliefs were 1.229 times more likely to have higher aspirations to pursue a STEM-related career compared to students with average epistemic belief scores. The effect of epistemic beliefs remained substantial after controlling student gender, grade level, and family SES (*β* =

.220, SE = .013, OR = 1.247). These finding support H3 that epistemic beliefs are positively associated with STEM career aspirations. As expected, the predictive effect of epistemic beliefs on STEM aspirations was reduced by more than half of their size (to β = .063, SE = .007, OR = 1.065) when controlling for the motivation variables, and it became insignificant when additionally controlling for achievement (β = -.002, SE = .006, p = .711; OR = .998). These findings suggest that the relation between epistemic beliefs and STEM career aspirations could be largely explained by achievement and motivation (see SM1.1 for more details about the relations between motivational constructs and STEM aspirations).

Supplemental Analyses

Mediation Model Test

The results above showed that once controlling for motivational constructs, the effects of epistemic beliefs on achievement-related outcomes were reduced, suggesting that mediation through motivational constructs may have been at work. Thus, we conducted supplemental analyses to test possible mediational pathways explicitly. Using Mplus (Version 8.1), we calculated the mediation effects of epistemic beliefs on achievement outcomes via each motivational construct while modeling the random effects of epistemic beliefs. In doing so, we first ran a mediation model for the effect of epistemic beliefs on achievement, where three motivational constructs were treated as mediators (see Table S6). Results showed a small but significant total mediated (indirect) effect (β = .045, SE = .005), which was mainly due to the indirect effect via intrinsic value (β = .040, SE = .005). Next, we ran another mediation model for the effect of epistemic beliefs on STEM aspirations, where three motivational constructs and achievement were included as mediators (See Table S7). Results showed that intrinsic value, utility value, and achievement were significant mediators (β = .073, SE = .007; β =

.067, SE = .009; β = .096, SE = .007, respectively). But the indirect effect via self-efficacy was not statistically significant (β = -.001, SE = .001). However, these supplemental results should be interpreted with caution, given the cross-sectional nature of our study design (see below for more discussion).

Science Instruction As A Control

Given that science instruction has been found to influence student science achievement, motivation, and career aspirations (Areepattamannil et al., 2020; Chen et al., 2014; OECD, 2017), we conducted a robustness check of our findings by further including two science instructional constructs (i.e., inquiry-based instruction and teacher-directed instruction) as covariates. The results showed that the relations between epistemic beliefs and desired outcomes stayed almost the same after further controlling for science instruction (Tables S8&S9): self-efficacy (from β = .135, SE = .008 to β = .122, SE = .007), intrinsic value efficacy (from β = .313, SE = .008 to β = .294, SE = .007), utility value (from β = .128, SE = .008 to β = .119, SE = .007), science achievement (from β = .205, SE = .010 to β = .195, SE = .009), and STEM career aspirations (from β = -.002, SE = .006, OR = .998 to β =-.013, SE = .004, OR = .988).

Gender and Epistemic Beliefs

Because girls are underrepresented in most STEM-related careers across countries, gender inequality in engagement in science careers has been a policy concern for a long time. Thus, we further examined whether gender disparity exists in students' epistemic beliefs. Interestingly, on average, although girls showed slightly lower science self-efficacy, intrinsic value, utility value, and achievement than boys (Cohen's ds = -.109, -.060, -.006, and -.020, respectively), girls tended to hold slightly more adaptive epistemic beliefs (Cohen's d = .053; see Table S13). Next, we explored whether such gender differences in epistemic beliefs could be explained by different characteristics of countries (i.e., HDI, religiosity, and GGI). We found that this gender difference was slightly smaller in more socioeconomically developed countries and in more gender-equal countries, and larger in more religious countries (see Table S14). Nevertheless, these country-level moderating effects were relatively small ($\beta < .027$), suggesting that they should not be over-interpreted. Moreover, the association of epistemic beliefs with motivation, achievement, and STEM aspirations were similar in size across genders (see Tables S19&S20).

