Article:

Li, X., Zhang, Y., Yu, F. et al. (3 more authors) (2024) Do science teachers' believes related to inquiry-based teaching affect students' science process skills? Evidence from a multilevel model analysis. Disciplinary and Interdisciplinary Science Education Research, 6 (1). 1. ISSN 2662-2300

https://doi.org/10.1186/s43031-023-00089-y https://doi.org/10.1186/s43031-023-00089-y

Disciplinary and Interdisciplinary Science Education Research

RESEARCH

Open Access

Do science teachers' believes related to inquiry-based teaching affect students' science process skills? Evidence from a multilevel model analysis

Xiying Li[1,2], Yuelai Zhang[1], Fabi Yu[2*], Xingyu Zhang[1], Xin Zhao[3] and Zhongling Pi[1*]

Abstract

Inquiry-based science teaching has emerged as a prominent trend in science education. Nevertheless, it remains uncertain how teachers' self-efficacy in regard to the teaching of science as inquiry (TSI) affects students' science learning, especially considering the scarcity of research on its impact on students' Science Process Skills (SPSs). To investigate the impact of teachers' TSI on students' SPSs, this study conducted a questionnaire survey involving 539 eighth-grade students and 75 teachers from 7 junior high schools. Our Multilevel Model analysis results revealed a positive correlation between students' creative tendencies and SPSs. The results of the Cross-Level Moderation Models indicated that TSI moderated the relationship between students' creative tendencies and their SPSs, with this relationship strengthening as TSI increased. These study findings carry significant implications for both inquiry-based science education and teacher education.

Keywords Science Process Skills, Self-Efficacy in Regard to the Teaching of Science as Inquiry, Teachers' Beliefs, Student Creative Tendency

Introduction

Teachers' beliefs can be defined as a teacher's judgement of the truth or falsity of a claim (Pajares, 1992). Bandura (1997) argued that these beliefs, rather than objective truth, shape teachers' instructional goals, emotion and interaction with students, which can facilitate or hinder their instructional practices (Fives & Buehl, 2012). Consequently, teachers' beliefs can influence their instructional decisions and subsequently shape the classroom climate, ultimately affecting teachers' professional development and students' learning. Teachers' beliefs encompass all aspects of education, including epistemology, teaching, learning, assessment, students, the school climate and so on. As part of teachers' beliefs, teachers' self-efficacy in regard to teaching plays a pivotal role, influencing the development of both teachers and students.

Research suggests that science ranks among the most challenging subjects in schools (Drew, 2011; Dweck, 2006; National Academies of Science, 2011). A sense of competence in teaching science, often referred to as teachers' self-efficacy in the subject, is critical for the success of science teachers (Grindrod et al., 1991; Skamp, 1995). Scientific inquiry is emerging as a predominant trend in science education worldwide. The

*Correspondence:
Fabi Yu
yufabi@qq.com
Zhongling Pi
pizl@snnu.edu.cn
[1] MOE Key Laboratory of Modern Teaching Technology (Ministry of Education), Shaanxi Normal University, South Chang'an Road 199, Yanta District, Xi'an 710062, Shaanxi Province, People's Republic of China
[2] Institute of Science Education, Beijing Normal University, Xinjiekouwai Street 19Haidian District, Beijing 1000875, People's Republic of China
[3] Information School, University of Sheffield, Sheffield, UK

primary objective is to foster inquiry-based learning and cultivate students' scientific literacy (European Commission Directorate-General for Research Innovation, 2015; Gericke et al., 2022; National Research Council, 1996, 2000; Rönnebeck et al., 2016). Therefore, teachers' self-efficacy in regard to the teaching of science as inquiry is crucial to the development of both teachers and students.

Teachers' self-efficacy in regard to the teaching of science as inquiry (TSI) is a context specific form of self-efficacy. It pertains to one's judgment of their capability to organize and carry out inquiry-based science teaching, as well as the anticipated outcomes this approach might yield. Numerous studies have identified a significant relationship between teachers' TSI and students' science achievement. Lumpe et al. (2012) found a positive correlation between elementary teachers' science self-efficacy and the science performance of students in both the fourth and sixth grade. Hakkarainen (2003) found that inquiry-based teaching improves the scientific understanding of children aged 10 and 11. Other research also suggests that TSI can advance both students' content knowledge (Sandoval, 2005) and their understanding of the nature of science (Schwartz & Crawford, 2004). Therefore, there is sufficient evidence to suggest that TSI can lead to enhanced learning outcomes for students in the science subject. However, standardized tests may not always serve as the best indicators of students' performance (Braun et al., 2010), especially in the context of scientific inquiry-based learning.

