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The relationship between epistemological beliefs, reflective thinking, and science identity: a structural equation modeling analysis

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Abstract

Background: Science identity is widely regarded as a key predictor of students' persistence in STEM fields, while the brain drain in STEM fields is an urgent issue for countries to address. Based on previous studies, it is logical to suggest that epistemological beliefs about science and reflective thinking contribute to the development of science identity. However, few empirical studies have focused on the relationship between these three variables. Therefore, using structural equation modeling, the present study constructed a model to explore the relationship between epistemological beliefs, reflective thinking, three science identity shaping constructs (interest, competence/performance beliefs, external recognition), and the holistic impression on science identity (a single indicator).

Results: The results indicated that the epistemological beliefs were positively correlated with interest and reflective thinking, as well as the direct effects of reflective thinking on interest or competence/performance beliefs were significant. In terms of indirect effect, interest plays a mediating role in the relationship between epistemological beliefs and holistic impression on science identity, while the mediation effect of competence/performance beliefs was not significant. Epistemological beliefs contributed to the holistic impression on science identity via reflective thinking, competence/performance beliefs, and interest or external recognition.

Conclusion: The results of this study reveal that epistemological beliefs and reflective thinking have a direct effect on science identity. In addition, epistemological beliefs have an indirect effect on scientific identity through reflective thinking. These provide insights for educators to figure out how to develop students' science identity by enhancing their epistemological beliefs and reflective thinking. Practical educational implications are also further discussed in the present study.

Keywords: Epistemological beliefs, Reflective thinking, Science identity, High school students, Structural equation modeling

Introduction

The development of students' science identity has received increasing attention from educational researchers. In developing the PISA (2024) assessment framework, the OECD (2020) first proposed including science identity as one of the learning outcomes for students, on the same level of importance as scientific knowledge and scientific competencies. Strategic Visioning Expert Group (SVEG) of PISA suggests that science identity is critical to help students adapt to such a complex and

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changing social environment currently and grow into competent social citizens (OECD, 2020).

The principal key role of science identity is reflected in raising students' STEM career aspirations. Despite cultivating talents in science, technology, engineering, and mathematics (STEM) fields being critical to promoting social and national development, the low retention rate of talents in STEM fields is a major challenge for all countries (Chen et al., 2021; Lytle & Shin, 2020). Cultivating students' STEM identities is deemed to be an important initiative to improve STEM talent retention. Since science identity is a key dimension of STEM identity and middle school students are more exposed to science in STEM fields, research on STEM identity is usually closely related to science identity (Dou et al., 2019). For example, some scholars have defined STEM identities as those who see themselves as science learners with an understanding and use of science, and who can contribute to science (Singer et al., 2020). In addition, there is growing evidence that science identity is one of the strongest predictors of student engagement, performance, and persistence in STEM fields, further contributing to higher retention rates within STEM fields (Perez et al., 2014; Vincent-Ruz & Schunn, 2018).

In China, the development of STEM talents is also a key issue that needs to be addressed urgently (Jiang et al., 2021). The China STEM Education White Paper noted that China has the world's largest workforce, but STEM talent is still unable to meet the demand for social development. The Ministry of Education of China promulgated the Outline of the National Science Quality Action Plan (2021–2035) also clearly states that it is necessary to enhance the scientific interests of adolescents and cultivate a large group of teenagers with scientist potential. However, the results of the PISA (2015) showed that only 16.7% of Chinese students who participated in the test were willing to pursue science-related careers (e.g., science and engineering professionals, technicians professionals), ranking only 68th out of 72 participating countries and regions (OECD, 2016). Likewise, in the 2018 PISA test, only 24.9% of Chinese students expect to pursue a science-related career at age 30, which is lower than the OECD average (32.3%) (OECD, 2019). Therefore, it is important to foster Chinese adolescents' science identity to enhance their scientific career aspirations.

In addition, the widespread penetration of science and technology in human life requires students not only to master scientific knowledge and abilities, but more importantly also to apply them critically to solve real-life problems (Sharon & Baram-Tsabari, 2020). Science identity as students' perceptions of the meaning and value of science, could affect students' willingness to actively transfer knowledge and abilities to the problem-solving process in real life (Gao & Riley, 2010). As the world's largest developing country, China has been committed to nurturing science and technology talents who are willing to contribute to solving global problems and maintaining sustainable human development. The development of science identity is equally important in encouraging individuals to become active, responsible global citizens who contribute to the sustainable development of humanity.

Although science identity is considered a key outcome of learning and a key component of STEM identities, we still know little about how to develop students' science identity. Especially high school students are usually facing choosing a major for college, and students who perceive science identity are more likely to choose a major in STEM fields (Alhadabi, 2021). Further, in the Chinese context, students are asked to select the subjects they want to study further after grade 10 (i.e., first grade in high school) in science-related subjects (including physics, chemistry, biology, geography), politics, and history, etc. The courses they choose at the end of 10th grade will determine what they take in 11th grade and also indirectly affect the majors they can choose to apply to in college. Likewise, high school students in many countries (e.g., France, Canada, and Korea) have to select elective courses for senior 2 after senior 1, depending on the major they are interested in. It follows the critical importance of identity formation for students in first-year high school. Given the present study was implemented primarily in a Chinese setting, the target population of the present study was first-year high school students.

Understanding what factors are directly or indirectly associated with students' science identity could be beneficial to designing appropriate teaching strategies that effectively enhance students' science identity during the teaching process (Vincent-Ruz & Schunn, 2018). Following previous studies, epistemological beliefs and reflective thinking may contribute to students' science identity development. Epistemological beliefs have been reported that could positively influence students' STEM-related career aspirations, which are strongly associated with the science identity (Guo et al., 2021). Meanwhile, the importance of epistemological beliefs in developing students' reflective thinking has been well confirmed (Phan, 2008). However, the direct effects of epistemological beliefs and reflective thinking on high school students' science identity, as well as whether epistemological beliefs indirectly enhance students' science identity through reflective thinking have not been well explored. Based on the above, the purpose of this study is to investigate how epistemological beliefs and reflective thinking affect high school students' science identity and further propose the educational implications.

Theoretical framing

The nature of science identity

Identity is a cognitive structure of self-definition formed in the process of participating in some activities, which is composed of the goals, values, and beliefs chosen by the individual in a specific community or role (Verhoeven et al., 2018; Waterman, 1984). Concerning the domain-specific, science identity is an individual's perception of being a science person (Chen & Wei, 2020). Individual recognition of themselves as a science person is influenced by several factors, including the confidence to perform as a scientist, recognition by others, and a strong desire to learn more about science and skills. Therefore, the researcher further defined competence/performance beliefs, interests, and external recognition as the three shaping constructs that work together to form science identity (Shein et al., 2019). Given the complexity of the construe of science identity, we first need to clarify science identity components and the relationships between components.

The components of science identity

The initial operational framework for science identity was proposed by Carlone and Johnson (2007), consisting of three sub-constructs: competence, performance, and recognition. Competence was defined as the individual having efficacy in understanding scientific knowledge in depth and perceiving its meaning (Carlone & Johnson, 2007). Performance refers to self-efficacy using the language and tools of science for scientific practices, such as communication with others and explaining the content of science (Kim & Sinatra, 2018). Recognition refers to whether one and others consider oneself as a scientific person (Carlone & Johnson, 2007).