Cross-National Generalizability

We evaluated the cross-national generalizability of our findings using four approaches: inspecting (i) the random variance components; (ii) the standard deviation (SD) of country-to-country variation of epistemic beliefs in multilevel mixed-effect models; (iii) the fixed effects for each country; and (iv) the cross-level interactions between epistemic beliefs and country-level measures (i.e., HDI, religiosity).

Random Variance Components

The random effect estimates in multilevel mixed-effect models represent the country- by-country variation in the fixed effects. Given the large sample size, nearly all the random effects are significant, from a purely statistical perspective. However, if the random effects are small relative to the corresponding fixed-effect estimate, there is good support for the generalizability of at least the direction of effects in relation to a priori predictions, even if there is significant country-to-country variation in the exact size of the effect (Marsh et al., 2020). The random variance components of epistemological beliefs when predicting science self-efficacy, intrinsic value, utility value, science achievement, and STEM career aspirations were <.01 (Tables 2-4): .004 (Model 1c), .004 (Model 2c), .004 (Model 3c), .007 (Model 4c), and .003 (Model 5c). Given that the square root of a variance component of .01 at the country level translates into an estimated *SD* = .1, we considered these variance components of less the .01 to be trivially small.

SD of Country-To-Country Variation

Alternatively, as suggested by Marsh (2016), if the *SD* of country-to-country variation is less than half that of a fixed-effect estimate in support of an a priori prediction, there is good support for the generalizability of the prediction. The rationale behind this is that the direction of the effect will not change even at relatively extreme values (i.e., an individual's epistemic beliefs that are two *SD*s from the mean). For example, consider the results in Model 4c (Table 3) that were used to test H3 (the positive effect of epistemic beliefs on achievement). For this prediction, it is relevant to juxtapose the fixed-effect estimate (β= .205) with the SD of the country-to-country variation (i.e., the square root of the corresponding random variance component, $.007^{1/2}$ = .084). Because the β = .205 is large relative to the *SD* = .084, there is support for the generalizability of the direction of the effect across countries and, thus, the a priori prediction. Following this guideline, there is strong support for the generalizability of all the predictions in relation to epistemic beliefs.

Fixed Effects for Each Country

An alternative perspective on generalizability is to consider the range of estimated effects for each country. In line with the findings for country-to-country variation based on the random effects as discussed above, the positive associations between epistemic beliefs and motivation were almost all significant in relation to self-efficacy (66/72 countries), intrinsic value (71/72 countries), and utility value (68/72 countries) (Table S10). Similarly, the effects of epistemic beliefs on achievement and STM career aspirations were positive and consistent in predicting achievement across all 72 and 71 of the 72 countries, respectively, when no controls (e.g., covariates, motivational constructs) were considered in the models (Tables S11&S12). To enhance the presentation, we also ran another parallel set of fixed- effect models for each motivation constructs in predicting achievement and STEM aspirations without controlling for epistemic beliefs and any other variables. When treated as separate predictors, epistemic beliefs were more strongly associated with science achievement than were self-efficacy, intrinsic value, and utility value in 72, 66, and 72 of the 72 countries, respectively (Figure 1); Intrinsic value and utility value were consistently and more strongly associated with STEM aspirations than were epistemic beliefs across countries, whereas the predictive effects for self-efficacy were similar with those for epistemic beliefs and small in size (Figure 2). The pattern of results remained similar, when epistemic beliefs and the three motivational constructs were added in the model simultaneously where the joint predictive effects were examined (See Figures S1&S2; also see SM1.2 for more details).

Cross-Level Interactions between Epistemic Beliefs and Country-Level Measures

Before examining the cross-level interactions between epistemic beliefs and country- level measures, we evaluated whether there were substantial country-level mean differences in epistemic beliefs and how such differences were related to country-level variables. Results showed that there was only a small variability in country-level epistemic beliefs with and without controlling for individual-level covariates ($SD = .021^{1/2} = .145$, $SD = .017^{1/2} = .130$, respectively; see Table S13). Such variability was significantly but weakly related to country- level socioeconomic development ($\beta = .079$, $SE = .014$) and religiosity ($\beta = -.044$, $SE = .019$), when not controlling for individual-level covariates (Table S14). These findings indicate that, on average, students have more adaptive epistemic beliefs in more socioeconomically developed societies, and in less religious societies tend to have more adaptive epistemic beliefs. However, these country-level associations disappeared when controlling for individual-level covariates.