Inquiry-based science education can equip students with essential knowledge and skills in science subjects (Aditomo & Klieme, 2020; Adler et al., 2018). However, many teachers argue that teaching science through inquiry isn't the most effective method for preparing students for standardized science tests (Fatma et al., 2021). Science process skills (SPSs) are defined as 'a set of skills used by scientists during their work, and the competencies displayed in solving scientific problems'. SPSs encompass a broad array of skills, including observing, measuring, classifying, communicating, predicting, inferring, using numbers, understanding space/time relationships, questioning, controlling variables, hypothesizing, defining operationally, formulating models, designing experiments, and interpreting data (American Association for the Advancement of Science, 1993). Research suggests that SPSs more closely reflect the process of science learning rather than merely focusing on the outcomes, making them as a suitable measure for inquiry-based science education (Af'idayani et al., 2018). Although previous studies have suggested that TSI can enhance student learning outcomes (Hakkarainen, 2003; Sandoval, 2005; Schwartz & Crawford, 2004), there is a lack of research exploring its impact on the student learning process.

Recognizing the significance of students' SPSs, we aim to investigate the psychological mechanisms underpinning TSI and its impact on students' SPSs. In particular, teachers' self-efficacy in regard to TSI is critical for the success of science teachers. Up to date, there is a dearth of research examining the relationship between inquiry-based science teaching and students' SPSs (Halim et al., 2021). Therefore, we conducted a questionnaire survey to examine the relationship between teachers' TSI and students' SPSs. Based on the aforementioned literature, we hypothesize that TSI could positively predict students' SPSs.

While TSI may not benefit every student, researchers have noted that factors like student readiness for inquiry-based learning activities can influence the efficacy of teachers' TSI on student learning (Wee et al., 2007). Wang et al. (2015) highlighted another influential factor, i.e. students' prior knowledge about inquiry-based learning activities. According to their research, this understanding can enhance learning motivation and amplify student interest. Of all the factors identified, creativity stands out as a focal point for researchers (Abd-el Khalick & Lederman, 2000). It permeates every stage of scientific inquiry and is especially crucial in the formulation of questions, hypotheses, and experimental designs. Consequently, science is not just a mere outcome, but a dynamic process infused with elements of creativity at every turn, as highlighted by Saxena (1994). Halim et al. (2021) discovered that students with greater creativity tend to have improved SPSs. Similarly, Yildiz and Yildiz (2021) observed that preschoolers with advanced creative thinking also show enhanced SPSs. Therefore, we hypothesized that students' creative tendencies can moderate the relationship between teachers' TSI and students' SPSs.

The primary aim of this study is to investigate the relationship between TSI and students' SPSs. Additionally, we aim to ascertain if students' creative tendencies mediate this relationship. To guide this exploration, we pose the following questions:

1) Is there a significant relationship between teachers' TSI and students' SPSs?
2) Does the relationship between teachers' TSI and students' SPSs vary based on student's creative tendencies?

Method

Participants

A total of 539 eighth-grade students from 7 junior high schools participated in this study, including 273 males, 250 females, and 15 gender data missing. Their average age was 14.02 (± 0.66) years old, with the age range spanning from 12 to 17 years. Furthermore, 75 teachers from these schools, who taught physics, biology, and chemistry, also participated in this study, including 16 males and 59 females. The average age of the teachers in this study was 37.89 (± 7.58) years, ranging from 24 to 55 years. Among these teachers, 21 held senior professional titles, 34 had first-level professional titles, and 14 had second-level professional titles. The number of students and teachers from each school is shown in Table 1.

Materials

Creative tendency questionnaire for adolescents

The study adopted the Creative Tendency Questionnaire for Adolescents developed by Shen et al. (2005). This questionnaire comprises 37 items, spanning five dimensions: self-confidence, exploration, curiosity, willpower, and challenge. The questionnaire uses a five-point rating scale, ranging from 1 (completely inconsistent) to 5 (completely consistent), to indicate the degree to which the statement matches the actual situation of the student. In this study, the Cronbach's α coefficient for the five dimensions of the questionnaire and the total score were 0.78, 0.78, 0.74, 0.50, 0.52, and 0.80, respectively.

Science process skills (SPSs)

The science process skills questionnaire was developed based on the evaluation indicators of SPSs. The questionnaire consists of 28 items, spanning nine dimensions: posing questions, forming hypotheses, selecting variables, experimental control, choosing experimental apparatus, observing, processing observational results, explaining and communicating (Li, 2016). The questionnaire uses a five-point rating scale, ranging from 1 (completely inconsistent) to 5 (completely consistent), to indicate the degree to which the statement matches the actual situation of the student. The Cronbach's α coefficient for this questionnaire in this study was 0.95.

Table 1 Number of students and teachers in different schools

	Student	Teacher
Beijing No. 20 Middle School	67	13
Beijing No. 19 Middle School	59	7
Jinling Middle School affiliated junior high School	85	22
Nanjing No. 8 Middle School	78	11
Tangshan 54th Middle School	96	8
No. 21 Middle School of Tangshan	53	9
Tangshan No. 12 Middle School	100	5

Self-efficacy in regard to the teaching of science as inquiry (TSI)

This study used the Self-Efficacy in Regard to the Teaching of Science as Inquiry (TSI) questionnaire developed by Smolleck et al. (2006). The questionnaire consists of 69 items, divided into two subscales: self-efficacy and outcome expectancy (Li et al., 2015). Each subscale is further divided into five dimensions: learner engages in scientifically oriented questions, learner gives priority to evidence in responding to questions, learner formulates explanations from evidence, learner connects explanations to scientific knowledge, and learner communicates and justifies explanations. The questionnaire uses a five-point rating scale, ranging from 1 (completely inconsistent) to 5 (completely consistent), to indicate the extent to which the statement matches the actual situation of the teacher. The Cronbach's α coefficient for this questionnaire in this study was 0.97. The Cronbach's α coefficient for self-efficacy was 0.95, and the coefficient for outcome expectancy was also 0.95.

