Disciplinary and Interdisciplinary Science Education Research

RESEARCH Open Access

Effects of professional development program on primary science teachers' ICT use in China: mediation effects of science teachers' knowledge, beliefs and instructional practice

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Abstract

Faced with international science and technology competition, strengthening information, communication, and technology (ICT) use has become the core goal of science education. Many studies have revealed that teachers' professional development programs could influence ICT use. However, whether the relationship could be mediated by teachers' knowledge, beliefs, and instructional practice remains unclear, especially in the context of China. Based on the Sociocultural Model of Embedded Belief Systems, a hypothesized model from teachers' professional development to ICT use that meditated by science teachers' knowledge, beliefs, and instructional practices was constructed. With the Structural Equation Model (SEM) method, 131,134 Chinese primary science teachers were surveyed to detect the interrelationships among the factors in the model. The path analysis revealed that: (1) Science teachers' professional development has not positively influenced ICT use, while science teachers' knowledge, beliefs, and instructional practices could significantly influence science teachers' ICT use; (2) Science teachers' knowledge, beliefs, and instructional practices not only respectively play a mediating role but also play a chain mediating role in the process of teachers' professional development influencing ICT use.

Keywords Primary science teachers, Teachers' professional development, Teachers' knowledge and beliefs, Instructional practices, ICT use

Introduction

In the face of fierce international competition in science and technology, strengthening the training of science and technology innovation reserve talents has become the core goal of science education. Many countries have invested considerable resources in information and communication technologies, or ICT (Bybee, 2013; Luu & Freeman, 2010; DeWitte & Rogge, 2014). Over the last decade, ICT has been widely used in the classroom, developing a series of technical tools and resources that can be used to create, share, store, and manage information. Therefore, the ICT use of teachers was a basic literacy for they adapt to the development of the information and intelligent age, and their attitude toward ICT use also influenced their students' intention to use ICT. Within a panorama of growing concern for digital training, many countries have designed their draft ICT standards for initial and ongoing teacher training. For example, in 2014, China published the ICT competence guideline for teachers emphasizing teacher training and digital literacy.

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Specially, China has further promulgated the Education Informatization 2.0 Action Plan, the National Education Digitalization Strategy Initiative, and the New Era Basic Education Strong Teachers Plan, all of which emphasized strengthening the digital practice of primary and secondary school teachers, and carried out a variety of types of teacher professional development training programs. Generally, Professional Development (PD) was considered to be a key component in helping teachers enhance and develop their ICT use (Ertmer et al., 1999), especially the "reflective thinking and instructional design" in the program training, which can significantly improve pre-service teachers' ICT use (Hsu & Lin, 2020). Several studies have also revealed that teachers' ICT use was significantly related to their role of beliefs about scientific knowledge (Bahcivan et al., 2019; Ifinedo et al., 2020) and their years of teaching experience (Jang & Tsai, 2012). On May 26, 2022, China's Ministry of Education issued the Notice of the General Office of the Ministry of Education on Strengthening Primary School Science Teacher Training, which aimed to strengthen the supply of highly qualified and specialized pre-primary school science teachers at the undergraduate level, improve the level of science education, and solidify the cultivation of innovative talents. Based on this background, this study systematically explored the relationship between the professional development of Chinese primary science teachers and their intention to use ICT by collecting data from 131,134 primary science teachers in 31 provinces of China, and deeply revealed the mechanism of the mediating role of teachers' knowledge, beliefs and instructional practices, in order to provide critical evidence and factual basis for understanding the Chinese primary science teachers' use of ICT.

Literature review

ICT use reflects individuals' perceptions of ICT and their willingness to use it, and many studies have revealed that teachers' ICT use could be influenced by various factors, which include teachers' background information, teachers' knowledge and beliefs, teachers' instructional practices, and teachers' professional development program (Hu et al., 2021; Fernández-Batanero et al., 2022; Kim et al., 2013; Agyei & Voogt, 2011). Teachers with adequate knowledge of ICT, constructivist pedagogical beliefs, and extensive teaching experience tended to perform better in ICT integration and use (Akram et al., 2022), while teachers who have received frequent ICT training also tend to perform better in ICT use and digital application (Méndez et al., 2022). Additionally, in order to examine the multiple reciprocal interactions between science teachers' motivation, knowledge, and skills as well as a particular instructional practice, a framework of the Sociocultural Model of Embedded Belief Systems was conducted by Jones and Carter (2007). Therefore, we will begin with a systematic review of the relationship between teachers' knowledge, beliefs, instructional practices, professional development, and ICT use. Subsequently, we will also briefly present some contextual information about PD on ICT use for primary science teachers in China.

The impact of teachers' professional development on the ICT using

In recent decades, many studies have revealed that the teachers' professional development programs were closely linked to teachers' digital competence and intention to use ICT (Hu et al., 2021; Fernandes et al., 2022; Hsu & Lin, 2020). Hu et al. (2021) showed that ICT application in teachers' professional development could provide teacher development resources, create learning opportunities, and even shift to an equal relationship between teachers and students by systematically reviewing empirical research. Fernández-Batanero et al. (2022) provided an overview of the research on teachers' professional training related to digital competence, and they revealed that most studies presented a lack of teacher training and insufficient ICT training by Meta-analysis. Additionally, teacher professional development programs with different technology tools and digital resources could facilitate science teachers' use of ICT along with their inquiry, constructivist, and conceptual instructional practices (Fernandes et al., 2022). Although teachers' professional development was beneficial to improving instructional practice, it was often insufficient to change teachers' instructional practices if the training program was a one-time, short-term workshop and demonstration (McConnell et al., 2012). In addition, a study also found a significant positive correlation between mathematics teachers' proficiency in using ICT and the frequency with which they applied computer-assisted instruction and intelligent boards, and some suggestions were demonstrated that teachers' ICT use could also be enhanced through in-service training activities (Birgin et al., 2020). Furthermore, Hsu and Lin (2020) also explored the effects of six training strategies (i.e., role modeling, reflection, instructional design, collaboration, authentic experience, and continuous feedback) on preservice language teachers' perceived technology knowledge and their attitudes toward technology integration and revealed that "reflection and instructional design" had the highest positive impacts on these preservice teachers' ICT knowledge and attitudes. In sum, teachers' professional development programs, which included some teachers' ICT training courses and some ICT supply equipment, could significantly influence teachers' attitudes toward ICT use.