Focusing on physical identity, Hazari et al. (2010) proposed that the interest should be added to Carlone and Johnson's (2007) framework. Interest refers to the degree of enjoyment of physical identity-related activities. In addition, Hazari et al. (2010) also redefined recognition as "recognition by others as being a good physics student". In short, "recognition" in Hazari's identity structure refers to external recognition. After empirical investigation, Hazari et al. (2010) further revised that the three sub-dimensions together constitute physical identity shaping: performance/competence, interest, and recognition. The reason is that adolescents' beliefs about performance and competence cannot be completely separated (Cribbs et al., 2015). Later, Hazari's physical identity structure has been widely applied in other fields (e.g., engineering identity, chemistry identity, and science identity) (Hosbein & Barbera, 2020a; Verdín, 2021). Meanwhile, "seeing oneself as a domain-specific person" (i.e., internal recognition by oneself) was used as a single indicator to measure students' overall feelings or holistic impression on domain-specific identity (Hosbein & Barbera, 2020b; Verdín, 2021). Therefore, this structure was utilized to guide the investigation of science identity in the present study.

The relationships between different components of science identity

Initially, competence/performance beliefs, interest, and external recognition were considered the basic shaping structures of identity, the holistic impression on identity was the focal structure, and the three basic structures together influenced the formation of the focal identity (Hazari et al., 2010). However, in subsequent studies, researchers have further identified more complex patterns of relationships in domain-specific identity indicators (Dou & Cian, 2021). Specifically, several studies found a significant predictive effect of interest and external recognition on the overall perception of identity, (Verdín, 2021). In addition, competence/performance beliefs are closely related to students' interests and external recognition, and competence/performance beliefs contributed to the holistic impression on identity through the mediating role of interest and external recognition (Dou & Cian, 2021; Verdín, 2021). This means that only those students who are confident in their competence and performance will be able to internalize others' recognition into forming a self-identity (Godwin et al., 2016). Also, boosting students' beliefs in understanding and becoming proficient in the domain will help students' interest increase and can support the formation of domain-specific identity (Fryer & Ainley, 2019; Godwin et al., 2016). The relationships between different indicators of identity are shown in Fig. 1.

Epistemological beliefs and their associations with science identity

Epistemological beliefs

Epistemological beliefs refer to students' beliefs about the nature of knowledge (i.e., what individuals believe knowledge to be) and the nature of knowing (i.e., how individuals acquired knowledge) (Green & Hood, 2013; Lee & Chan, 2018). The complexity of epistemological beliefs held by different individuals is different (Ogan-Bekiroglu & Sengul-Turgut, 2011). A growing body of research has been widely noted and discussed the importance of developing high-level epistemological beliefs on learning processes (e.g., the choice of learning approaches and cognitive strategies) and outcomes (e.g., academic achievement, learning motivation) (Choung et al., 2020). For example, Lin et al. (2012)

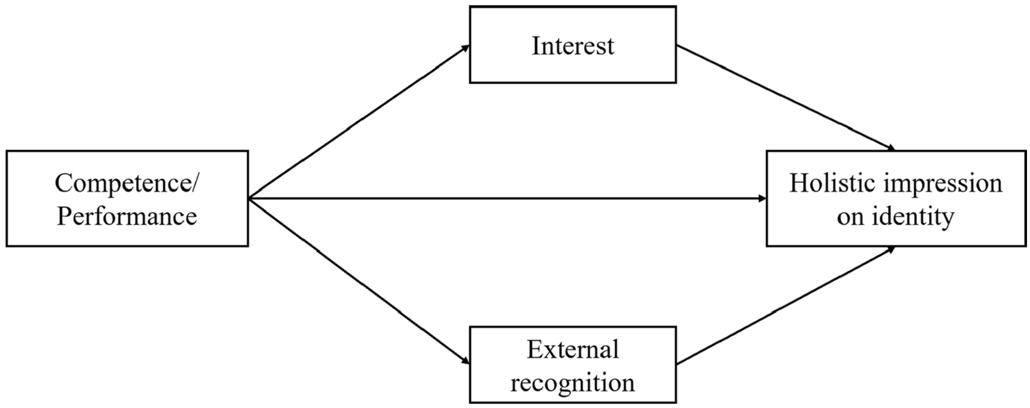

Fig. 1 The relationships between different indicators of science identity

found that students who had more complex epistemological beliefs (i.e., knowledge is uncertain, evolving, constructed by the brain–mind, and recognize the value of experimentation) tended to use deep learning strategies and have mixed motivation. Students who believed in the certainty of knowledge tended to use surface learning strategies and exhibited surface motivation.

Regarding the relationship between epistemological beliefs and identity, it has been confirmed that epistemological beliefs influence the development state of identity through the identity formation process (Krettenauer, 2005). Although science identity is a domain-specific identity and an important outcome of scientific learning, there is a lack of systematic research on whether epistemological beliefs could affect the shaping constructs of science identity to further enhance students' overall perception of science identity. Of note is that external recognition emphasizes the social component of identity formation (Godwin & Potvin, 2017). Conversely, epistemological beliefs belong to the cognitive system that primarily affects intra-individual factors (Bromme et al., 2009). In particular, epistemological beliefs affect the learning process and outcomes primarily by influencing students' understanding of the learning task and the knowledge to be acquired (Bromme et al., 2009). Therefore, it is reasonable to believe that epistemological beliefs do not have a direct effect on external recognition, but rather indirectly influence external recognition by enhancing students' competence/performance beliefs. Accordingly, we discuss below only the direct relationship between epistemic beliefs and interest and competence/performance beliefs.

The relationship between epistemological beliefs and competence/performance beliefs

Competence/performance beliefs are students' perceptions of the likelihood of understanding domain content knowledge and the ability to complete domain tasks (Verdín, 2021). Few studies directly examined the relationship between epistemological beliefs and competence/performance beliefs. However, self-efficacy and self-concept are two constructs that are closely related to competence/performance beliefs, the contribution of epistemological beliefs to self-efficacy and self-concept has been established extensively in a variety of settings.

Regarding the relationship between competence/performance beliefs, self-efficacy, and self-concept, a portion of researchers have argued that competence/performance beliefs encompass self-efficacy (i.e., self-perception about the ability to accomplish a specific task) and self-concept (i.e., the overall perception of self-competence in a discipline) (Robinson et al., 2020; Scherer, 2013). Some other scholars believe that competence/performance beliefs are similarly structured to self-efficacy and self-concept (Verdín, 2021). Either understanding suggests that the influence of epistemological beliefs on self-efficacy or self-concept could support an account of the relationship between epistemological beliefs and competence/performance beliefs.