Analysis strategy

Multilevel models (MLM) were developed for hierarchical data, which can offer analysis at both the individual level (micro level) and the group level (macro level). Many research inquiries involve examining issues at both these levels. For instance, individuals might be grouped based on different geographical units (e.g. communities, cities, regions, etc.), necessitating empirical models that examine both micro and macro data. Consequently, multilevel modeling, which accommodates both levels, has gained widespread application.

In this study, we utilized a multilevel model (MLM) to analyze our hierarchically structured data, categorizing students (Level 1) by their respective schools (Level 2). This approach helped us mitigate potential discrepancies in our findings due to variations between schools and teachers.

First, Model 1 was established. Within this model, Level 1 predictors included students' creative tendencies, age, and gender, and Level 2 variable included teachers' self-efficacy for science teaching. Subsequently, Models 2 and 3 were established as cross-level moderation models. In Model 2, Level 1 predictors included students' creative tendencies, age, and gender, with creative tendencies being group-centered. The Level 2 variables included teacher self-efficacy, the cross-level interaction term of creative tendencies and self-efficacy, and with the self-efficacy score being standardized. In Model 3, the Level 1 variables

Table 2 Means and standard deviations of student and teacher variables

	M	*SD*
Student		
Creative Tendencies	3.38	0.44
Self-confidence	2.43	0.79
Exploration	3.76	0.76
Curiosity	3.91	0.69
Willpower	3.77	0.74
Challenge	3.16	0.59
SPSs	3.88	0.61
Teacher		
TSI	3.87	0.33
Self-efficacy	3.92	0.34
Outcome expectancy	3.88	0.30

Table 3 Results of the multi-level model of the relationship between scientific process skills, creative tendency, and teaching efficacy

Model 1	Estimate	*S.E.*	*p*
Intercept	3.41	0.68	< .001
Gender	0.07	0.04	.064
Age	-0.01	0.04	.767
Creative tendency	0.32	0.08	< .001
TSI	-0.13	0.26	.613

Note. S.E. Standard error

were the same as Model 2, whereas Level 2 variables included teacher outcome expectancy, the cross-level interaction term of creative tendencies and outcome expectancy, with the outcome expectancy score being standardized. Finally, Models 4–13 were established to explore the results of the five dimensions of creative tendencies.

Results

Descriptive statistics

The means and standard deviations of creative tendencies, SPSs, and TSI are presented in Table 2.

Multilevel model of the relationship among SPSs, creative tendencies, and TSI

As shown in Table 3, there was a significant positive relationship between creative tendencies and SPSs ($B = 0.32$, $p < 0.001$), with higher scores in creative tendencies being associated with higher scores in SPSs. However, there was no significant relationship between TSI and SPSs ($B = -0.13$, $p = 0.613$).

Cross-level moderation models of self-efficacy for science teaching

As shown in Table 4, in Model 2, the cross-level interaction term between creative tendencies and self-efficacy was significant ($B = 0.13$, $p < 0.001$). Self-efficacy moderated the relationship between creative tendencies and SPSs, with the relationship becoming stronger as self-efficacy increased. Further simple slope tests, as shown in Fig. 1, revealed that when levels of self-efficacy were high, there was a significant positive relationship between creative tendencies and SPSs ($B = 0.46$, $p < 0.001$); when self-efficacy levels were moderate, there was a significant positive relationship between creative tendencies and SPSs ($B = 0.33$, $p < 0.001$); when self-efficacy levels were low, there was a significant positive relationship between creative tendencies and SPSs ($B = 0.19$, $p < 0.001$).

Similar to the results of Model 2, as shown in Table 4, in Model 3, the cross-level interaction term between creative tendencies and outcome expectancy was significant ($B = 0.13$, $p < 0.001$). Outcome expectancy moderated the relationship between creative tendencies and SPSs, with the relationship becoming stronger as outcome expectancy increased. Further simple slope tests, as shown in

Table 4 Results of the cross-level moderating effect model of self-efficacy for science teaching

	Model 2			Model 3		
	Estimate	*S.E.*	*p*	Estimate	*S.E.*	*p*
Intercept	3.91	0.55	< .001	3.91	0.55	< .001
Gender	0.06	0.04	.087	0.06	0.04	.087
Age	-0.01	0.04	.875	-0.01	0.04	.880
Creative tendency	0.33	0.06	< .001	0.32	0.06	< .001
Self-efficacy	-0.05	0.07	.503			
Creative tendency × Self-efficacy	0.13	0.03	< .001			
Outcome expectancy				-0.06	0.06	.266
Creative tendency × Outcome expectancy				0.13	0.03	< .001