The impact of teachers' knowledge, beliefs and instructional practices on the ICT using

Teachers' knowledge and beliefs could significantly influence their ICT use. Some studies revealed that teachers' epistemological and pedagogical beliefs were key factors that influenced their attitudes toward ICT use (Kim et al., 2013; Liu et al., 2011; Ifinedo et al., 2020). For example, Kim et al. (2013) found that teachers with constructivist pedagogical beliefs tended to be more inclined to integrate ICT into their instructional practice than those with teacher-centered pedagogical beliefs. Through a survey of 1139 Taiwanese junior high school teachers, Liu et al. (2011) also found that teachers who hold student-centered beliefs were more likely to apply ICT in their inquiry activities, and their intentions toward technology were often influenced by external factors such as ICT equipment, student achievement, and government policy supports. Furthermore, a study showed that technical knowledge, pedagogical knowledge, and technology integration knowledge can also directly influence teachers' ICT integration, while teachers' gender, age, years of teaching experience, and class size can also significantly influence ICT use (Ifinedo et al., 2020). With the method of structural equation model, Koh et al. (2013a) indicated that the formation of TPACK (Technological pedagogical content knowledge) of teachers could be directly influenced by technological knowledge and pedagogical knowledge, and this knowledge could contribute to the development of technological pedagogical knowledge and technological content knowledge, which further formulated to the teachers' TPACK. Subsequently, based on the behavioral planning theory, Habibi et al. (2023) further explored the relationship between teachers' knowledge/beliefs and the integration of information technology during pre-service teachers' practices in Indonesia, and the study revealed that beliefs were more important in influencing behaviors related to technology integration than their knowledge. Overall, teachers' attitudes and intentions toward ICT could be influenced by their teachers' knowledge and beliefs.

In addition to the direct influence of teachers' knowledge and beliefs, many studies also revealed that the teachers' years of teaching experience and instructional practices still influence their intention to use ICT. For example, Jang and Tsai (2012) have indicated that older teachers were more aware of the role of ICT and were more likely to apply ICT to their teaching. Agyei and Voogt (2011) indicated that lack of training in acquiring knowledge of ICT integration and opportunities for teaching practice were the most influential factors influencing the integration and application of ICT among mathematics teachers in Ghana. Kreijns et al. (2013) also explored internal and external factors that affect teachers' ICT use based on the comprehensive model of behavioral theory and found that teachers' experience of technology integration was often seen as one of the critical factors influencing teachers' ICT use. Similarly, Ertmer and Ottenbreit-Leftwich (2010) also emphasized that providing enough opportunities to implement new practices and receive feedback from technology-intergrade teaching practices could change per-service teachers' existing knowledge, self-efficacy, pedagogical beliefs related to ICT, and their intention to use ICT. The reason for that was mainly because ICT expands the space for teachers to apply teaching strategies, methods, and various teaching activities, providing teachers and students with multiple opportunities for interaction and communication (Chen et al., 2021). Some strategies, such as tutor modeling and hands-on exploration of ICT tools, appeared to be more advantageous for fostering technological knowledge and technological pedagogical knowledge of pre-service teachers (Koh & Divaharan, 2013b). Additionally, Uluyol and Şahin (2016) also investigated primary teachers' motivators for using ICT and demonstrated that lack of time for ICT training, lack of ICT pedagogical training, and lack of experience in applying ICT skills were the most influence factors in increasing the level and quality of ICT usage in classrooms. Overall, it was clear that ICT use was closely related to teachers' instructional practices, indicating that the general pedagogy, disciplinary pedagogy, and teacher-student interaction instruction employed by teachers may all directly impact ICT use.

Mediating effects of teachers' knowledge, beliefs and instructional practices in teachers' professional development and ICT use

Excerpts for teachers' knowledge, beliefs, and instructional practices directly influence ICT use, and these variables can also play an essential mediating role in the influence of teachers' professional development on their ICT use.

Firstly, the knowledge and beliefs possessed by teachers may play significantly mediated roles in the relationship between teachers' professional training and their intention to integrate ICT into the classroom. For example, Ertmer and Ottenbreit-Leftwich (2010) emphasized that teachers eventually integrated computers into classroom instruction were powerfully mediated by their technology knowledge, pedagogical integration knowledge, and interrelated belief systems about learners and technology in the specific context of teachers' professional development. With the method of structure equation model, Taimalu and Luik (2019) also indicated that knowledge of technology had a direct effect on technology integration, while beliefs about the value of technology could indirectly influence technology integration, and pedagogical knowledge had a significant total effect on technology integration. Campbell et al. (2014) further explored the

time-lapse changes in science teachers' pedagogical orientations and technology-enhanced beliefs in a professional training program, and they revealed that science teachers were more likely to hold student-centered views of teaching, understand more complex manifestations of beliefs about scientific knowledge, shown stronger technology-enhanced beliefs and demonstrated high level of willingness to use ICT.

Secondly, instructional practices also play an important role in the relationship between teachers' professional development programs and their intention toward ICT use. Brown and Warschauer (2006) revealed that integrating ICT training into pre-service teachers' curricular practices (rather than simply teaching ICT knowledge or skills) could increase pre-service teachers' intentions to use ICT. Wu et al. (2022) explored the relationship between ICT training for teachers and the use of digital educational resources (DERs), and they found that the total number of hours, type, and subject matter of ICT training attended by teachers had a positive effect on teachers' use of DERs. In particular, teachers who had attended and practiced ICT courses were more effective in teaching with technology tools and more likely to choose constructivist teaching beliefs than those teachers who had not attended ICT training (Winzenried et al., 2010). Hughes (2005), in addition, also found that when teachers' learning experiences and knowledge were focused on technology with no connections to their content areas, they used less innovative technology-supported pedagogy during their technology professional training programs. Hence, teachers' instructional practices may play an important mediated role around their teachers' professional ICT training programs and their intention toward ICT use.

Thirdly, several studies have confirmed that significant interaction effects exist between teachers' instructional practices and teaching beliefs (Fives & Gill, 2015; Pajares, 1992). For example, Deng et al. (2014) found that teachers' epistemological beliefs and pedagogical theories can significantly influence their intention to apply ICT, and the epistemological beliefs held by teachers can also indirectly influence ICT use through teachers' constructivist pedagogical practices. The study of Tondeur et al. (2017) also demonstrated that teachers' beliefs would significantly affect their information technology integration through teaching practices, and the intention to apply ICT into their teaching has become one of the necessary teaching skills in the 21st century. Therefore, teachers' knowledge and beliefs may act indirectly through pedagogical practices in the process of ICT pedagogical application in the classroom.