Furthermore, self-efficacy and self-concept have been proven can be influenced by epistemological beliefs (Burns et al., 2018; Khine et al., 2020). For instance, Hofer (1994) surveyed 438 college students majoring in mathematics, the results indicated that those students with more sophisticated epistemological beliefs had higher self-efficacy and were more confident in their ability to perform well in mathematics. Similarly, within the scientific domain, Chen and Pajares (2010) also found that individuals with more complex epistemological beliefs are more confident in their learning abilities and successful completion of learning tasks. In addition, there is empirical evidence that epistemological beliefs in science are positively associated with self-concept (Urhahne, 2006).

The relationship between epistemological beliefs and interest

Interest is a relatively stable motivational characteristic defined by positive emotions and personal meaning in a specific learning domain (Brandmo & Bråten, 2018), while epistemological beliefs play an important role in understanding students' motivational constructs (Choung et al., 2020; Kizilgunes et al., 2009). Several studies have indicated positive correlations between epistemological beliefs and interest. Students with sophisticated epistemological beliefs have a strong desire for learning itself, rather than for external rewards such as compliments from teachers or a degree certificate (DeBacker & Crowson, 2006). They see themselves as constructors of knowledge and expect to obtain evidence to confirm or disprove their claims through scientific inquiry, while those individuals who placed more emphasis on rules of inquiry and evidence assessment were more likely to be interested in the learning domain (Strømsø & Bråten, 2009). Likewise, Kapucu and Bahçivan (2015) found that the more complex the epistemological beliefs of high school students, the deeper they were able to understand the importance of physics in their lives and society, and the higher their interest in the physics curriculum.

Combining the relationship between different indicators of science identity and the influence of epistemological beliefs on different indicators of identity as confirmed by previous studies, we can further construct a schematic representation of the relationship between epistemological beliefs and science identity (as shown in Fig. 2).

The mediating effect of reflective thinking on the relationship between epistemological beliefs and science identity

Bromme et al.'s (2009) findings suggested that in the latter stages of self-regulation learning, epistemological beliefs have a profound impact on learning only when reflective thinking is fully activated. Similarly, with science identity as a learning outcome influenced by epistemological beliefs, we wanted to explore whether reflective thinking plays an important role in the relationship between epistemological beliefs and science identity.

Reflective thinking is often stated as a key competency that students should possess (Sabariego Puig et al., 2020). John Dewey first clearly defined reflective thinking in 1933 and believed that one of the primary purpose of education should be to cultivate students' reflective thinking (Hong & Choi, 2011). Reflective thinking refers to an individual's active, continuous, and thoughtful consideration of any belief or assumed knowledge based on supporting reasons and held tendencies, as well as to further redraw conclusions (Dewey, 1933; Hong & Choi, 2011).

The relationship between epistemological beliefs and reflective thinking

There is a consensus that the development of epistemological beliefs is a prerequisite for enhancing reflective thinking (Feucht et al., 2017; Hyytinen et al., 2014). Reflective thinking could be developed in the process of completing learning tasks, while the complexity of

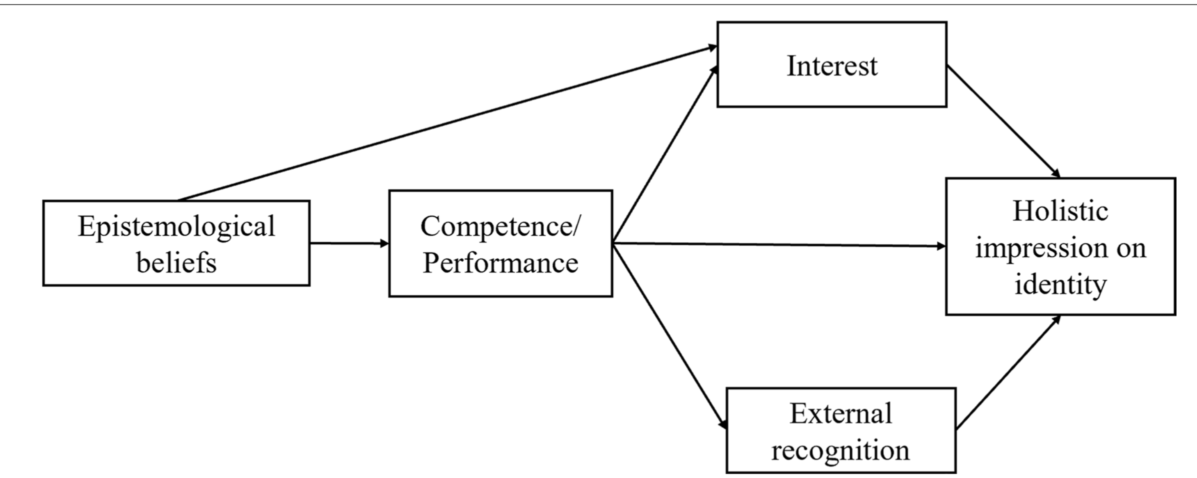

Fig. 2 The relationships between epistemological beliefs and different indicators of science identity

epistemological beliefs somehow determines students' thinking styles in the problem-solving process (Chan et al., 2011). Students who believe that knowledge is certain, completely objective, and can be obtained directly through expert lectures, usually do not question the knowledge taught by authority figures during the learning process (Phan, 2009). As a result, such students cannot apply and develop reflective thinking in the learning process but are accustomed to obtain answers directly from authority figures (Felton & Kuhn, 2007). In contrast, individuals with complex epistemological beliefs always believe that knowledge is interconnected, complex, subjectively constructed, and developed over time, as well as experts' opinions are not necessarily correct. Therefore, in the process of solving learning tasks, individuals tend to reflect on the validity of their previous views or experts' opinions in the context of specific situations, reasonably raise their questions, and conduct scientific investigations to obtain objective evidence (Greene & Yu, 2015). Ample evidence unraveled the relationships between individuals' epistemological beliefs and reflective thinking (Chi et al., 2021). For example, Phan (2008) showed the complexity of epistemological beliefs held by students significantly predicted their level of reflective thinking.

The relationship between reflective thinking and science identity

Regarding the relationship between reflective thinking and science identity, the value of reflective thinking in constructing learning meaning firstly determines it is essential for developing interest and competence/performance beliefs of science identity. Identity theory argues that an individual's identity is shaped by experience (Burke & Stets, 2009). Thus, students' learning experience regarding science is critical to the formation of science identity. Reflective thinking could help students to establish a strong connection between scientific knowledge and life experience in learning processes, to further perceive the meaning of science (Engelbertink et al., 2020). Understanding the meaning of science is helpful for students to have high competence/performance beliefs and interests, as well as be willing to act and think like scientists, which leads to students' insights on science identity and thus developing the science identity (Huvard et al., 2020).

Secondly, autonomy and self-regulation are key elements in triggering interest (Heddy et al., 2016; Hidi & Renninger, 2006; Krapp, 2005), while reflective thinking is a significant predictor of autonomy and a key aspect of self-regulation (Helle et al., 2013; Orakcı, 2021). Thirdly, individuals with reflective thinking could analyze the process of learning science more actively and rationally, as well as realize and examine their state and feelings about learning science from multiple perspectives. Therefore, they are more likely to perceive the value of being a science person, think rationally about the reasons for being a science person, and make efforts to do so.