Cross-level interactions between epistemic beliefs and country-level measures (i.e., HDI and religiosity) on motivation, achievement, and aspirations were tested to examine the cross-national generalizability of our findings (Tables S15-S18). Results showed significant and positive cross-level interaction effects between epistemic beliefs and HDI as well as between epistemic beliefs and religiosity in predicting three motivational constructs and two outcome variables. These findings revealed that the positive effects of adaptive epistemic beliefs on science motivation, achievement, and STEM aspirations were slightly stronger in more socioeconomically developed societies and in less religious societies ($|\beta s| < .05$, see Tables S15-S18). In other words, students in more socioeconomically developed societies and in less religious societies tend to benefit more when holding more adaptive epistemic beliefs. However, given all the cross-level interaction effects $|\beta s|$ were below .05, we considered the moderating effects to be small, both in absolute terms and compared to the main effects of epistemic beliefs. As such, the findings provide evidence of the cross-national generalizability of the relations.

In summary, our findings provide strong support for the cross-national generalizability of the theoretical predictions particularly in relation to epistemic beliefs, from a universalist perspective (RQ4).

Discussion

In the digital age, adaptive epistemic beliefs in science can help people more effectively synthesize the diverse range of available scientific information, and thus make informed day-to-day decisions (Sandoval et al., 2016). Our findings suggest that such epistemic beliefs are positively and consistently related to adolescents' science learning across countries. Students who have adaptive views that knowledge is changeable and comes from experimentation tend to show high science achievement, feel more self-efficacious, are both intrinsically and extrinsically motivated to engage in science learning, and have higher aspirations to pursue a career in STEM-related fields.

By juxtaposing multiple task values and self-efficacy, our study provides a more nuanced understanding of how epistemic beliefs facilitate motivational process. Among three motivational constructs, adaptive epistemic beliefs are more positively associated with science intrinsic value (i.e., enjoyment) than with utility value and self-efficacy. Indeed, the close relation between epistemic beliefs and enjoyment is theoretically elaborated in Muis et al.'s (2015) work. They demonstrate that an individual who believes that knowledge is justified via inquiry (i.e., more constructivist beliefs) are more likely to experience enjoyment in learning activities, particularly when being confronted with contradictory learning material, compared with those holding less constructivist beliefs (Bråten et al., 2011).

Another interesting finding is that epistemic beliefs were shown to positively and consistently relate to science self-efficacy across countries, which is inconsistent with previous research (e.g., Alpaslan, 2017; Chen et al., 2014). There are two possible reasons why previous research did not find such relations. First, previous studies assessed different dimensions of epistemic beliefs when evaluating this relation. For example, Chen et al. (2014) only assessed the justification in terms of authority (e.g., individuals believe that authority in the form of an expert, teacher, or another reputable source is sufficient to warrant a knowledge claim). They did not consider the justification of evidence and reasoning through experimentation, which are critical aspects in the domain of science. Second, previous studies relied on different measures of self-efficacy with a different level of domain specificity. For instance, Alpaslan (2017) used a generalized measure of science self-efficacy (e.g., "I believe I will receive an excellent grade in science class") rather than a task-specific measure as used in this study. In this sense, generalized measures of science self-efficacy are conceptually similar to domain-specific self-concept (see Marsh et al., 2019 for more discussion). Hence, further work is needed to replicate our findings by using different measures of epistemic beliefs and self-efficacy (see below for more discussion).