Research context: the challenge of primary science teachers' professional development and their intention to use ICT in China

In order to promote the development of education informatization in the 21st century and cultivate primary and secondary school teachers' digital competence, China, a socialist country, attaches particular importance to the balanced information infrastructure and digital resources of urban and rural teachers with equipment much ICTs, launched a series of teacher training programs for rural teachers (Chen & Zhi, 2018). However, the content focus, total contact time, and frequency of teachers' engagement within the PD presented lower and unbalanced, especially for Chinese primary science teachers.

Currently, China has adopted both centralized and decentralized training to carry out professional development training, which was mainly implemented by educational governments and involves training courses that include professional concepts (professional ethics, professionalism), expert knowledge of teaching (subject knowledge, pedagogical content knowledge, and general knowledge), and professional competence (instructional design, instructional evaluation, research, the use of educational technology, classroom management, etc.) (Hu & Shou, 2018). Although ICT has been incorporated into professional training programs, the ICT use of Chinese primary science teachers provided an interesting case study.

Firstly, there was insufficient provision of science courses, and science courses were often regarded as marginal subjects in primary schools in China. The number of periods of science in compulsory education in China has been fixed for Grades 3–6, while science lessons occupied only 2–3 h per week of approximately 30 h of whole instruction per week. Additionally, according to a survey of western and northern rural schools in Guangdong Province (Zhang, 2015), science classes in most schools are insufficient: 46.7% of schools have an hour per week, and 7.6% do not have any science.

Secondly, the degrees or academic backgrounds of primary science teachers in China often do not correspond to the curricula that they have been trained in, and teachers with backgrounds in liberal or arts disciplines (non-science or engineering) account for the majority of primary science teachers. For example, a large-scale survey collected from 31 Chinese Provinces revealed that only 27.5% of primary science teachers had a science background, while teachers with liberal or arts background degrees dominated 72.5%, especially those majoring in Chinese Language and Literature (23.6%) far exceeding the proportion of those majoring in other majors (Zheng et al., 2023).

Thirdly, along with the emergence of AI and big data technologies, the Chinese government has placed special

emphasis on enhancing the digital competence of primary and secondary school teachers through professional development programs. For example, in 2018, Ministry of Education issued "the Action Plan for the Revitalization of Teacher Education (2018–2022)", which aimed to make full use of new technologies and methods (such as cloud computing, big data, virtual reality, artificial intelligence, etc.) to promote the construction and application of information teaching service platforms for teacher education, so as to accomplish the "Internet + Teacher Education" innovation action.

Overall, whether primary science teachers in marginalized disciplines would apply ICT in their classrooms and the contradiction between their degree backgrounds and the curricula they have been exposed to would influence the effectiveness of their professional training were still unclear. Among many research efforts on teachers' digital competence, exploring the relationship between professional development and the ICT use of K-12 teachers in China is lacking. Therefore, we would focus on exploring the impact of teacher professional development programs on primary science teachers' ICT use in the context of Chinese culture and to further analyze the mediating roles of teachers' knowledge, beliefs, and pedagogical practices in the pathway between teachers' professional training and their intention to use ICT.

Research questions

Although many studies have reported the relationship among teachers' beliefs, knowledge, practices, teacher professional development, and their ICT use, the effects of those factors seem to not have reached a consistent conclusion. Furthermore, few studies have focused on a more complex perspective by simultaneously combining the variables of primary science teachers' knowledge, beliefs, and practices with science teacher professional development and ICT use, especially in a Chinese context. Based on this, this research aims to evaluate the relationships among those factors and further explore the differences in structural relations with the structural equation modeling method. The research questions investigated were as follows:

(1) Whether primary science teachers' professional development, teachers' knowledge and beliefs, and teachers' instructional practices can influence teachers' intention to ICT use?

(2) Whether primary science teachers' knowledge beliefs and instructional practices can play an important intermediary role between teacher professional development and ICT use?

Conceptual framework

The conceptual framework underlying this study is shown in Fig. 1. Specifically, we hypothesized that primary science teachers' professional development and knowledge, beliefs, and instructional practices can directly impact their intention to use ICT. Furthermore, primary science teachers' professional development could still influence teachers' knowledge, beliefs, and instructional practices, which, in turn, impact science teachers' ICT use. The theories and previous literature described below constructed this conceptual model.

The Sociocultural Model of Embedded Belief Systems (Jones & Carter, 2007) indicates that a series of belief systems, prior knowledge, epistemology, attitudes, knowledge, and skills directly influence teachers' instructional practices. These factors are interconnected, and teacher belief systems are the critical factor influencing practices. According to this framework, science teachers' epistemologies include teachers' beliefs about science, science

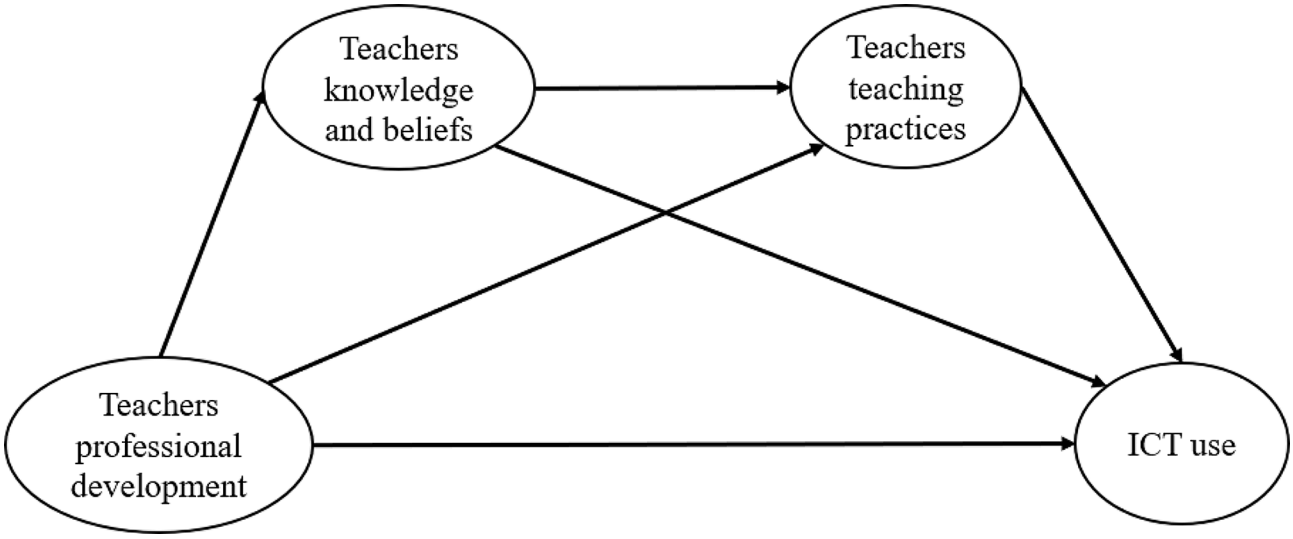

Fig. 1 A chain mediating role model between teachers' professional development and their intention to use ICT