In summary, epistemological beliefs are significant predictors of reflective thinking, and reflective thinking is positively related to constructs of scientific identity such as competence/performance beliefs and interest in a variety of ways. Accordingly, we can further propose that epistemic beliefs may influence science identity through

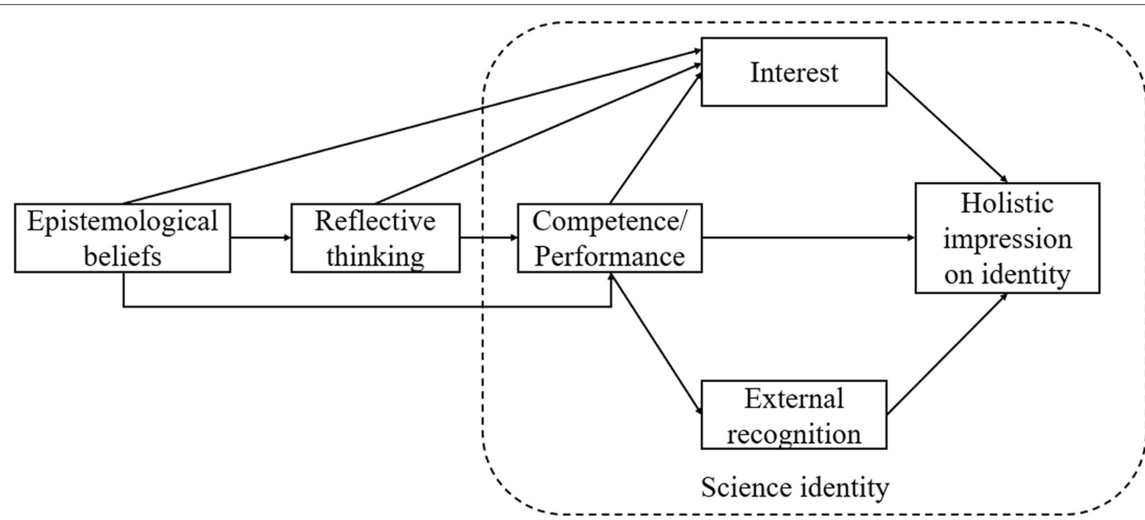

Fig. 3 The hypothesized model of the relationships between epistemological beliefs, reflective thinking, and science identity

the mediating role of reflective thinking (as shown in Fig. 3).

The present study

The study focused on investigating relationships between epistemological beliefs, reflective thinking, and science identity. Based on the aforementioned theoretical analysis, it is logical to suggest that both epistemological beliefs and reflective thinking have a positive influence on students' identity development (Boyes & Chandler, 1992; Engelbertink et al., 2020; Krettenauer, 2005). However, both epistemological beliefs and identity are domain-specific (Hofer, 2006; Robinson et al., 2019). What is missing from the previous research is the empirical investigation of close relationships among high school students' epistemological beliefs, reflective thinking, and identity within the field of science. Thus, the primary focal aim of this study is if the epistemological beliefs students hold about science, as well as their reflective thinking in science learning, have associations with their science identity.

In addition, previous research also has shown that the more complex the epistemological beliefs held by individuals have more predictive power on the level of reflective thinking. Accordingly, it is logical to further hypothesize that reflective thinking plays a mediating role in the relationship between epistemological beliefs regarding science and science identity. Therefore, the second purpose of this study is to examine whether epistemological beliefs about science indirectly influence science identity through reflective thinking.

As mentioned earlier, science identity consists of three sub-constructs (competence/performance beliefs, interest, and external recognition) that work together to shape students' overall perceptions of science identity. However, based on the constructions of science identity and analysis of previous theories, epistemological beliefs, and reflective thinking develop students' science identity primarily by influencing their cognitive processes (Berzonsky & Kuk, 2000; Boyes & Chandler, 1992). Therefore, this study does not examine the direct effects of epistemological beliefs and reflective thinking on external recognition. Based on the above, we first proposed the following research questions:

(1) Do epistemological beliefs and reflective thinking affect students' competence/performance beliefs or interests, respectively?
(2) Does reflective thinking play a mediating role in epistemological beliefs and competence/performance beliefs or interests?
(3) Do epistemological beliefs predict holistic impression on science identity through reflective thinking and competence/performance beliefs or reflective thinking and interest?

Furthermore, research findings on students' domain-specific identity showed that competence/performance beliefs influenced students' view of "I see myself as a domain-specific person" through the mediating role of interest and external recognition by others (Godwin et al., 2016; Verdín, 2021). Therefore, this study also wants to investigate whether epistemological beliefs and reflective thinking indirectly influence interest and external recognition through competence/performance belief, as well as further influence holistic impression on science identity. Specifically, the following research questions can be further formulated:

(4) Do epistemological beliefs contribute to a holistic impression on science identity via reflective thinking, competence/performance beliefs, and interest?
(5) Do epistemological beliefs contribute to a holistic impression on science identity via reflective thinking, competence/performance beliefs, and external recognition?

Combining the above five research questions, we constructed the specific hypothetical model shown in Fig. 3. In addition, previous research has provided evidence that there are gender differences in students' science identities (Alhadabi, 2021). The main purpose of this study was to clarify the relationship between the variables rather than gender differences. Therefore, gender was used as a control variable in this study.

Methods

Sample

A total of 544 students were recruited from two Chinese public schools. To find out the outliers, we converted all scores into standard z-scores and then removed 7 participants within the range of -3 to 3 as appropriateness criteria (Bakeman & Robinson, 2014). Students' ages varied 14–17 years old ($M = 15.36$, $SD = 0.597$). Of these students, 44.32% ($n = 238$) were male and 55.68% ($n = 299$) were female. These students had just completed their first year of senior schooling. In China, students take common science curriculums including physics, chemistry, biology, and geography in their first senior year. Consent was obtained from the parents and teachers of the students before the implementation of the survey. In addition, all students participated in the survey voluntarily.

The two schools represent model public high schools in Chinese municipalities and ordinary provinces. First, Chinese municipalities directly under the central government have important political, economic, scientific, cultural, and transportation status in the country, and their administrative status is the same as that of provinces, which have special characteristics. Therefore, we selected a high school from a municipality and a general province, respectively.

Second, the reasons for selecting the demonstrative high schools included two points. On the one hand, science-related experiences are the basic conditions and play a critical role in the development of science identity. Therefore, when testing the relationship between epistemological beliefs, reflective thinking, and science identity, we needed to select participants who had extensive science-related experience. The purpose is to avoid the objective condition of lack of science experience that leads to low science identity among students so that the results have value for countries and regions that attach importance to STEM education. Both schools selected offered STEM-related elective courses and provided a variety of learning resources. For example, teachers always take students to nature for scientific observation, organize science learning in museums, science and technology galleries, and university laboratories, as well as invite scientific experts in related fields to give science lectures to students. Both demonstrative high schools can provide students with rich STEM learning resources to enrich their STEM experience. On the other hand, demonstrative high schools have fully implemented the national education policy to promote the development of students' core literacy. At the same time, they actively carry out classroom teaching reforms, and all adopt constructivism as the basis for inquiry-based teaching, emphasizing students' initiative and autonomy in the process of knowledge construction. As a result, demonstrative high schools are widely recognized as having normative and representative in China and can serve as exemplars among all schools. Therefore, the results of the survey are also typical and representative of China.