Note. S.E. Standard error

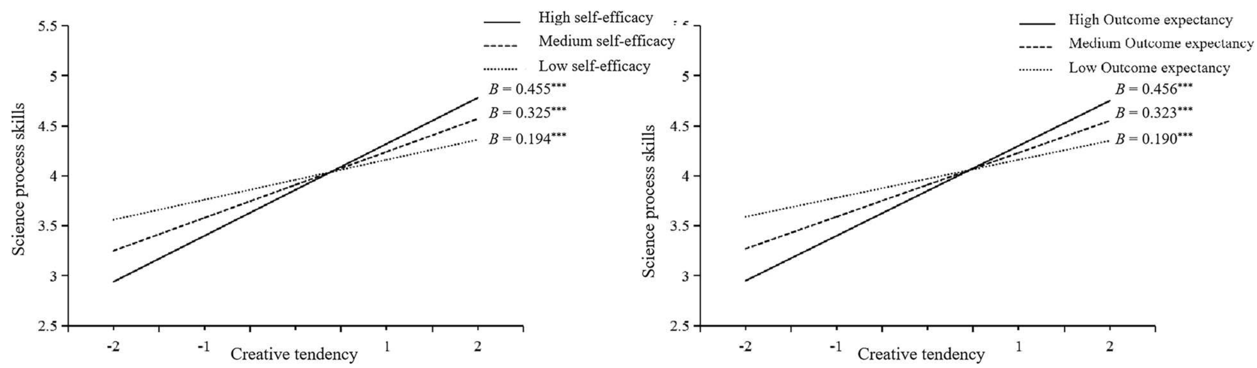

Fig. 1 The moderating effect of self-efficacy for science teaching on the relationship between creative tendency and SPSs. Note. *B* represents slope, *** $p < 0.001$

Fig. 1, revealed that when levels of outcome expectancy were high, there was a significant positive relationship between creative tendencies and SPSs ($B = 0.46$, $p < 0.001$); when outcome expectancy levels were moderate, there was a significant positive relationship between creative tendencies and SPSs ($B = 0.33$, $p < 0.001$); when outcome expectancy levels were low, there was a significant positive relationship between creative tendencies and SPSs ($B = 0.19$, $p < 0.001$).

Cross-level moderation models of the relationship between SPSs and different dimensions of creative tendencies

As shown in Table 5, in Model 5, the cross-level interaction term between curiosity and self-efficacy was significant ($B = 0.08$, $p < 0.001$). Self-efficacy moderated the relationship between curiosity and SPSs, with the relationship becoming stronger as self-efficacy increased. Further simple slope tests, as shown in Fig. 2, revealed that when levels of self-efficacy were high, there was a significant positive relationship between curiosity and SPSs ($B = 0.34$, $p < 0.001$); when self-efficacy levels were moderate, there was a significant positive relationship between curiosity and SPSs ($B = 0.26$, $p < 0.001$); when self-efficacy levels were low, there was a significant positive relationship between curiosity and SPSs ($B = 0.18$, $p < 0.001$).

In Model 6, similar to Model 5, the cross-level interaction term between exploration and self-efficacy was significant ($B = 0.09$, $p < 0.001$). Self-efficacy moderated the relationship between exploration and SPSs, with the relationship becoming stronger as self-efficacy increased. Further simple slope tests, as shown in Fig. 2, revealed that when levels of self-efficacy were high, there was a

Table 5 Results of cross-level moderating effects on different dimensions of creative tendency

	Model 4		Model 5		Model 6		Model 7		Model 8	
	Estimate	*S.E.*	Estimate	*S.E.*	Estimate	*S.E.*	Estimate	*S.E.*	Estimate	*S.E.*
Intercept	3.64***	0.33	3.90***	0.59	4.01***	0.36	4.17***	0.45	3.92***	0.48
Gender	0.11**	0.04	0.07	0.04	0.10**	0.03	0.06	0.04	0.08*	0.03
Age	0.01	0.02	-0.01	0.04	-0.01	0.03	-0.02	0.03	-0.01	0.03
Self-confidence	-0.20***	0.04								
Exploration			0.26***	0.05						
Curiosity					0.40***	0.02				
Willpower							0.32***	0.07		
Challenge									0.04	0.06
Self-efficacy	-0.05	0.07	-0.05	0.07	-0.05	0.07	-0.05	0.07	-0.05	0.07
Self-confidence × Self-efficacy	0.05	0.03								
Curiosity × Self-efficacy			0.08***	0.01						
Exploration × Self-efficacy					0.09***	0.01				
Curiosity × Outcome expectancy							0.08***	0.03		
Exploration × Outcome expectancy									0.09***	0.04