learning, and science teaching, while the epistemological beliefs could impact the teacher's attitude towards classroom instruction. Many other external factors, such as social norms and environmental constraints, can also impact science teachers' attitudes toward classroom instruction (Luft & Roehrig, 2007). Based on this framework, we have further linked the teachers' knowledge, beliefs, and instructional practices to primary science teachers' professional development and ICT use. On the one hand, teacher professional development programs were closely linked to ICT use, and some studies revealed that science teacher professional development programs could facilitate science teachers' use of ICT along with their inquiry, constructivist, and conceptual instructional practice (Fernandes et al., 2022; Birgin et al., 2020).

Hence, this research proposed the following hypotheses:

H1 Primary science teachers' professional development can positively influence ICT use.

On the other hand, science teachers' knowledge and beliefs could influence their instructional practices and still mediate between teachers' professional development and their ICT use. As we have reviewed, some previous studies have demonstrated that science teachers' knowledge, beliefs, and instructional practices could directly influence teachers' intentions to use ICT (Koh et al., 2013a; Ifinedo et al., 2020; Agyei & Voogt, 2011), as well as play a mediator role between teachers' professional programs and their intentions to use ICT (Hughes, 2005; Taimalu & Luik, 2019; Tondeur et al., 2017). Therefore, we further proposed the following hypotheses:

H2 Teachers' knowledge and beliefs can positively influence ICT use.

H3 Teachers' instructional practices can positively influence ICT use.

H4 Teachers' knowledge and beliefs play a mediating role in the pathway between teachers' professional development and ICT use.

H5 Teachers' instructional practices mediate the path between teachers' professional development and ICT use.

H6 "Teachers' knowledge and beliefs → teachers' instructional practices" mediates the chain between teachers' professional development and ICT use.

In summary, considering the interaction between teachers' professional development, teachers' knowledge, beliefs, and practices and their intention to use ICT, the study constructs a model of chain mediation between teachers' professional development, teachers' knowledge, beliefs, teaching practices, and ICT use (Fig. 1).

Method

Data and sample

Data were obtained from the Program of the China Primary School Science Teacher Workforce (CPSST). CPSST is an extensive survey that has been conducted by the Chinese government since 2021 in order to understand the current situation of primary science teachers in China, report to the Ministry of Education of China, and give suggestions for improving the quality of science teachers in primary schools. A total of 134,973 online questionnaires were collected. After sorting out the collected questionnaires and deleting some incomplete or contradictory responses questionnaires, the study finally obtained 131,134 valid questionnaires. Therefore, the effective response rate of this questionnaire was 97.2%, with 36,250 male teachers and 94,614 female teachers. The percentage of male and female teachers was 27.64% and 72.36%, respectively, indicating a lower representation of male teachers in primary schools. Additionally, among all participants, 42,682 were from remote rural schools, 41,739 from remote township schools, 22,354 from district and county schools, 6,055 from municipal standardized schools, and 18,304 from provincial standardized high schools. The corresponding percentages were 32.54%, 31.83%, 11.04%, 4.63%, and 13.96%, respectively. These percentages effectively represent the distribution of primary schools in China. Furthermore, we also described the years of teaching of primary science teachers, and a total of 35,510 teachers have less than 5 years of teaching, 21,710 teachers have 6–10 years of teaching, 20,431 teachers have 11–20 years of teaching, 36,794 teachers have 21–30 years of teaching, and 16,689 teachers have more than 30 years of teaching (Table 1).

Measures and quality

Based on the Teaching and Learning International Survey (TALIS) questionnaire implemented by OECD, the project team first designed the questionnaire indicators and item pools around the dimensions of primary science teacher knowledge beliefs, instructional practices, professional development, and ICT use. With the method of Delphi Expert consultation, the initially designed questionnaires and item pools were submitted to six experts who studied science education for more than 5 years, to ensure each item was according to the wording and the definition of belonging dimensions.

The original questionnaire was divided into four dimensions: background information, teachers' knowledge and beliefs, instructional practices, and professional development. Firstly, teachers' knowledge and beliefs focused on the knowledge and beliefs perceived by

Table 1 The status of participants

	Years of teaching					Female	Male
	0–5 years	6–10 years	11–20 years	21–30 years	>31years		
Remote rural schools	12,361	6546	5649	12,405	5721	14,533	28,149
Remote township School	11,252	6682	6023	11,748	6034	12,730	29,009
District School	4430	3993	4542	6935	2454	4397	17,957
Municipal School	1860	1157	1006	1405	627	1423	4632
Provincial School	5607	3332	3211	4301	1853	3437	14,867
Totally	35,510	21,710	20,431	36,794	16,689	36,520	94,614

science teachers, which were composed of three evaluation indicators: science teachers' knowledge, science teachers' instructional beliefs, and science teachers' epistemological beliefs. Based on the TALIS questionnaire and adapted and translated from the Attitude, Knowledge, and Application questionnaire (Wahono & Chang, 2019a, b), 3 items were designed to investigate teachers' understanding of TPACK knowledge required by science teachers. An example of an item regarding science teachers' knowledge was, "I can understand the core concepts of science-related disciplines." In addition, 6 items of science teachers' beliefs were also used to describe primary science teachers' instructional beliefs and epistemological beliefs about science. Some examples of these items were "I can proficiently grasp the content of the elementary science textbooks I currently teach to expand with other interdisciplinary areas," "I can understand scientific knowledge was accumulated from people's practices," "I am sure students will gain more values if I integrated inquiry activities approaches in teaching science in the classroom." All 9 items were together composed of the science teachers' knowledge and beliefs.