In addition, this study used a stratified sampling method to draw subjects. We divided students in two schools into three levels according to academic achievement (high, medium, and low), and approximately 90 students from each level in each school were selected to participate in the survey. This ensures a diversity of participants.

Measures

All questionnaires in this study were derived from established questionnaires that already existed. The original questionnaires were in English and. Therefore, they were translated into Chinese and revised to ensure that they were readable by the participants in this study. To ensure the validity of the translation, Two PhDs in the field of education and a Ph.D. in the field of psychology jointly negotiated the translated questionnaires. In addition to this, to ensure the validity and reliability of the translated instruments, an exploratory factor analysis (EFA) and a confirmatory factor analysis (CFA) were conducted for each instrument in this study, as presented in the Results sections.

Epistemological beliefs

A questionnaire on epistemological beliefs was translated and revised according to Conley et al. (2004). The structure of epistemological beliefs were conceptualized as four sub-dimensions: source (i.e., the belief that knowledge is obtained from authority or actively constructed by oneself), certainty (i.e., the answer to the question is unique or more than one), development (i.e., the belief that knowledge is fixed or changeable), justification (i.e., beliefs about experimental evidence and how to prove knowledge) (Conley et al., 2004). Items are scored on a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). The justification dimension of the revised questionnaire contains 7 items, and the other three sub-dimensions contain 4 items, respectively.

Reflective thinking

Reflective thinking was evaluated using the reflection sub-scale taken from the Reflective thinking questionnaire (RTQ) developed by Kember et al. (2000), which includes four items. The items are on a five-point scale (1 = definitely disagree, 5 = definitely agree). A sample item includes "I often re-appraise my experience so I can learn from it and improve for my next performance".

Science identity

Based on the common definition structure of students' domain-specific identity by different researchers, science identity examined in this study consists of three sub-dimensions of shaping science identity (competence/performance beliefs, interest, external recognition) and a single indicator for students' overall feeling or holistic impression on science identity (I see myself as a science person). According to Engineering Identity Measures (EIM) (Godwin et al., 2016), we selected 12 items from Chen and Wei's (2020) Student Science Identity (SSI) questionnaire. All items were scored on a five-point Likert scale with a range from "strongly disagree" to "strongly agree".

Data analysis

The research procedure in the present study includes two phases. Firstly, an exploratory factor analysis (EFA), a confirmatory factor analysis (CFA), and Cronbach's

Alpha (α) test were conducted using SPSS 21.0 and AMOS 23.0 to provide evidence for the validity and reliability of each instrument. Secondly, structural equation modeling (SEM) was used to examine the relationships among epistemological beliefs regarding science, reflective thinking, and science identity.

According to Hair (2006), the total sample was randomly divided into two sub-samples for EFA analysis and CFA analysis, respectively, to ensure the robustness of the statistical results of this study. This study began with an EFA of sample I ($n = 269$) using SPSS 21.0 to ensure that each translated instrument was consistent with the original factor structure. After the initial deletion and restructuring of items in each instrument through EFA, a CFA was then performed on sample II ($n = 268$) using AMOS 23.0 to ensure that each instrument had good content validity (i.e., items were consistent with the purpose and content of the measure). After removing inappropriate items from the questionnaire based on EFA and CFA, each questionnaire and its sub-questionnaires were tested for Cronbach's Alpha (α) to ensure the reliability of each questionnaire.

For EFA, when KMO > 0.6 and the p-value of Bartlett's spherical test are significant, it indicates that exploratory factor analysis can be performed (Field, 2000). Regarding CFA, several indexes such as χ2/df, RMSEA, SRMR, and CFI were used for model fit evaluation (Browne & Cudeck, 1993; Schumacker & Lomax, 2010). According to Wang and Wang (2012), if the χ2/df value is below 5; both RMSEA and SRMR are less than 0.08; CFI, TLI, NFI, GFI, and IFI are all greater than 0.9, respectively, indicating that the model fit is within acceptable limits. In addition, when RMSEA and SRMR are less than 0.05, as well as CFI, TLI, NFI, GFI, IFI are all greater than 0.95, it means a close model fit (Schumacker & Lomax, 2010).

The direct and indirect relationships between the variables were tested by path analysis of structural equation modeling using AMOS 23.0 software. We first constructed hypothetical models based on theoretical analysis as shown in Fig. 3. And then, the SEM was used to analyze whether the data collected supported the hypothesized model. The degree of model fit was assessed in the same way as for CFA, through χ2/df, GFI, TLI, CFI, SRMR, and RMSEA. Further, the bootstrap method of bias-corrected percentages is widely accepted as one of the best methods for testing mediating effects (Edwards & Lambert, 2007; Preacher & Hayes, 2008). Therefore, the mediating effect between variables in the present study was tested by the 5000 bootstrap samples along with 95% confidence intervals. Indirect effects are significant if the 95% bootstrap confidence interval does not include 0 (Preacher & Hayes, 2008).

Results

Preliminary analysis

Descriptive statistics

The means and standard deviations of each measured variable are presented in Table 1. In addition, skewness and kurtosis values were examined for each variable using SPSS to test whether each variable satisfied a normal distribution. As shown in Table 1, all individual variables' skewness and kurtosis were fell within ± 3, confirming all variables satisfied the assumption of univariate distribution normality (Verdín, 2021; West et al., 1995).

Validity and reliability of the instruments

Epistemological beliefs For the results of EFA, the KMO was 0.903, and Bartlett's spherical test value was 2322.235, $p < 0.001$, indicating that the data were suitable for EFA. A total of four factors with eigenvalues greater than one were extracted, explaining a total variance of 62.250%. The factor loading values for each item were within the range of 0.483 ~ 0.784 and the commonalities values were in the range of 0.434 ~ 0.752. The CFA analysis results revealed the good validity of the questionnaire: $\chi^2/\text{df} = 1.398$; GFI = 0.930; SRMR = 0.045; RMSEA = 0.039; CFI = 0.966; IFI = 0.966; TLI = 0.972; NFI = 0.909. The Cronbach's α coefficient was 0.884, suggesting good reliability of the instrument.

Science identity The EFA results of modified SSI showed that the KMO was 0.900 and Bartlett's spherical test value was 2065.561 (p < 0.001). There are three factors with eigenvalues greater than 1, with a cumulative variance of 78.073%. In addition, all items ranged in 0.630 ~ 0.943 for commonalities and factor loadings ranged from 0.742 to 0.833. The results of the validation factor analysis were as follows, showing a good model fit: $\chi^2/\text{df} = 2.500$; GFI = 0.936; SRMR = 0.0443; RMSEA = 0.075;

Table 1 Descriptive statistics of measured variables

	Mean	SD	Skew	Kurt
SOU	3.78	0.82	− 0.31	− 0.41
CER	4.10	0.70	− 0.69	0.21
DEV	4.21	0.61	− 0.77	1.59
JUS	4.27	0.52	− 0.32	− 0.34
RT	3.98	0.60	− 0.49	1.18
Com/Per	3.62	0.81	− 0.42	0.53
ER	2.78	1.06	0.08	− 0.43
INT	4.01	0.76	− 0.80	1.48
HISI	2.96	1.21	− 0.02	− 0.76

EB epistemological beliefs, *RT* reflective thinking, *Com/Per* competence/performance, *INT* interest, *ER* external recognition, *HISI* holistic impression on science identity

CFI = 0.974; IFI = 0.974; TLI = 0.962; NFI = 0.957. The Cronbach's α coefficient for the overall questionnaire was 0.918. The Cronbach's α coefficient for the three sub-dimensions were 0.879, 0.963, 0.830, respectively.