Note. S.E. Standard error; * $p < .05$; ** $p < .01$; *** $p < .001$

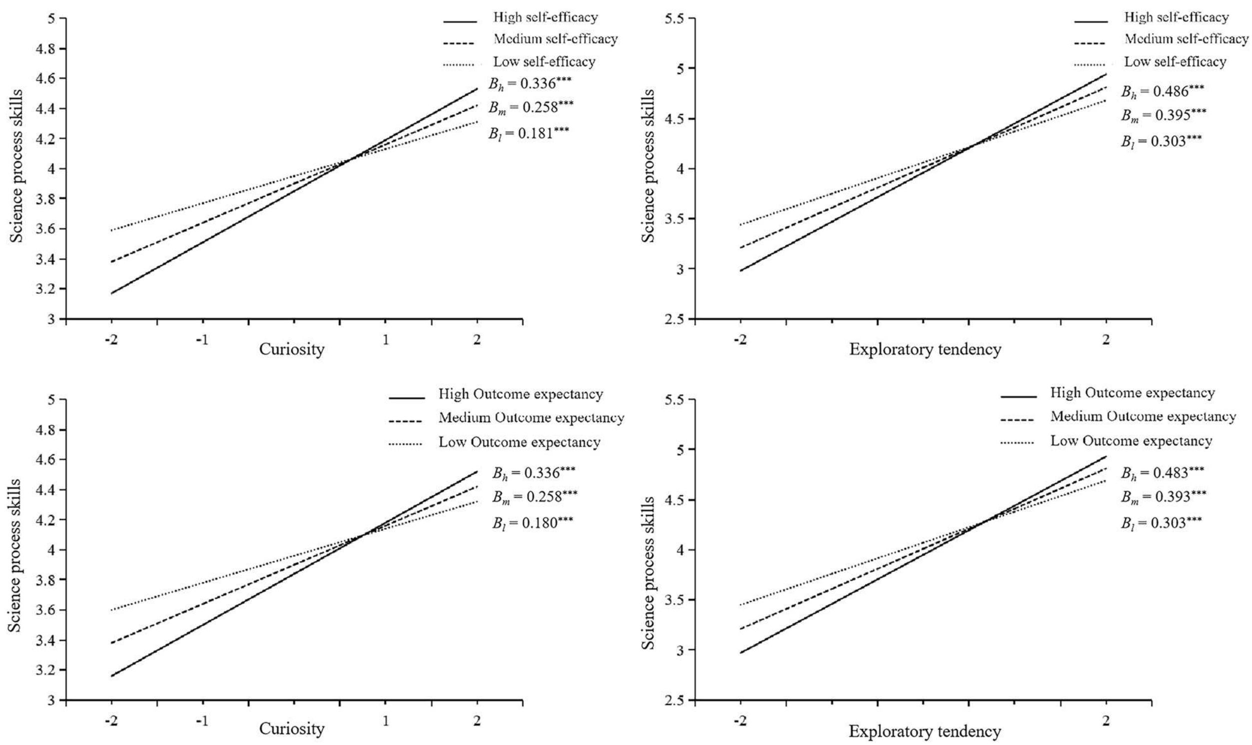

Fig. 2 The moderating effect of self-efficacy for science teaching on the relationship between different dimensions of creative tendency and SPSs. Note. *B* represents slope, *** $p<0.001$

significant positive relationship between exploration and SPSs ($B=0.49$, $p<0.001$); when self-efficacy levels were moderate, there was a significant positive relationship between exploration and SPSs ($B=0.40$, $p<0.001$); when self-efficacy levels were low, there was a significant positive relationship between exploration and SPSs ($B=0.30$, $p<0.001$).

As shown in Table 5, in Model 7 the cross-level interaction term between curiosity and outcome expectancy was significant ($B=0.08$, $p<0.001$). Outcome expectancy moderated the relationship between curiosity and SPSs, with the relationship becoming stronger as outcome expectancy increased. Further simple slope tests, as shown in Fig. 2, revealed that when levels of outcome expectancy were high, there was a significant positive relationship between curiosity and SPSs ($B=0.34$, $p<0.001$); when outcome expectancy levels were moderate, there was a significant positive relationship between curiosity and SPSs ($B=0.26$, $p<0.001$); when outcome expectancy levels were low, there was a significant positive relationship between curiosity and SPSs ($B=0.18$, $p<0.001$).

In Model 8, similar to Model 7, the cross-level interaction term between exploration and outcome expectancy was significant ($B=0.09$, $p<0.001$). Outcome expectancy moderated the relationship between exploration and SPSs, with the relationship becoming stronger as outcome expectancy increased. Further simple slope tests, as shown in Fig. 2, revealed that when levels of outcome expectancy were high, there was a significant positive relationship between exploration and SPSs ($B=0.48$, $p<0.001$); when outcome expectancy levels were moderate, there was a significant positive relationship between exploration and SPSs ($B=0.39$, $p<0.001$); when outcome expectancy levels were low, there was a significant positive relationship between exploration and SPSs ($B=0.30$, $p<0.001$).