It is interesting to compare our findings with that previous research that has examined the relations between epistemic beliefs and other motivational constructs (e.g., mastery- approach goals, test anxiety). The sizes of relations of epistemic beliefs (i.e., justification and development) with intrinsic value in the present study are comparable to relations with mastery-approach goals found in previous studies (e.g., Winberg et al., 2019; Chen & Pajares, 2010). Indeed, intrinsic values and mastery-approach goals represent conceptually and empirically similar constructs (e.g., $r = .68$ in Linnenbrink-Garcia et al., 2018). Compared to studies exploring relations of epistemic beliefs with maladaptive motivational variables (e.g., test anxiety, performance-avoidance goals), the relations with adaptive motivational constructs found in the present study were consistently stronger. There is a need to more systematically compare relations of epistemic beliefs with both adaptive and maladaptive motivational variables in further cross-cultural research.

A salient result is that epistemic beliefs are more strongly linked to science achievement than is motivation. This finding suggests another avenue to elevate students' achievement in science that education policies have focused on. Indeed, current intervention efforts have disproportionately focused on promoting students' science motivation (e.g., intrinsic value and utility value; see Lazowski & Hulleman, 2016; Rosenzweig & Wigfield, 2016, for reviews) in order to improve their science achievement. Limited efforts have been exerted on students' epistemic beliefs. For example, in a recent meta-analysis of the effects of epistemic cognition interventions on academic achievement (Cartiff et al., 2020), only 11 intervention studies were identified in K-12 settings with a focus on science. Aligned with our findings, the interventions focusing on justification of knowledge produced a stronger positive effect on students' performance compared to those targeting other dimensions of epistemic beliefs (Cartiff et al., 2020; Mason et al., 2014). However, beliefs in the developing nature of science (i.e., development of knowledge) have rarely been targeted in the design of interventions. Given the close relation between justification and development of knowledge, our results suggest that interventions focusing on both epistemic belief dimensions may be most fruitful. In addition to conducting interventions, integrating epistemic cognition in regular science teaching is crucial for teachers. For instance, providing students with opportunities to discuss the evolution of scientific knowledge (*history of science*; Matthews, 2014), to closely mimic how scientists perform experiments (*scientific inquiry*; Schwartz et al., 2004), and to experience and understand the epistemic basis of scientific practice (*argumentation*; Bell & Linn, 2000) has been shown as effective in bolstering students' scientific epistemic beliefs.

The present study is among the first to apply domain-specific (science) epistemic beliefs and examine its relation with STEM aspirations. In contrast with Trautwein and Lüdtke's study (2007) relying on domain-general epistemic beliefs, our findings indicate that students holding adaptive views on science tends to have higher aspirations to STEM-related career. It reveals the importance of considering domain-specific constructs in epistemic cognition research. Furthermore, the positive relation between epistemic beliefs and STEM- related career aspirations is largely explained by students' performance and the extent to which students enjoy and value learning science. It suggests that compared to motivation, career aspiration is a more distal outcome for epistemic beliefs. Our findings imply that interventions designed to promote more adaptive epistemic beliefs by themselves may not be effective in propelling students toward STEM pathways. Multiple-component interventions, integrating those epistemic cognition interventions with motivation components, would be more beneficial for boosting students' STEM aspirations. However, such multiple-component intervention has not yet been developed and investigated in relation to science school learning.

Testing the cross-national generalizability of findings as done in the present study is pivotal as it will not only advance theory but also bring significant educational and practical impacts in a global context. Typically, meta-analyses are used to test generalizability. However, meta-analyses usually suffer from the heterogeneity of original studies with regards to participants, measures, and research designs, and from their reliance on samples from WEIRD countries (Marsh et al., 2020). Further, meta-analyses rarely have assessed individual-level data that are assumed to influence desired outcomes, such as individual background variables (e.g., family socioeconomic status, gender). Scholars tend to realize the problem of meta-analysis and conduct cross-national comparisons in single studies (i.e., traditional cross-national studies) to scrutinize the cross-national generalizability of theories. However, these studies usually suffer from many of the same limitations as meta-analyses, such as small sample sizes of countries, unclear equivalence of measures and participants across countries, etc. Given that the PISA data provides nationally representative samples, validated measures, a consistent research design, and rich individual-level data, it provides a potentially stronger basis for evaluating the cross-national generalizability of theoretical predictions than do meta-analyses or traditional cross-national studies.