Reflective thinking Reflective thinking is a single dimension containing four items. Only one factor was extracted from the EFA results, and the cumulative variance was 58.815% (KMO = 0.729; Bartlett's spherical test value = 287.175, $p < 0.001$). All items loaded ranged from 0.695 to 0.832 and the commonalities ranged from 0.478 to 0.692. The results of the CFA and Cronbach's α showed that the scale has good reliability and validity: χ^2/df = 1.245; GFI = 0.995; SRMR = 0.0212; RMSEA = 0.030; CFI = 0.998; IFI = 0.998; TLI = 0.993; NFI = 0.989; Cronbach's α = 0.722.

Structural equation model

The results of the structural equation model analysis for hypothetical model indicated a good fit (χ2/df = 2.271; GFI = 0.981; SRMR = 0.0397; RMSEA = 0.049; CFI = 0.985; IFI = 0.985; TLI = 0.971; NFI = 0.973). Figure 4 and Table 2 show the direct and indirect effects between the variables. As shown in Fig. 4, the epistemological beliefs regarding science were positively related to reflective thinking ($\beta = 0.33$, $p < 0.001$), interest ($\beta = 0.24$, $p = 0.001$), and competence/performance beliefs ($\beta = 0.13$, $p = 0.009$). Reflective thinking had positive significant effects on competence/performance beliefs ($\beta = 0.45$, $p < 0.001$) and interest ($\beta = 0.11$, $p = 0.002$). In terms of the relationship between the different dimensions within science identity, competence/performance beliefs positively predicted interest ($\beta = 0.50$, $p < 0.001$), external recognition ($\beta = 0.55$, $p = 0.001$), and students' holistic impression on science identity ($\beta = 0.13$, $p = 0.002$). Additionally, both external recognition ($\beta = 0.69$, $p = 0.001$) and interest ($\beta = 0.08$, $p = 0.017$) significantly supported students' holistic impression on science identity (i.e., I see myself as a science person), respectively.

Table 2 showed the mediating effects between the different variables. As can be seen in Table 2,

Table 2 Indirect effects of epistemological beliefs, reflective thinking, competence/performance, interest, external recognition, and holistic impression on science identity

Paths	β	SE	Bootstrap 95% CI	
			Lower	Upper
EB → RT → Com/Per	0.274	0.055	0.182	0.394
EB → RT → INT	0.064	0.026	0.022	0.124
EB → Com/Per → INT	0.113	0.039	0.035	0.189
EB → Com/Per → ER	0.174	0.062	0.051	0.294
EB → RT → Com/Per → INT	0.130	0.029	0.082	0.202
EB → RT → Com/Per → ER	0.200	0.041	0.131	0.292
EB → INT → HISI	0.056	0.027	0.012	0.119
EB → Com/Per → HISI	0.048	0.023	0.015	0.110
EB → Com/Per → INT → HISI	0.015	0.009	0.003	0.039
EB → Com/Per → ER → HISI	0.138	0.05	0.042	0.235
EB → RT → Com/Per → HISI	0.055	0.021	0.023	0.107
EB → RT → INT → HISI	0.009	0.005	0.002	0.022
EB → RT → Com/Per → INT → HISI	0.018	0.009	0.004	0.039
EB → RT → Com/Per → ER → HISI	0.158	0.033	0.103	0.236

EB epistemological beliefs, *RT* reflective thinking, *Com/Per* competence/performance, *INT* interest, *ER* external recognition, HISI holistic impression on science identity. If the 95% bootstrap confidence interval (Boot LLCIBoot ULCI) does not overlap with zero, the effect is significant

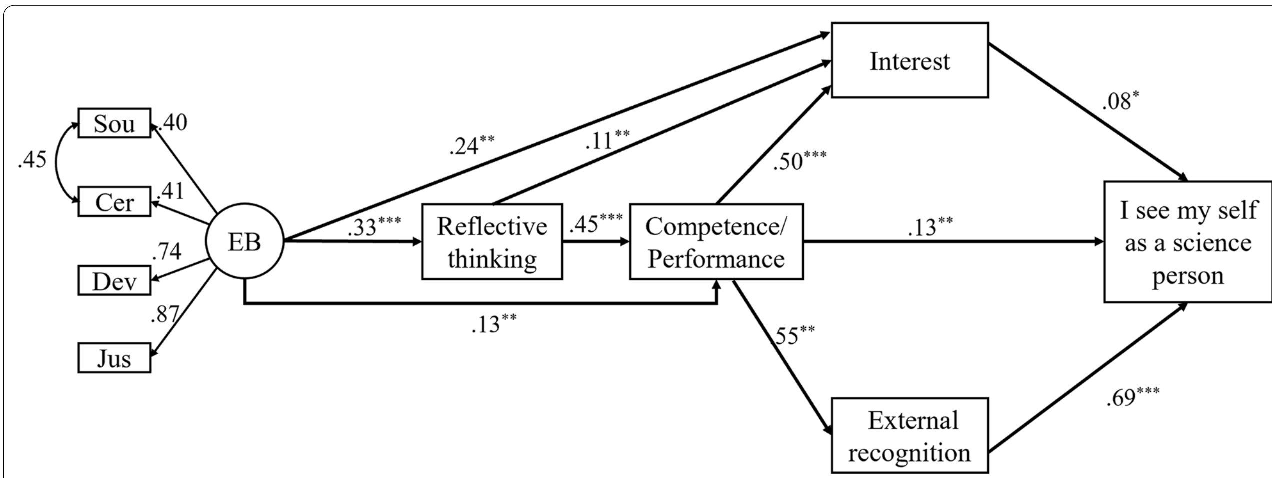

Fig. 4 Direct effects of epistemological beliefs, reflective thinking, competence/performance, interest, external recognition, and holistic impression on science identity. Note: ***$p < .001$; **$p < .01$; *$p < .05$

epistemological beliefs regarding science significantly influenced competence/performance beliefs and interests via reflective thinking with indirect effects of 0.274 (95% CI was 0.182–0.394) and 0.064 (95% CI was 0.022–0.124), respectively. Competence/performance beliefs also play a partial mediating role in the relationship between epistemological beliefs and interest (β = 0.113, 95% CI was 0.035–0.189). In addition, the pathway from epistemological beliefs to students' interest via the chain role of reflective thinking and competence/performance beliefs was significant, with the effect of 0.130 (95% CI was 0.082–0.202). And the epistemological beliefs could significantly influence students' external recognition through the mediating role of competence/performance beliefs with the effect of 0.174 (95% CI was 0.051–0.294), as well as chain mediation of reflective thinking and competence/performance with an effective value of 0.200 (95% CI was 0.131–0.292).