Discussion

Overall, results of the Multilevel Model analysis showed that students with higher scores in creative tendencies were associated with higher scores in SPSs. However, there was no significant relationship between TSI and SPSs. Results of the Cross-Level Moderation Models revealed that (1) TSI moderated the relationship between creative tendencies and students' SPSs, with the relationship becoming stronger as TSI increased. (2) Specifically, our simple slope tests revealed when levels of TSI were higher, there was a more positive relationship between curiosity and SPSs. (3) Similarly, when levels of TSI were higher, there was a more positive relationship between exploration and SPSs.

Firstly, our study found that the higher a student's creative tendency score, the higher their SPSs score. Discovery, inquiry, and creativity are often used interchangeably in the literature (Lucas, 1971). Notably, creative personalities account for 11% of creative variation in Chinese adolescents and 15% in American adolescents (Li et al., 2014a, 2014b). Therefore, students' creative tendency is likely to predict their SPSs, which aligns with our results. However, our study did not find a significant relationship between TSI and SPSs. This could arguably be attributed to two reasons. First, TSI represents a belief that needs to be translated into actionable teaching practice to impact students' behavior and learning outcomes. Second, Science is viewed as one of the more challenging subjects in secondary schools (Drew, 2011; Dweck, 2006; National Academies of Science, 2011). Taking both factors into consideration, the inquiry-based science teaching approach may be too demanding for some students (Halim et al., 2021; Yildiz & Yildiz, 2021). Research underscores the importance of providing continuous professional development for both teachers and students in scientific inquiry-based learning tasks to improve the SPSs of students from diverse backgrounds (Yumusak, 2016; Lati, 2012). On the one hand, understanding and applying SPSs pose a significant challenge, requiring students to exert considerable cognitive effort (Piekny & Maehler, 2013). On the other hand, the efficacy of the inquiry-based teaching approach hinges on teachers providing explicit instructional support to learners. (Kruit et al., 2018; Lazonder & Harmsen, 2016). According to various studies, primary school students often struggle to understand and apply SPSs in inquiry-based learning settings, likely due to inadequate scaffolding or clear explanations from their teachers (Coil et al., 2010; Durmaz & Mutlu, 2016). Therefore, enhancing students' SPSs is a long-term endeavor and may be challenging to achieve in the short term. Secondly, Cross-Level Moderation Models revealed that TSI moderated the relationship between creative tendencies and SPSs of students. In other words, as TSI increased, the relationship between creative tendencies and SPSs strengthened. Research suggests that teachers' beliefs influence their classroom instruction (Luft, 2001; Clarke & Hollingsworth, 2002; Buehl & Beck, 2015; Chen, et al., 2015). For instance, Fatma et al. (2021) demonstrates that there are strong connections between teachers' self-efficacy beliefs and their implementation of inquiry. Teachers with strong self-efficacy beliefs are more likely to effectively implement inquiry-based learning activities, formulating better questions and providing guidance to students. Our results align with this finding, further supporting that TSI strengthens the relationship between students' creative tendencies and SPSs. Specifically, this enhancement is evident only in the curiosity and exploration dimensions of creative tendencies. Curiosity is a psychological and behavioral motivation triggered by novel stimuli, serving as an internal drive for knowledge. While exploration refers to the persistent characteristics of students in identifying challenges, contemplating solutions, delving into the unknown, and uncovering truths through practical experiences (Wang et al., 2015). Therefore, students with high curiosity and exploration tend to demonstrate greater courage, adopt a positive mindset, and generate diverse ideas to solve problems. Such students often collect diverse viewpoints and identify patterns and key information when searching or inquiring for solutions (Zhu & Zhang, 2014). Our findings align with this perspective, suggesting that students with higher curiosity and exploration are more receptive to teachers' instructions, thereby facilitating the enhancement of their SPSs.

The results of this study offer important insights for the design of inquiry-based teaching. Firstly, teachers' beliefs profoundly affect their teaching practices, which in turn shape the learning outcomes of students. As a result, to enhance teaching practices and students' SPSs, it is essential to enhancing teachers' TSI. Secondly, although inquiry-based teaching is a valuable method in science education, it's not suitable for every student. Indeed, without clear instruction from teachers, some students may become confused by this approach.

We recognize two limitations in the current study. The first limitation pertains to our methodology. We employed a multi-level model to offset variations among school types. However, since the study relied on a single cross-sectional questionnaire without tracking or manipulating specific variables, thereby our findings suggest correlations rather than causative relationships. The second limitation is that students' SPSs were assessed using self-reports, which may not precisely capture their actual inquiry-based learning abilities. Future research should consider utilizing scores from inquiry-based tasks to evaluate students' SPSs.

Conclusion

In this study, we conducted a questionnaire survey of 539 eighth-grade students from 7 junior high schools. To mitigate potential discrepancies arising from different schools and teachers, we employed a Multilevel Model for data analysis. Our findings revealed that SPSs represent a complex, advanced cognitive ability, and that students' creative tendencies can serve as predictors for SPSs. Furthermore, Teachers' self-efficacy in inquiry-based teaching can amplify the predictive effects of students' curiosity and exploration on their SPSs. This underscores the significant impact of teachers' beliefs on student learning, indicating that teacher education should emphasize interventions to strengthen these beliefs.