Notably, the findings show that the positive relations of epistemic beliefs with desired outcomes were generalizable across 72 countries. Furthermore, we found that the strength of these relations did not vary as a function of gender; indeed, girls endorsed more adaptive epistemic beliefs than boys even though they had lower levels of science achievement, self- efficacy, intrinsic value, and utility value. Overall, our findings suggest that holding adaptive epistemic beliefs is equally crucial for boys and girls across different countries, providing first-ever and strong evidence for the cross-national generalizability of our predictions on the role of epistemic beliefs for important outcomes.

PISA data, despite its many strengths, has its own limitations. The major limitation is the cross-sectional nature of the study design. As such, we are unable to establish whether the associations between epistemic beliefs, motivational constructs, and desirable outcomes represent causal links and mediational processes. Although the motivational constructs and outcome variables examined in our research can be plausibly portrayed as consequences of epistemic beliefs, epistemic beliefs are dynamic and responsive to ongoing experience; as such, their relations with motivational constructs and outcome variables could be reciprocal over time (e.g., Chen et al., 2014). Nevertheless, educational and psychological research, especially cross-cultural studies, routinely must rely on non-experimental data, as it would not be feasible and also unethical to randomly assign students to different schools, let along different countries (Marsh et al., 2020). Hence, our findings must be interpreted with these issues in mind. Longitudinal, large-scale, cross-national studies are, at present, aspirational rather than realized; fulfilling this aspiration in the future would yield incredibly valuable theoretical and applied information. Another limitation is that all participants were from a single age group (i.e., 15-year-old students). Previous research indicates that the development of epistemic beliefs and their associations with motivation and achievement might differ across age (Cartiff et al., 2020; Conley et al., 2004; Winberg et al., 2019), which potentially limits the generalizability of our findings to other developmental periods. However, 15-year- old is a particularly important age, as students from many countries are approaching the end of mandatory education and make critical decisions in relation to further education, training, and work. Whether our findings are generalizable across different age groups warrants further investigation.

There are also a few additional caveats. First, while epistemic beliefs are considered as multidimensional constructs, we only focused on two dimensions - justification and development - as only these two dimensions were available in the PISA data. These two dimensions have been theoretically and empirically considered as main components in science curriculum (Conley et al., 2004; Elder, 2002; Wong & Hodson, 2009). Nevertheless, other dimensions, such as certainty of knowledge and source of knowledge, should also be included in future investigations. Second, the use of self-report questionnaires that focus students' attention on specific aspects of epistemic beliefs may lead them to report more adaptive beliefs than may be found in interviews, discourse analysis, and think-aloud protocols, although previous research has shown that there is at least a fair amount of agreement between questionnaires and interviews assessing epistemic cognition (Elder, 2002). In addition, the PISA2018 assessment provides psychometrically strong measures of motivation and science instruction constructs, but these measures are also based on self- report (OECD, 2019). Gathering the relevant data from multiple sources will undoubtedly increase the time and effort involved in cross-national research. However, the information gleaned will be critical in cross-validating and replicating the current results. Third, this study tests the generalizability of the relations between epistemic beliefs and desirable outcomes by focusing on between-country differences. Given that there can be multiple cultures within countries, one direction for future research is to examine cross-cultural generalizability of our findings both between and within countries using data that include more detailed information about students' cultural background. Fourth, there are some limitations of the measures of country-level variables used in this study. Specifically, the HDI is an average measure and, thus, masks disparities within countries. Furthermore, it only reflects long-term changes (e.g., changes in life expectancy) and does not reflect the recent short-term changes. Besides the neglect of wide divergence within countries, religiosity data were retrieved from surveys with adults so that we cannot be sure that the measures can be generalized to the age group in question. There is little research on the development of religiosity across the lifespan (Bengtson et al., 2015). Hence, future research needs to extend our research with comprehensive measures of these country-level variables in the future.