Further, our results verified that epistemological beliefs significantly predicted students' holistic impression on science identity through eight distinct pathways, the results were as follows: the indirect effects through either interest or competence/performance beliefs were 0.056 and 0.048 (95% CI were 0.012–0.119 and 0.015–0.110); the chain mediating effect of competence/performance beliefs and interest was significant (β = 0.015, 95% CI was 0.003–0.039); the mediating effect through competence/performance beliefs and external recognition was significant, and the path coefficient was 0.138 (95% CI was 0.042–0.235); epistemological beliefs weakly and significantly predicted holistic impression on science identity through reflective thinking and interest, with the effect of 0.009 (95% CI was 0.002–0.022); reflective thinking and competence/performance play a chain mediating role in the relationship between epistemological beliefs and holistic impression on science identity, with the effect of 0.055 (95% CI was 0.023–0.107); the multiple mediation effect of epistemological beliefs → reflective thinking → competence/performance → interest → holistic impression on science identity was 0.018 (95% CI was 0.004–0.039); the effect of epistemological beliefs → reflective thinking → competence/performance → external recognition → holistic impression on science identity was 0.158 (95% CI was 0.103–0.236).

Discussion

Epistemological beliefs have been shown to have a significant impact on domain-general identity (Boyes & Chandler, 1992), while research also indicated that reflective thinking was a key element in influencing an individual's professional identity (Engelbertink et al., 2020). These suggest that there is an inextricable relationship between epistemological beliefs, reflective thinking, and identity. It is worth noting that both epistemological beliefs and identity are domain-specific. For adolescents, science identity is widely recognized as a key domain-specific identity to develop in their learning process, as well as epistemological beliefs regarding science and reflective thinking play an important role in students' learning. However, there is still a lack of empirical research on whether epistemological beliefs regarding science and reflective thinking support the development of high school students' science identity. In addition, previous studies indicated the gender differences in science identity among students in STEM (Williams & George-Jackson, 2014). Therefore, this study aims to explore the associations between epistemological beliefs about science, reflective thinking, and science identity after controlling for the impact of gender.

Relationship between epistemological beliefs, reflective thinking, and science identity constructs

The result indicated that epistemological beliefs directly supported students' competence/performance beliefs interest and reflective thinking in science. A similar result finding was found in Renken et al. (2015) research that students' psychology-specific epistemological beliefs influenced their interest in psychology courses. Phan's (2008) investigation also supports the finding that epistemological beliefs were significant predictors of reflective thinking. In addition, as expected, reflective thinking had a significant positive relationship with key components of science identity such as interest and competence/performance belief. Only few studies investigated the direct relationship between reflective thinking and university students' professional identity, and their results are consistent with the present study (Bowen, 2016; Engelbertink et al., 2020). And Tracey and Hutchinson (2016) found that embedding reflective writing instruction in design education can facilitate the exploration and formation of professional identity among college students. Therefore, in conjunction with the results of this study, embedding the training of students' reflective thinking in STEM education may be beneficial to the development of high school students' STEM identity.

Further, the findings showed that the three shaping constructs of science identity (i.e., interest, competence/performance beliefs, and external recognition) were significant variables for predicting students' holistic impression on science identity. The results of previous studies showed that interest and external recognition have a positive and sufficient impact on university students' STEM identity (including math identity and engineering identity), in alignment with the results of this study (Godwin & Kirn, 2020; Godwin et al., 2016). However, there are inconsistent findings from previous studies regarding the relationship between competence/performance beliefs and students' holistic impression on science identity. A portion of the research supports the findings of the present study (Robinson et al., 2018; Robnett et al., 2015). For example, the findings of both Chemers et al. (2011) and Robnett et al. (2015) suggested that students' self-efficacy directly supported students' science identity, while self-efficacy is considered a key contributor to competence and performance beliefs (with a significant overlap between the two) (Verdín, 2021). Meanwhile, some results showed that competence/performance beliefs alone do not affect students' overall perception of identity. But through the mediation of interest or external recognition, the effect becomes positive and significant (Godwin & Kirn, 2020; Godwin et al., 2016).

The conflict may be caused by the different survey respondents and the field of study. The survey respondents of previous studies were university students in the field of engineering who had already chosen a specific field based on their learning experience within different disciplines and were pursuing further professional studies. As a result, university students will have a deeper and more systematic understanding of a specific field they have chosen than high school students. Further, they could redefine whether they are really interested in the field based on its essential characteristics. This may result in some university students who with a deep understanding of their major, having less interest in a specific domain than they were in high school. This further leads to a lower perception of domain-specific identity despite their having high competence/performance beliefs of the major.

In contrast, high school students need to study a variety of disciplines and compare their experiences in multiple disciplines to make a final choice of major. High school students were more likely to develop an identity with disciplines that had high competence/performance beliefs (Patrick et al., 2010). High school students also have less in-depth knowledge of the discipline and the resulting interest may not be as clear and stable as that of university students. Therefore, the effect of high school students' competence/performance beliefs on domain-specific identity may be more significant than university students. In addition to this, students know less about the engineering field than the science field before they enter university (Godwin et al., 2016), so university students' interests have a greater impact on engineering identity than science identity. In addition, interest in engineering is also likely to vary more than interest in science. This means that research on STEM identity needs to be tailored to students in different subject areas and educational contexts, so those appropriate strategies can be adopted to effectively help different students develop their STEM identities.

In addition to direct effects, epistemological beliefs can also have indirect effects on interest and competence/performance beliefs through reflective thinking. Consistent with previous research, individuals who hold higher levels of epistemic belief development have higher levels of reflective thinking and situational judgment (King & Kitchener, 2004). This further implies that individuals with higher levels of epistemological beliefs are more able to activate reflective thinking to make their judgments about real and ill-structured STEM problems, thus could perform better on STEM tasks and develop a deeper understanding of the meaning of STEM learning (Akpur, 2020; Ghanizadeh, 2016; Lodewyk, 2007), as well as therefore increase students' interest and competence/performance beliefs.

As pointed out by Godwin et al. (2016), competence/performance beliefs, interest, and external recognition are the key conditions for individuals to recognize themselves as a STEM person. Also, the present study has demonstrated that epistemological beliefs and reflective thinking have direct effects on interest and competence/performance beliefs, as well as have indirect effects on external recognition and interest through competence/performance beliefs. Based on these findings, it is reasonable to hypothesize that epistemological beliefs contribute to enhancing individuals' perceptions of themselves as a science person through reflective thinking, as well as the three shaping constructs of science identity. As we expected, the results showed that epistemological beliefs significantly influenced the holistic impression on science identity through eight indirect pathways that included reflective thinking, competence/performance beliefs, interest, and external recognition.

It is worth noting that the total indirect effect generated by the eight paths was 0.497, in which the two most significant paths (epistemological beliefs → competence/performance beliefs → external recognition → holistic impression on science identity and epistemological beliefs → reflective thinking → competence/performance beliefs → external recognition → holistic impression on science identity) accounting for 60%. Similarly, Godwin et al. (2016) found that external recognition has twice the impact on overall perceptions of identity as interest, while individuals are more likely to internalize external recognition to influence only when they perceive themselves to be competent.