Acknowledgements
We thank Professor Jiliang Shen for his great help in the whole research project and data collection.

Authors' contributions
LX: Conceptualization; Writing – original draft; Formal analysis; Funding acquisition. ZhYL:Writing – original draft, review & editing. YF: Investigation; Methodology. ZhXY: Formal analysis. ZhX Writing – review & editing. PZh: Project administration; Writing – review & editing. All authors read and approved the final manuscript.

Funding
This work was supported by the National Natural Science Foundation of China under Grant [62007023] and the Fundamental Research Funds for the Central Universities [2022ZYYB22/GK202303003].

Availability of data and materials
Data and materials will be made available on request.

Declarations

Competing interests
There is no conflict of interest.

Received: 29 June 2023 Accepted: 23 November 2023
Published online: 02 January 2024

References

Abd-el Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching, 37*(10), 1057–1095.
Adler, I., Schwartz, L., Madjar, N., & Zion, M. (2018). Reading between the lines: The effect of contextual factors on student motivation throughout an open inquiry process. *Science Education, 102*(4), 820–855.
Aditomo, A., & Klieme, E. (2020). Forms of inquiry-based science instruction and their relations with learning outcomes: Evidence from high and low-performing education systems. *International Journal of Science Education, 42*(4), 504–525.
Af'idayani, N., Setiadi, I., & Fahmi, F. (2018). The effect of inquiry model on science process skills and learning outcomes. *European Journal of Education Studies, 12*(4), 177–182.
Bandura, A. (1997). Self-Efficacy: The Exercise of Control. *Journal of Cognitive Psychotherapy, 13*, 158–166.
Braun, H. I., Chudowsky, N., & Koenig, J. A. (2010). *Getting Value Out of Value-Added: Report of a Workshop.*
Buehl, M. M., & Beck, J. S. (2015). The relationship between teachers' beliefs and teachers' practices. *International Handbook of Research on Teachers' Beliefs, 1*, 66–82.
Chen, J. A., Morris, D. B., & Mansour, N. (2015). Science teachers' beliefs: Perceptions of efficacy and the nature of scientific knowledge and knowing. In H. Fives & M. G. Gill (Eds.), *International handbook of research on teachers' beliefs* (pp. 370–386). Routledge.
Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education, 18*(8), 947–967.
Coil, D., Wenderoth, M. P., Cunningham, M., & Dirks, C. (2010). Teaching the process of science: Faculty perceptions and an effective methodology. *CBE-Life Sciences Education, 9*(4), 524–5351.
Drew, C. (2011, November 4). Why science majors change their minds (it's just so darn hard). The New York Times. Retrieved September 2, 2013, from http://www.nytimes.com/2011/11/06/education/edlife/whyscience-majors-change-their-mind-its-just-so-darn-hard.html?pagewanted=all&_r=0
Durmaz, H., & Mutlu, S. (2016). The effect of an instructional intervention on elementary students' science process skills. *The Journal of Educational Research, 110*(4), 433–445.
Dweck, C. S. (2006). Is math a gift? Beliefs that put females at risk. In S. J. Ceci & W. M. Williams (Eds.), *Why aren't more women in science? Top researchers debate the evidence* (pp. 47–55). American Psychological Association.
European Commission Directorate-General for Research Innovation. (2015). *Science education for responsible citizenship: Report to the European Commission of the expert group on science education*. Publications Office.
Fives, H., & Buehl, M. M. (2012). Spring cleaning for the "messy" construct of teachers' beliefs: What are they? Which have been examined? What can they tell us? In K. R. Harris, S. Graham, T. Urdan, S. Graham, J. M. Royer, & M. Zeidner (Eds.), *APA educational psychology handbook Vol. 2. Individual differences and cultural and contextual factors* (pp. 471–499). American Psychological Association.
Gericke, N., Högström, P., & Wallin, J. (2022). A systematic review of research on laboratory work in secondary school. *Studies in Science Education, 59,* 245-285.
Grindrod, A., Klindworth, A., Martin, M. D., & Tytler, R. (1991). A survey of pre-service primary teachers' experiences of science in schools. *Research in Science Education, 21*, 151–160.
Halim, A., Farada, S., Hamid, A., Mahzum, E., & Irwandi, I. (2021). Effect of concept attainment model on student's science process skills. *In Journal of Physics: Conference Series, 1882*(1), 12157. IOP Publishing.
Hakkarainen, K. (2003). Progressive Inquiry in a Computer-Supported Biology Class. *Journal of Research in Science Teaching, 40*, 1072–1088.
Kaya, F., Borgerding, L. A., & Ferdous, T. (2021). Secondary Science Teachers' Self-Efficacy Beliefs and Implementation of Inquiry. *Journal of Science Teacher Education, 32*(1), 107–121.
Kruit, P. M., Oostdam, R. J., Van den Berg, E., & Schuitema, J. A. (2018). Effects of explicit instruction on the acquisition of students‟ science inquiry skills in grades 5 and 6 of primary education. *International Journal of Science Education, 40*(4), 421–441.
Lati, W., Supasorn, S., & Promarak, V. (2012). Enhancement of learning achievement and integrated science process skills using science inquiry learning activities of chemical reaction rates. *Procedia-Social and Behavioral Sciences, 46*, 4471–4475.
Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning: Effects of guidance. *Review of Educational Research, 86*(3), 681–718.
Li, X., Wang, L., Shen J., Hu, W. (2015) On Sources of Variance in the Self-efficacy in the Inquiry Teaching of Sciences for Junior High School Science Teachers. *Contemporary Teacher Education, 8*(03), 79-84.
Li, X. (2016). *Science Textbooks Evaluation in Middle School: Theme in Scientific Inquiry*. Science Press.
Li, X., Liu, X., & Shen, J. (2014). The Relation between Adolescents' Creative Personality and Creativity: Evidence from Comparisons of Adolescents in American and China. *Psychological exploration, 34*(2), 186–192.
Li, X., Wang, L., Shen, J., & Hu, W. (2014b). On Sources of Variance in the Self-efficacy in the Inquiry Teaching of Science for Junior High School Science Teachers. *Contemporary Teacher Education, 8*(3), 79–84.
Lucas, A. M. (1971). Creativity, discovery and inquiry in science education. *The Australian Journal of Education, 15*, 185–196.
Luft, J.A. (2001). Changing inquiry practices and beliefs: The impact of an inquiry-based professional development programme on beginning and experienced secondary science teachers. *International Journal of Science Education, 23,* 517-534.
Lumpe, A. T., Czerniak, C. M., Haney, J. J., & Beltyukova, S. (2012). Beliefs about teaching science: The relationship between elementary teachers' participation in professional development and student achievement. *International Journal of Science Education, 34*(2), 153–166.
National Academy of Sciences. (2011). *Expanding underrepresented minority participation: America's science and technology talent at the crossroads*. National Academies Press.
National Research Council. (1996). *National science education standards.* National Academies Press.
National Research Council. (2000). *Inquiry and the National science education standards: A guide for teaching and learning*. The National Academies Press.