Secondly, teachers' instructional practices describe some strategies that teachers use to help students become independent and strategic learners in the classroom (Francisco & Celon, 2020). We can understand the concept as all the actions performed by the teacher to create and maintain a learning environment that enables successful instruction. Therefore, in our study, 8 items were designed to investigate teachers' instructional practices from planning strategies, instructional strategies, and assessment practices of teachers. Some example items were "I consider the influence of students' prior knowledge and experience and design scientific investigations that meet students' psychological characteristics and activities" and "I could organize and design instruction by using different ways of presenting scientific knowledge (e.g., analogies, explanations, physical models, demonstration experiments, etc.)" "I could develop diverse assessment methods based on student characteristics in my science classroom (e.g., observations, activity record sheets, project work, growth portfolios, paper and pencil tests, etc.)." All 8 items were together composed of the science teachers' instructional practices.

Thirdly, considering this study aimed to explore the relationship between teachers' professional training and their intention to use ICT and the chain-mediated effects of teachers' knowledge, beliefs, and teaching practices during the period, the professional development programs of teachers in the study were synthesized from three secondary indicators under the professional development dimension: frequency of professional scientific training, frequency of activity in teaching materials, and teaching and research community, and three items were designed to investigate teachers' professional development programs. Some example items were "How many times per year are you able to attend scientific professional training? (teachers responded: 1=Never participated, 2=participated once, 3=participated twice, 4=participated three times, 5=participated four times or more than four times.)" "How many times per year are you able to attend activities in the teaching materials? (Teachers responded: 1=never participated, 2=participated once, 3=participated twice, 4=participated three times, 5=participated four times or more than four times). All 3 items were together composed of the science teachers' professional development. Lastly, one item was also designed to investigate the science teacher's intention to use ICT, which represented that "I would use ICTs in my further science teaching" (Teachers responded: 1=strongly disagree, 2=disagree, 3=neutral, 4=agree,5=strongly agree).

Subsequently, in order to detect the measurement model of teacher PD, teacher knowledge and beliefs, instructional practice among some items, we further used reliability testing and confirmatory factor analysis to test the overall quality of the sample data with the software of Amos 26.0 and SPSS22.0. The results showed that the total reliability coefficient of the scale was 0.830, with teachers' professional development, knowledge and beliefs, and instructional practice respectively 0.763, 0.958, and 0.792. According to the reliability test standard of Cronbach's alpha above 0.7 (Taber, 2018), this scale has a high internal consistency. Besides, the confirmatory factor analysis was also conducted. The results showed that RSMEA=0.071(<3, good fit), and the goodness of fit indexes in the model are mostly all greater than 0.9 (NFI=0.912, RFI=0.900, IFI=0.912, CFI=0.912), which

indicates that the structure of the scale is reasonable (Anderson & Gerbing, 1988; Fornell & Larcker, 1981).

Statistical analysis

Based on the structural equation model method, we have detected the effects of professional development programs on primary science teachers' ICT use, which is mediated by science teachers' knowledge, beliefs, and instructional practice with the software SPSS22.0 and AMOS 26.0. Firstly, descriptive statistics and Pearson's bivariate correlation analyses were conducted to examine the relationship between ICT use and primary science teachers' professional development, teachers' knowledge and beliefs, and teachers' instructional practices to understand the fundamental features of the data with the software SPSS22.0.

Secondly, we explored the pathways between primary science teachers' ICT use, teachers' knowledge and beliefs, teachers' instructional practices, and teachers' professional development with the method of structural equation modeling. The path analysis followed the conceptual framework (Fig. 1), in which several paths were assumed to detect the relationship between primary science teachers' development programs and ICT use. On the one hand, primary science teachers' professional development and their knowledge, beliefs, and instructional practices can directly and positively impact teachers' intention to use ICT. On the other hand, science teachers' knowledge, beliefs, and instructional practices can also play a mediator and chain mediator effects in the pathway between science teachers' professional development and ICT use.

To test the overall fit of a measurement model, several model fit indices were considered: chi-square statistic ($\chi 2$), root mean square error approximation (RMSEA), root mean square residual (RMR), normed fit index (NFI), comparative fit index (CFI) and adjusted goodness of fit index (AGFI). There is a need for clarification that the chi-square statistic was sensitive to large sample sizes, which can lead to poor fit results and misinterpretation (Kenny & McCoach, 2003). Therefore, considering the enormous sample size exhibited in this study, the current study would focus on the following good model fit indices: the RMSEA value should be less than 0.10, the RMR value should be less than 0.05, and the NFI, CFI, TFI, and AGFI values should be greater than 0.90 (Anderson & Gerbing, 1988). Therefore, when the model meets the above model-data-fit criteria, we could further obtain the direct, indirect, and total model effects tested in the model.

Results

Table 2 presented descriptive statistics and correlation results among primary science teachers' professional development, knowledge and beliefs, instructional practices, and ICT use. The correlation analysis results revealed a statistically significant correlation among those variables in our study. Among those variables, primary science teachers' ICT use has the highest correlation with teachers' instructional practices (r=0.038), followed by teachers' knowledge and beliefs (r=0.037) and teachers' professional development (r=-0.016). In addition, the current study also presented some significant positive correlations between science teachers' professional development and teachers' knowledge beliefs (r=0.363) and teachers' instructional practices (r=0.405) and a significant positive correlation between teachers' knowledge beliefs and teachers' instructional practices (r=0.618). Based on the significant correlation among those variables, we further tested the effect of the pathway in the conceptual model constructed in the study (Fig. 1).

The structural equation model and path coefficient estimation

A structural equation model was constructed with teachers' professional development as the independent variable, ICT use as the dependent variable, and teachers' knowledge, beliefs, and instructional practices as mediating variables. By using Amos 26.0 software, we have calculated and obtained some fit indicators for the model (RMSEA=0.080, RMR=0.024, GFI=0.937, AGFI.

=0.907, NFI=0.960, IFI=0.960, CFI=0.960, and TLI=0.949), which indicated that the model had a good fit (Wen et al., 2004).