Practical implications for education

The findings of this study provide feasible solutions and pathways for teachers to enhance the science identity of high school students. As found in the study, increasing the complexity of epistemological beliefs held by students can facilitate students' interest in learning science and acquiring scientific knowledge, which can further enhance their overall perception of science identity. When students perceive scientific knowledge as uncertain, requiring constant revision, and refinement through scientific inquiry, they are more willing to explore the principles behind scientific phenomena through independent inquiry, developing curiosity and a sophisticated appreciation for science, which helps students maintain or enhance their interest in learning science. Conversely, students who believe that knowledge is certain and can be acquired quickly, have difficulty developing and maintaining an interest in science (Ricco et al., 2010).

However, to enhance students' science identity in a comprehensive and multidimensional way, it is necessary not only to improve their epistemological beliefs, but also to develop their reflective thinking. The reason is that epistemological beliefs have twice the indirect effect on competence/performance beliefs through the mediating role of reflective thinking than the direct effect, whereas competence/performance beliefs are important for students to internalize the external recognition and enhance their interest in learning.

Scientific inquiry can be seen as an effective learning approach for students to improve their epistemological beliefs about science, enhance their reflective thinking skills and further strengthen their perception of science identity and STEM identity. Firstly, scientific inquiry learning emphasizes students formulate scientific questions by observing phenomena in their lives, designing experimental solutions by themselves, and to provide own possible explanations for the questions (Alake-Tuenter et al., 2012; Lin et al., 2019). This contributes to the students' autonomy perception and facilitates the understanding that science concepts were constructed by the individual based on experiences, thus enabling students to develop complex epistemological beliefs (Peffer et al., 2015; Zhao et al., 2021).

Next, current STEM instruction and science education both emphasize scientific inquiry in real-world contexts, and these real-world problems often are ill-structured and have multiple different solutions. Students with complex epistemological beliefs can further communicate and debate problem explanations or problem solutions during the inquiry process, reflect on their inquiry process and what they have learned, and attribute reasons for their success or failure (Alake-Tuenter et al., 2012; White & Frederiksen, 1998). Sound reflection not only promotes a deeper and more general understanding of the science learning process, but also helps students to develop correct and positive beliefs about their competence (Abd-El-Khalick et al., 2004). In addition, the authenticity of the context can help students make connections between different disciplines and their lives during scientific inquiry to understand the meaning of learning (Peffer et al., 2015), as well as help them make connections between disciplines and understand the need for interdisciplinary learning (ElSayary, 2021), thus enhancing their sense of science identity and STEM identity. Hughes et al. (2013) also suggested that authentic STEM activities are an effective means of enhancing the relevance of STEM learning to students' lives and improving STEM identity.

At the same time, teachers should take care to provide support and encouragement to students in the learning process and guide them to make reasonable comments and praise others. As presented in the results of this study, approval from others, such as teachers, peers, and parents, had a significant and large impact on students' perceptions of science identity. Likewise, according to previous studies, gender-based and trait-based stereotypes can negatively affect students' STEM interests, identity, career choices, and so on (Starr, 2018). This suggests that the recognition of students by teachers and parents, among others, is critical to students' participation in STEM learning and careers.

Limitations and future work

Although this study provides a possible pathway for developing high school students' science identity, there are some limitations to this study. Firstly, this study was conducted on Chinese students only. Students' epistemological beliefs, reflective thinking, and science identity may be different in other countries due to a variety of factors such as teaching styles and education contexts. Therefore, the results of this study cannot be directly generalized to other countries, but they can still provide possible approaches for developing students' science identities in different countries. Later, we can further investigate students in different countries and analyze their characteristics. On the other hand, the students in this study were from schools with the middle and upper levels of teaching quality in China, and there is a lack of investigation of students with lower quality teaching.

Second, the data in this study were obtained from students' self-reports, which may create bias and threaten internal validity. In future studies, on the one hand, parent and teacher evaluations of students can be integrated to obtain more objective conclusions. On the other hand, we can combine classroom observations and interviews to gain a more comprehensive and deeper understanding of students' science identity.

Third, the present study lacked contextual information about parents' jobs, parents' perceptions of scientific knowledge, and stereotypes, which may also influence students' epistemological beliefs and scientific identity. For example, studies have shown that STEM stereotypes can have a significant impact on STEM identity (Starr, 2018). Therefore, contextual information should also be included in SEM in future studies.

Conclusion

Based on previous theoretical and empirical studies, this study constructed a hypothetical model to investigate the relationship between epistemic beliefs, reflective thinking, and science identity among high school students. According to the analysis results of SEM, the following conclusions can be drawn: first, epistemological beliefs and reflective thinking had direct and significant effects on interest and competence/performance beliefs, which are shaping constructs of science identity; Second, reflective thinking mediated the relationship between epistemological beliefs and science identity. Specifically, epistemological beliefs support high school students' competence/performance beliefs and interests through the mediating role of reflective thinking. Further, epistemological beliefs influenced students' holistic impression on science identity through multiple paths, which include reflective thinking, competence/performance beliefs, interest, and external recognition.

Research design

The present study focused on investigating relationships between epistemological beliefs, reflective thinking, and science identity. Based on previous studies, it is logical to suggest that epistemological beliefs about science and reflective thinking contribute to the development of science identity. However, few empirical studies have focused on the relationship between these three variables. Therefore, using structural equation modeling, the present study constructed two models to explore the relationship between epistemological beliefs, reflective thinking, the three scientific identity shaping structures (interest, competence/performance beliefs, external recognition), and the holistic impression on science identity (a single indicator). In addition, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were conducted for all the measurement instruments used in this study to ensure the reliability and validity of the measurement instruments.

Abbreviations

EB: Epistemological beliefs; RT: Reflective thinking; Com/Per: Competence/performance; INT: Interest; HISI: Holistic impression on science identity; 95% bootstrap CI: 95% Bootstrap confidence interval; SEM: Structural equation modeling; STEM: Science, Technology, Engineering, and Mathematics; EFA: Exploratory factor analysis; CFA: Confirmatory factor analysis; KMO: Kaiser–Meyer–Olkin; CFI: Comparative fit index; TLI: Tucker–Lewis index; GFI: Goodness-of-fit index; SRMR: Standardized root mean square residual; RMSEA: Root mean square error of approximation.

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Author contributions

XG contributed to data collection, analysis, and interpretation, and writing the manuscript. XH provided insights, data interpretation, and revising the manuscript. WD and XJ contributed to data collection. SX contributed to data interpretation. WH contributed to the design of the study and revising the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets analyzed during the current study are not publicly available due to the request made in the consent forms issued to participants.

Declarations

Ethics approval and consent to participate

This study gained ethical approval from the Ethics Committee of the Academic Committee of the Ministry of Education of Key Laboratory of Modern Teaching Technology, Shaanxi Normal University in China. And participants were provided informed consent. All the students volunteered to participate in the study with no additional reward.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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