Pajares, M. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*, 307–332.
Piekny, J., & Maehler, C. (2013). Scientific reasoning in early and middle childhood: The development of domain-general evidence evaluation, experimentation, and hypothesis generation skills. *British Journal of Developmental Psychology, 31*(2), 153–179.
Project 2061 (American Association for the Advancement of Science). (1993). *Benchmarks for science literacy*. Oxford University Press.
Rönnebeck, S., Bernholt, S., & Ropohl, M. (2016). Searching for a common ground: A literature review of empirical research on scientific inquiry activities. *Studies in Science Education, 52*(2), 161–197.
Sandoval, W. A. (2005). Understanding Students' Practical Epistemologies and Their Influence on Learning Through Inquiry. *Science Education, 89*, 634–656.
Saxena, S.P. (1994). *Creativity and Science Education*, Creativity and Science Education preservice education program project president; Khandelwal, B.P. [On-line] http://www.education.nic.in/cd50years/q/6J/BJ/6JBJ0401.htm, (03.10.2006).
Schwartz, R. S., & Crawford, B. A. (2004). Authentic scientific inquiry as context for teaching nature of science. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science* (pp. 331–355). London: Kluwer.
Skamp, K. (1995). Student teachers' conceptions of how to recognise a "Good" primary science teacher: Does two years in a teacher education program make a difference? *Research in Science Education, 25*, 395–429.
Smolleck, L. D., Zembal-Saul, C., & Yoder, E. (2006). The Development and Validation of an Instrument to Measure Preservice Teachers' Self-Efficacy in Regard to The Teaching of Science as Inquiry. *Journal of Science Teacher Education, 17*(2), 137–163.
Shen, J., Wang, X., & Shi, B. (2005). A Study on the Structure and Development of Creative Tendencies. *Psychological Development and Education, 04*, 28–33.
Wang, P. H., Wu, P. L., Yu, K. W., & Lin, Y. X. (2015). Influence of implementing inquiry-based instruction on science learning motivation and interest: A perspective of comparison. *ProcediaSocial and Behavioral Sciences, 174*, 1292–1299.
Wee, B., Shepardson, D., Fast, J., & Harbor, J. (2007). Teaching and learning about inquiry: Insights and challenges in professional development. *Journal of Science Teacher Education, 18*(1), 63–89.
Yildiz, C., & Yildiz, T. G. (2021). Exploring the relationship between creative thinking and scientific process skills of preschool children. *Thinking Skills and Creativity, 39*, 100795.
Yumusak, G. K. (2016). Science Process Skills in Science Curricula Applied in Turkey. *Journal of Education and Practice, 7*(20), 94–98.
Zhu, H., & Zhang, Q. (2014). A Research on the Influence of Creative Tendency on Prototype Position Effect in Scientific Problem-Solving. *Studies of Psychology and Behavior, 12*(5), 616–620.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.