Conclusion

Our study is the first to systematically test and compare how epistemic beliefs are associated with important performance and motivation outcomes of science learning across 72 countries/regions. The positive and robust associations between students' epistemic beliefs and their motivation, STEM aspirations, and particularly achievement suggest that preparing students for 21st-century challenges will require policy initiatives that ensure epistemic beliefs are considered a core component of science education and scientific literacy.

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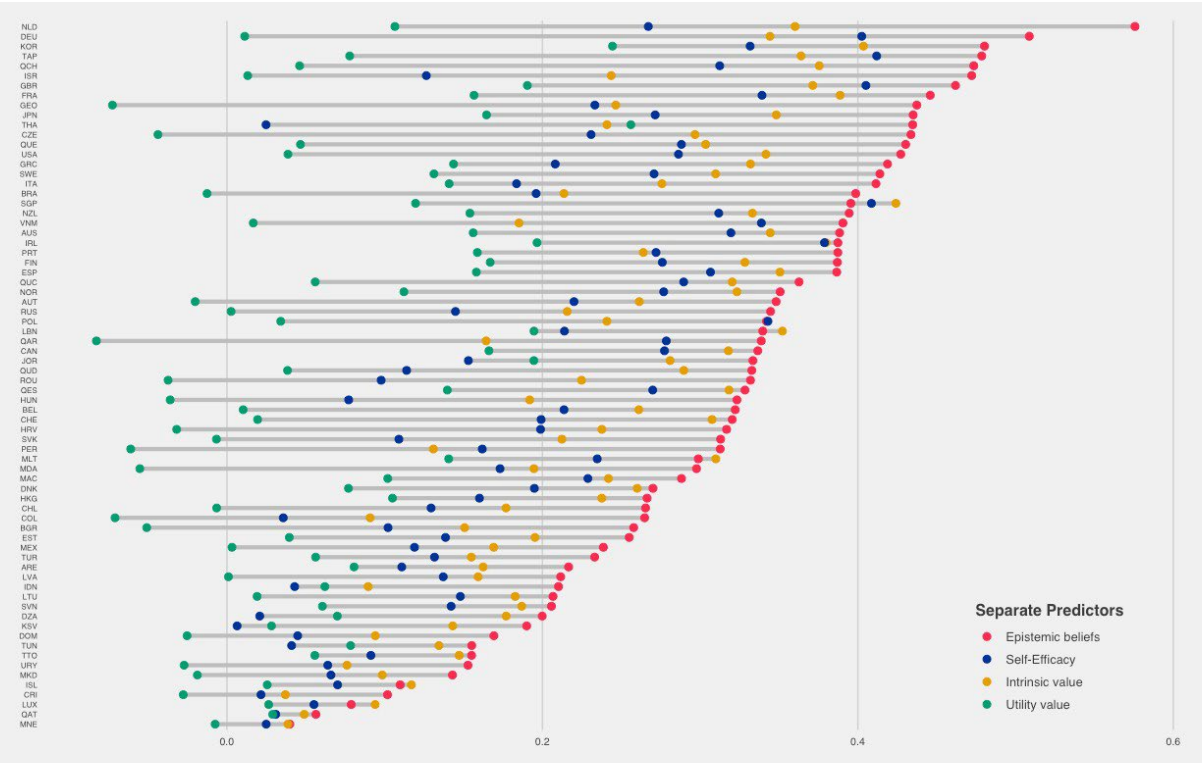

Figure 1. Separate predictive effects of epistemic beliefs and motivation on science achievement across 72 countries/regions.
Notes. See SMs for country abbreviation key and specific effect sizes.