To answer question 1: whether primary science teachers' professional development, teachers' knowledge and beliefs, and teachers' instructional practices can influence teachers' intention to use ICT, we further explored the path coefficient of the constructed model among the relationship between teachers' professional development, teachers' knowledge and beliefs, teachers' instructional

Table 2 Descriptive statistics and correlation analysis (N=131,134)

Variables	Mean	SE	1	2	3	4
Teachers' Professional Development	2.6311	1.20665	1			
Teachers' Knowledge and Beliefs	1.9989	0.35404	0.363**	1		
Teachers' Instructional Practice	3.2416	0.72954	0.405**	0.618**	1	
ICT use	2.6389	0.25812	-0.016**	0.037**	0.038**	1

Note: N=131,134; * indicates $p<0.05$, ** indicates $p<0.01$, and *** indicates $p<0.001$

practices, and teachers' intention to use ICT and revealed the direct effects of variables in detail (Fig. 2). The structural path coefficients indicate that teachers' professional development does not positively predict primary science teachers' ICT use but significantly and negatively linked with ICT use (*B=-0.05, p<0.001*), and Hypothesis 1, which the theoretical model predicted, was not tested. However, teachers' instructional practices (*B=0.04, p<0.001*) and teachers' knowledge and beliefs (*B=0.03, p<0.001*) both statistically significantly and positively predicted ICT use, which indicated that model hypotheses 2 and 3 were empirically verified. Therefore, the teaching beliefs possessed by teachers, subject knowledge, and the general pedagogy, subject pedagogy, teacher-student interaction, and higher-order thinking employed by teachers in their teaching practices may have an impact on ICT use (Campbell et al., 2014; Ghavifekr & Rosdy, 2015). Furthermore, the path model plots showed that teacher professional development was also able to significantly and positively predict both teacher knowledge and beliefs (*B=0.39, p<0.001*) and teacher instructional practices (*B=0.23, p<0.001*), as well as teacher knowledge and beliefs, could also significantly and positively influence teacher teaching practices (*B=0.54, p<0.001*). The results demonstrated that there might exist some mediating chain effects in the relationship between teachers' professional development, teachers' knowledge and beliefs, teachers' instructional practices, and ICT use.

Mediating effects of teachers' knowledge, beliefs and instructional practices in the relationship between professional development and ICT use

To answer question 2, can primary science teachers' knowledge, beliefs, and instructional practices play a significant intermediary role between teachers' professional development and ICT use? Chain mediation path tests were also conducted to detect the mediation effects of variables of teachers' knowledge and beliefs, and instructional practices in the relationship between teachers' professional development and teachers' intention to use ICT. The Bootstrap method was used to repeat the sampling 5000 times, 95% unbiased confidence intervals were constructed, and the significance of the hypothesized path-mediated effect was tested according to whether the 95% confidence interval contained 0. Finally, the indicators of direct effect, indirect effect, and the total effect of the hypothesized path in the model were obtained (Table 3).

The intermediary effect of teachers' knowledge, beliefs, and instructional practices on primary science teachers' professional development and teachers' ICT use was mainly realized through three intermediary paths: teachers' knowledge and beliefs, teachers' instructional practices, and a chain mediator among teachers' knowledge and beliefs and instructional practices. The 95% confidence interval of Bootstrap for these three paths does not include 0 ($p<0.05$), which means that they have a significant intermediary effect in the relationship between primary science teachers' professional development and teachers' intention to use ICT, and further verified H4-H6 hypotheses. Table 3 indicated that there exists a statistically significant positive correlation between teachers' knowledge and beliefs, as well as instructional practices, and the professional development of primary science teachers (β_direct=0.039, SE=0.002, $p<0.001$; β_direct=0.030, SE=0.003, $p<0.001$). Moreover, both teachers' knowledge and beliefs, and instructional practices also exhibit statistically significant direct effects on

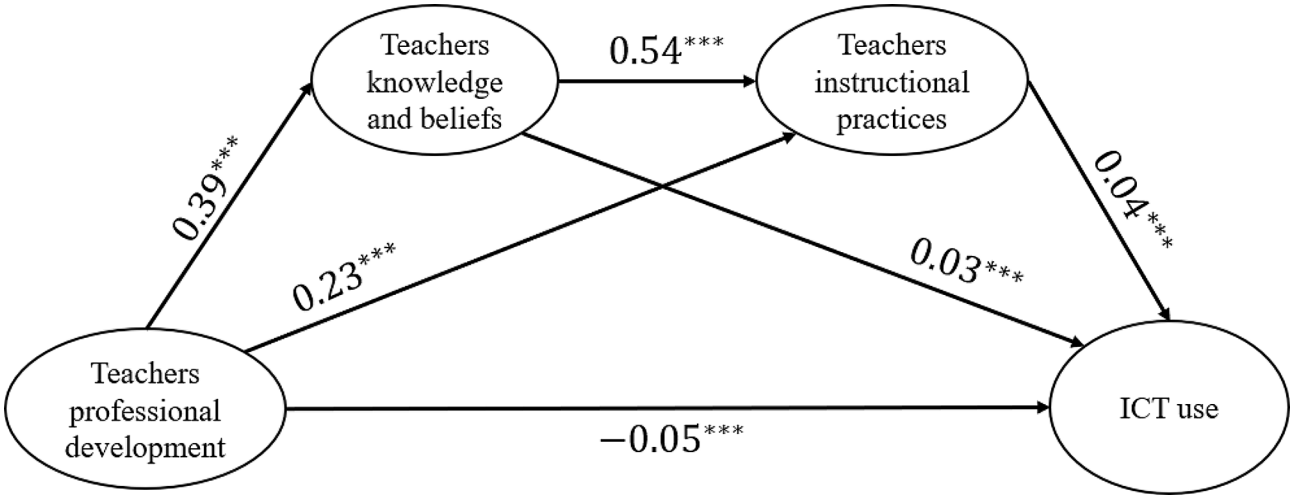

Fig. 2 The structural equation model describes the direct effect of each path between teachers' professional development, teachers' knowledge and beliefs, teachers' instructional practices, and teachers' intention to use ICT. The one-way arrow describes the standardized regression coefficient, and the solid line represents the meaningful path ($p<0.05$)

Table 3 Mediating Effects of teachers' knowledge, beliefs, and instructional practices in the relationship between teachers' professional development and ICT Use

Path	Direct effect				Indirect effects					Total effect		
	B	*SE*	*P*	f2	*B*	*SE*	Bootstrap 95% CI		*P*	*B*	*SE*	*P*
							Lower	Upper				
TIP→ICT	0.039**	0.002	0.000	0.001								
TKB→ICT	0.030**	0.003	0.000	0.02								
TPD→ICT	-0.047**	0.001	0.000	0.003								
TPD→TKB→ICT					0.012**	0.001	0.009	0.014	0.000			
TPD→TIP→ICT					0.009**	0.001	0.007	0.011	0.000			
TPD→TKB→TIP→ICT					0.008**	0.001	0.007	0.010	0.000			
										-0.017**	0.003	0.000
TKB→TIP	0.54	0.005	0.000	0.280								
TPD→TIP	0.231	0.003	0.000	0.130								
TPD→TKB	0.386	0.001	0.000	0.110								