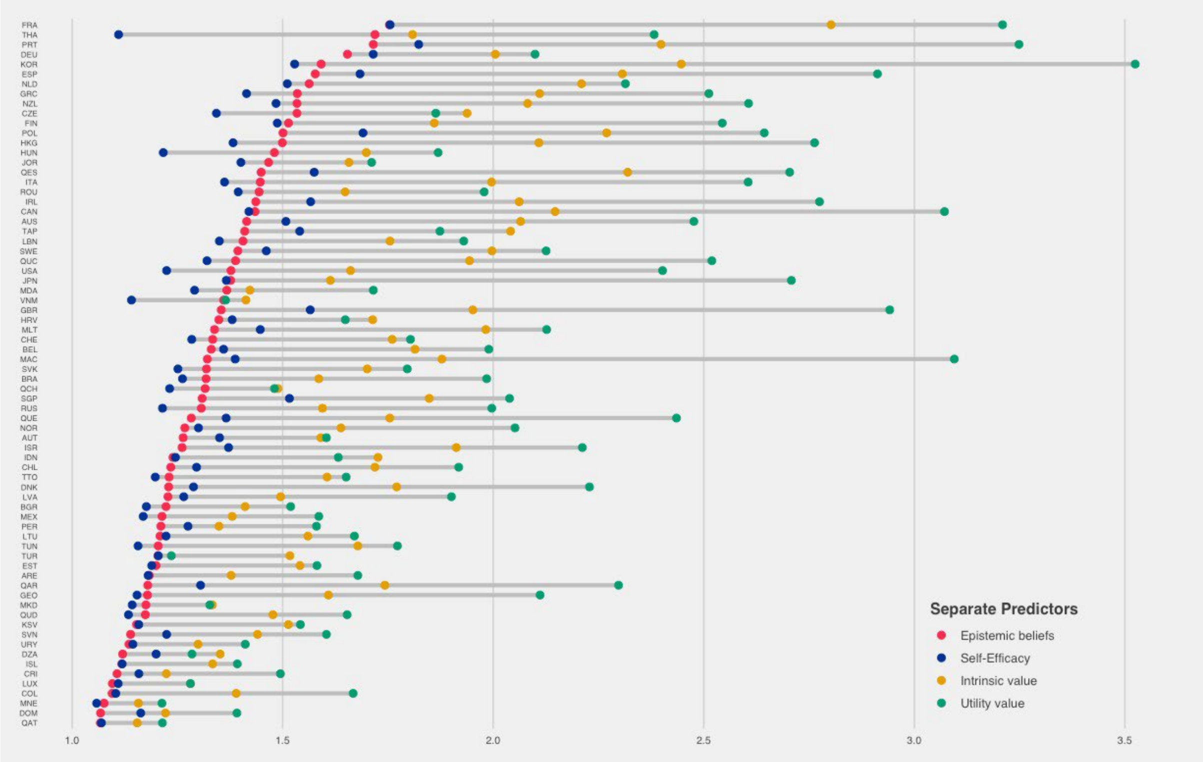

Figure 2. Separate predictive effects (Odds Ratio) of epistemic beliefs and motivational variables on STEM aspirations based on single logistic regression across 72 countries/regions.

Notes. X-axis are Odds Ratio, indicating that how many times students who were 1 standard deviation (SD) above the mean in each independent variable are likely to aspire pursuing a STEM-related career compared with students with average scores in corresponding variables.

Table 1
Correlations between the Study Variables Based on the Entire Sample

	SA	ASP	SEB	SSE	SIV	SUV	Male	Grade	SES
SA	1								
ASP	.134***	1							
SEB	.258***	.093***	1						
SSE	.123***	.102***	.135***	1					
SIV	.146***	.194***	.279***	.252***	1				
SUV	.007**	.235***	.115***	.224***	.349***	1			
Male	.009***	.002	-.027***	.039***	.022***	.002	1		
Grade	.294***	.038***	.070***	.035***	.012***	-.021***	-.060***	1	
SES	.337***	.101***	.130***	.128***	.029***	-.014***	.018***	.220***	1
Mean	469.939	–	-.014	.062	.164	.293	–	–	-.256
SD	98.971	–	.982	1.246	1.090	.968	–	–	1.108
α	–	–	.875	.867	.933	.917	–	–	–

Notes. SA = science achievement; ASP= STEM career aspirations; SEB = scientific epistemic beliefs; SSE = science self-efficacy; SIV = science intrinsic value; SUV = science utility value. ** $p < .01$;

*** $p < .001$.

Table 2

Hierarchical Linear Models Predicting Science Motivation

	Self-efficacy		Intrinsic value		Utility value	
	Model 1a	Model 1b	Model 2a	Model 2b	Model 3a	Model 3b
	coef (SE)	coef (SE)	coef (SE)	coef (SE)	coef (SE)	coef (SE)
Fixed Effect						
Intercept	-.003	-.041**	.000	-.031	-.011	-.017
	(.009)	(.014)	(.023)	(.024)	(.021)	(.021)
Epistemic beliefs	.152***	.135***	.316***	.313***	.127***	.128***
	(.009)	(.008)	(.008)	(.008)	(.008)	(.008)
Male		.080***		.064***		.012***
		(.003)		(.003)		(.003)
Grade		.003		-.003		-.017***
		(.002)		(.002)		(.002)
SES		.126***		.034***		.007*
		(.003)		(.003)		(.003)
Random Effect (Country-level)						
Epistemic beliefs	.004***	.004***	.004***	.004***	.004***	.004***
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
Variance Components						
Student	.847	.833	.795	.793	.846	.846
	(.002)	(.002)	(.003)	(.003)	(.003)	(.003)
Country	.012	.013	.037	.041	.032	.032
	(.002)	(.002)	(.006)	(.001)	(.005)	(.005)

Notes. coef = coefficient; SE = standard error. * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 3

Hierarchical Linear Models Predicting Science Achievement

	Model 4a	Model 4b	Model 4c
	coef (SE)	coef (SE)	coef (SE)
Fixed Effect			
Intercept	-.020 (.055)	-.042 (.050)	-.032 (.052)
Epistemic beliefs	.316*** (.014)	.259*** (.013)	.205*** (.010)
Male		.044*** (.003)	.025*** (.003)
Grade		.233*** (.001)	.232*** (.001)
SES		.251*** (.002)	.234*** (.002)
Self-efficacy			.076*** (.008)
Intrinsic value			.141*** (.007)
Utility value			-.040*** (.006)
Random Effect (Country-level)			
Epistemic beliefs	.013*** (.002)	.011*** (.002)	.007*** (.001)
Self-efficacy			.004*** (.001)
Intrinsic value			.003*** (.001)
Utility value			.002*** (.000)
Variance Components			
Student	.719 (.002)	.614 (.002)	.589 (.001)
Country	.221 (.037)	.182 (.031)	.196 (.033)

Notes. coef = coefficient; SE = standard error. *** $p < .001$

Table 4

Multilevel Generalized Linear Models Predicting STEM Aspirations

	Model 5a		Model 5b		Model 5c		Model 5d	
	coef (SE)	OR	coef (SE)	OR	coef (SE)	OR	coef (SE)	OR
Fixed effect								
Intercept	-.751*** (.040)	.472	-.754*** (.046)	.470	-.781*** (.039)	.458	-.774*** (.049)	.461
Epistemic beliefs	.261*** (.015)	1.299	.220*** (.013)	1.247	.063*** (.007)	1.065	-.002 (.006)	.998
Male			.047 (.037)	1.048	.022 (.033)	1.022	.013 (.032)	1.013
Grade			.102*** (.016)	1.107	.116*** (.014)	1.123	.040*** (.012)	1.041
SES			.231*** (.017)	1.260	.219*** (.014)	1.245	.138*** (.011)	1.148
Self-efficacy					.014* (.007)	1.014	-.009 (.007)	.991
Intrinsic value					.285*** (.012)	1.330	.235*** (.011)	1.264
Utility value					.503*** (.024)	1.654	.508*** (.024)	1.662
Achievement							.334*** (.016)	1.396
Random effect (Country-level)								
Epistemic beliefs	.014*** (.120)		.013*** (.113)		.003*** (.054)		.003*** (.051)	
Self-efficacy					.003*** (.052)		.003*** (.054)	
Intrinsic value					.010*** (.102)		.008*** (.090)	
Utility value					.050*** (.223)		.051*** (.227)	

Notes. coef = coefficient; SE = standard error; OR = odds ratio; * $p < .05$; *** $p < .001$.