Note: *** indicates significance at the *P*<0.001 level; ** indicates significance at the *P*<0.01 level; * indicates significance at the *P*<0.05 level; TPD stands for Teachers' Professional Development; TKB stands for Teachers' Knowledge and Beliefs; TIP stands for Teachers' Instructional Practices; ICT stands for Teachers' ICT Use. ***f2*** represented the effect sizes of the path coefficients which means the degree of the impact of specified exogenous latent variables toward the endogenous latent variables

the ICT use by primary science teachers (β_direct=0.039, SE=0.002, $p<0.001$; β_direct=0.030, SE=0.003, $p<0.001$). Therefore, primary science teachers' knowledge, beliefs, and instructional practices could both play an important mediator role in the relationship between teachers' professional development and their intention to use ICT, whose indirect influence effects were 0.012 and 0.009 respectively (βindirect=0.012, SE=0.001, $p<0.001$; βindirect=0.009, SE=0.001, $p<0.001$). Additionally, teachers' knowledge, beliefs, and instructional practices also presented a chain mediation path to influence the relationship between teachers' professional development and their intention to use ICT. The chain mediator effects of "teachers' knowledge and beliefs → teachers' instructional practices" were 0.008 (βindirect=0.008, SE=0.001, $p<0.001$), which presented the lowest effects among three intermediary paths. Given the very large sample size, we also calculated effect sizes of the path coefficients with the parameters of $f2$. Especially, the f^2 value was an equation with $(R2\ included - R2\ excluded)/(1 - R2 included)$, assesses the degree of the impact of specified exogenous latent variables toward the endogenous latent variables by measuring the degree of the R^2 change on the endogenous latent variables (Ziggers & Henseler, 2009). According to the standardized f^2 value proposed by Cohen (1988), the small, medium, and large effect sizes were viewed as 0.12, 0.15, and 0.35, respectively. From Table 3, we conclude that the exogenous latent construct of TIP ($f^2 = 0.001$), TKB ($f^2 = 0.000$), TPD ($f^2 = 0.003$) have no effect sizes towards the endogenous latent construct ICT, and TPD (f^2 = 0.130), TKB (f^2 = 0.280) have small effect sizes, medium effect size towards the endogenous latent construct TIP, respectively. The reason mainly was that the items in primary science teachers' professional development primarily centered on enhancing teachers' science knowledge and providing training in teaching strategies, with minimal integration of Information and Communication Technology (ICT). This emphasis was reflected in the observed effects on the endogenous latent construct ICT ($f^2 = 0.003 < 0.12$), indicating a negligible impact. Conversely, there are small effect sizes associated with the endogenous latent construct TIP (f^2 = 0.130 > 0.02), suggesting a comparatively more substantial influence. Moreover, teachers' knowledge and beliefs demonstrated a statistically significant relationship with teachers' instructional practices (f^2 = 0.280 > 0.02), indicating a substantial influence of science teachers' knowledge and beliefs on instructional practices and the shaping of teaching approaches.

Discussion

Based on the Sociocultural Model of Embedded Belief Systems, this study investigated the relationship among teachers' beliefs and knowledges, instructional practices,

teacher professional development and their ICT use and answered two questions: First, it investigated the directly effects of primary science teachers' professional programs, teachers' knowledges and beliefs, teachers' instructional practices on their intention to use ICT. Second, it also explored the indirect mediator effects of teachers' knowledge and beliefs and instructional practices in the relationship between teachers' professional development and ICT use.

Firstly, based on the path coefficients, this study revealed that primary science teachers' professional development does not exert a positive influence on ICT use, while science teachers' knowledge, beliefs, and instructional practices demonstrated significant positive effects on science teachers' ICT use. Primary science teachers' professional development demonstrated a negative association with ICT use, a finding inconsistent with prior research (Yang & Hong, 2022). This discrepancy may be attributed to the current state of professional development training for Chinese primary science teachers, where the integration of ICT into training programs was inadequate. Furthermore, primary science teachers continue to lack emphasis on ICT use in various aspects, including science professional training, science textbook training, and teaching and research community seminars. Consequently, this deficiency contributes to the limited engagement of primary school science teachers in ICT utilization. Analysis of a substantial survey dataset has revealed that 17.4% of Chinese primary science teachers have not participated in instructional practices training or professional development programs in the past year and that training and programs rarely involve the use of information technology in subject teaching (Zheng et al., 2023).

Additionally, science teachers' knowledge, beliefs, and instructional practices were found to significantly influence their ICT use, aligning with several previous studies (Kim et al., 2013; Liu et al., 2011; Ifinedo et al., 2020). For instance, certain research has indicated that teachers' epistemic beliefs, pedagogical beliefs, and technological knowledge play crucial roles in their capacity to integrate ICT into instructional practices, and these teachers were also more inclined to choose a constructive teaching philosophy (Hsu, 2013; Kim et al., 2013; Bahcivan et al., 2019). Moreover, a study illustrated that science teachers, prior to commencing teacher professional training, tended to harbor traditional conceptions of teaching and learning, weaker perspectives on the nature of science, and insufficient technology-enhanced beliefs. However, following the completion of the training, these teachers were more inclined to embrace student-centered views of teaching and learning, exhibit more nuanced beliefs about scientific knowledge and its nature, and manifest significantly stronger technology-enhanced beliefs (Campbell et al., 2014). In addition to the influence of science teachers' knowledge and beliefs, we also revealed that teachers' instructional practices could influence science teachers' intention to use ICT. Jang and Tsai (2012) revealed that ICT use was significantly and positively influenced by teachers' teaching experience, especially teachers with more years of teaching experience demonstrated significantly higher Technological Pedagogical Content Knowledge (TPACK) than teachers with fewer years of teaching experience. Therefore, the reconstruction of primary science teachers' knowledge and beliefs, coupled with the expansion of teachers' instructional practices, is essential to enhance their willingness to use ICT. In this regard, information and communication technology should be actively integrated into training activities such as teaching reflection and instructional design, and innovative teaching ways and contents of information technology should also be used based on teachers' practical experiences to satisfy their teaching needs (Zhao et al., 2014).

Secondly, this study also revealed that primary science teachers' knowledge, beliefs, and instructional practices can play an important intermediary and chain mediator effects in the relationship between teachers' professional development and ICT use. The results were consistent with previous studies, indicating that teachers' knowledge, beliefs, and instructional practices in professional development training programs tend to indirectly influence their intention to use ICT (Fives & Gill, 2015; Deng et al., 2014; Campbell et al., 2014). For example, Campbell et al. (2014) investigated the temporal changes in science teachers' pedagogical orientations and technology-enhanced beliefs within a professional training program, and revealed that, initially, science teachers tended to embrace traditional conceptions of teaching, were unfamiliar with the nature of science, and possessed insufficient technology-enhanced beliefs before the commencement of the training. However, after the training, they exhibited a greater inclination to integrate ICT. Furthermore, some studies also revealed that teacher training programs that integrate ICT can have an impact on teachers' perceptions and practices, especially when teachers recognize that ICT tools can effectively facilitate student learning and understanding (Ihmeideh & Al-Maadadi, 2018). Additionally, teachers' ICT knowledge continues to exert an influence on their intention to use ICT. A study conducted by Aslan and Zhu (2017) revealed that pedagogical knowledge, participation in ICT-related courses, and perceived ICT competence significantly predicted the integration of ICT into teaching practices. Collectively, these factors accounted for 17% of the variance in the integration of ICT into teaching practices.

In addition to the mediating effects of teachers' knowledge and beliefs and teachers' instructional practices, a chain mediator, specifically "teachers' knowledge and beliefs → teachers' instructional practices," could also play a crucial role. The results were consistent with the interaction effects observed between teachers' instructional practices and teaching beliefs, underscoring the significant influence of individuals' beliefs on their behaviors and practices (Deng et al., 2014; Fives & Gill, 2015; Pajares, 1992). Deng et al. (2014) found that teachers' epistemological beliefs and pedagogical theories can significantly influence their intention to apply ICT, and the epistemological beliefs held by teachers can also indirectly influence ICT use through teachers' constructivist pedagogical practices. Therefore, in the professional training of teachers incorporating ICT technology, attention should be paid on cultivating teachers' knowledge and beliefs regarding ICT use and expanding ICT application opportunities in teachers' teaching practices, aiming to continually enhance teachers' willingness to use ICT, which was important for improving teachers' ICT literacy (Wu et al., 2022).

Overall, the results of our study can help Chinese education authorities to understand the performance of teacher professional development training and ICT use among Chinese primary science teachers so that they can better optimize and adjust the frequency and content of training for primary science teachers. At the same time, by examining the mediating effects of teachers' knowledge, beliefs, and practices in the context of teachers' professional training programs and ICT use, the study unveiled multiple pathways for enhancing the utilization of ICT among primary science teachers. These findings, in turn, offer valuable insights for optimizing educational and teaching practices for primary science teachers. Additionally, while numerous scholars have investigated the professional training of primary and secondary teachers and their inclination to use ICT, much of the research has been conducted in Western cultural contexts. In these studies, teachers' training programs primarily concentrated on designing science curriculum, teaching methods, and engaging in discussions about science concepts. Therefore, to some extent, our study serves to bridge the gap between teacher professional development and the willingness of primary science teachers to use ICT in China.

Conclusion, limitation and implications

In this study, utilizing a large sample of collected data (N=131,134), we employed structural equation modeling (SEM) to investigate the relationships among teachers' professional development, knowledge and beliefs, instructional practices, and their intention to use ICT. The results revealed notable influence effects among the above factors, except for teachers' professional development, which has not positively influenced ICT use. Other factors, such as teachers' knowledge and beliefs and teachers' instructional practices, could significantly influence science teachers' ICT use. Moreover, science teachers' knowledge, beliefs, and instructional practices not only serve as mediators but also play a chain mediating role in the process of teachers' professional development influencing ICT use. Therefore, the results of this study suggest that the ICT literacy of primary science teachers can be enhanced through the implementation of professional training programs that integrate ICT, the cultivation of teachers' concepts of ICT application, and the innovation of ICT teaching practice pathways.

This study also has some limitations that are closely connected to future research. Firstly, considering the research purpose and the numerous survey items, the consolidation of science teachers' knowledge and beliefs into one dimension may simplify certain results. Thus, the study cannot fully and intricately reveal the relationships among science teachers' epistemic and pedagogical beliefs, technological knowledge, and instructional practices. Additionally, it cannot demonstrate the influential effects of teachers' epistemic and pedagogical beliefs, as well as technological knowledge, on ICT use. Therefore, future research should separately explore the direct effects of teachers' epistemic and pedagogical beliefs, technology knowledge, and instructional practices on primary science teachers' intention to use ICT and reveal the multiple mediating effects of teachers' beliefs, knowledge, and instructional practices in the relationship between teachers' professional development and ICT use.

Secondly, while the coefficients for both direct and indirect paths to ICT use were statistically significant, it is worth noting that the path coefficients are relatively small. One possible reason was that the items of primary science teachers' professional development were mainly focused on teachers' frequency of science knowledge training and hardly involved ICT integrated, might impact the mediated effect of science teachers' knowledge, beliefs, and instructional practices in the process linking teachers' professional development to their intention to use ICT. Therefore, future research would continue to involve other predictors that may be more influential to the outcome variable.

Overall, our studies were important for science teachers' professional development. On one hand, our study reveals that current teacher training lacks content related to the use of information technology, focusing instead on simple knowledge while neglecting the practical application of information technology. On the other hand, the findings of our study can also assist educational policymakers in designing training curricula. This design should prioritize training that encompasses not

only scientific subject knowledge and science teaching but also emphasizes beliefs about the nature of science, cross-curricular teaching, and the effective use of information technology.

Acknowledgements
Sincere thanks to the editors and reviewers for their guidance and suggestions, as well as the members of the Science Teaching Special Committee of the Basic Education Guidance Committee of the Ministry of Education of China and frontline science teachers for their support of the questionnaire survey.

Author contributions
Jingying Wang (corressponding author) led the research project, designed the research framework and survey questionnaires. Beibei Lv collected and analyzed the data, and also wrote the manuscript. Danhua Zhou and Zhenshan Rong were instrumental in gathering and analyzing preliminary data, and they also played a key role in the manuscript's revision process. Xuewai Tian contributed to the literature review of the manuscript and give some suggestions for the analysis of data. All authors read and approved the final manuscript.

Funding
This paper was supported by the National Natural Science Foundation of China (72074031).

Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
We have no conflict of interest to declare.

Received: 5 July 2023 / Accepted: 13 February 2024
Published online: 05 March 2024

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