frontiers | Frontiers in Education

TYPE Original Research
PUBLISHED 29 August 2023
DOI 10.3389/feduc.2023.1147441

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OPEN ACCESS

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RECEIVED 18 January 2023
ACCEPTED 16 August 2023
PUBLISHED 29 August 2023

CITATION
von Knebel K, Schroeder S and Bögeholz S (2023) Factors influencing self-efficacy beliefs of interdisciplinary science teaching – the role of teaching experience, science subjects studied, and desire to teach interdisciplinary science.
Front. Educ. 8:1147441.
doi: 10.3389/feduc.2023.1147441

Factors influencing self-efficacy beliefs of interdisciplinary science teaching – the role of teaching experience, science subjects studied, and desire to teach interdisciplinary science

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Introduction: Teacher education for interdisciplinary science teaching at secondary schools shows shortcomings in several countries. One of these countries is Germany. Germany provides teacher education studies for secondary education in biology, chemistry, and physics. This discipline-specific single science subject teacher education results in partly out-of-field teaching of secondary teachers regarding interdisciplinary science. Thus, interdisciplinary science teaching is a new and difficult challenge for (prospective) teachers in Germany. Self-efficacy beliefs refer to the belief in the own abilities to tackle new and difficult challenges, such as interdisciplinary science teaching. Empirical research on self-efficacy beliefs of interdisciplinary science teaching (SElf-ST) is important to foster SElf-ST, e.g., in teacher education. Up to now, empirical research on influencing factors on SElf-ST takes mainly primary education into account. Empirical evidence for influencing factors regarding secondary science education is still needed because of the context-specificity of self-efficacy beliefs. Thus, this paper investigates factors possibly influencing SElf-ST in secondary education: teaching experience, number and type of science subjects studied and desire to teach interdisciplinary science.

Methods: We conducted a cross-sectional questionnaire study with German pre-service, trainee, and in-service biology, chemistry, and physics teachers ($n = 589$) on SElf-ST.

Results: In-service teachers had the highest beliefs in nearly all SElf-ST scales. Hardly any difference occurred between trainee teachers and pre-service teachers. Our study provides empirical support that in addition to teaching experience, the number of studied science subjects, and the desire to teach interdisciplinary science are factors that influence SElf-ST not only in primary education but also in secondary education. The novel examination of the so far unknown influence of studying biology, chemistry, or physics on the SElf-ST reveals an impact of any subject but in different ways. The effect of studying chemistry on the science-teaching-specific SElf-ST stands out.

Discussion: In sum, our results reveal possibilities in the context of, e.g., organizing teacher education to promote (prospective) teachers' SElf-ST in secondary education.

KEYWORDS

self-efficacy beliefs, science teacher education, secondary education, interdisciplinary science teaching, teaching experience, biology, chemistry, physics

1. Introduction

Science can be taught in different ways: this includes teaching biology, chemistry, and physics in a discipline-specific way, or more interdisciplinary approaches that tackle science as one subject (Metzger, 2010; Broggy et al., 2017). Bringing interdisciplinary science into secondary education is a serious challenge nowadays in several countries. This is rooted in failings of teacher education for interdisciplinary science subjects, e.g., no interdisciplinary science teaching degree program (e.g., Geraedts et al., 2006; Bröll and Friedrich, 2012). Integrated science teaching (in the following: interdisciplinary science teaching) is a major issue in Germany (e.g., Bröll and Friedrich, 2012). In interdisciplinary science teaching, one teacher teaches biology, chemistry, and physics together as one subject (Metzger, 2010; Labudde, 2014).

In Germany, grammar and comprehensive schools provide lower and upper secondary education. Discipline-specific science, i.e., biology, chemistry, and physics, dominates the teaching in secondary education. Apart from that, teachers have to teach interdisciplinary science in grades 5 and 6 at grammar schools in many federal states (Graube et al., 2013). In addition, comprehensive schools often offer interdisciplinary science, for example, as a subject in grades 5 to 10 in lower secondary education (e.g., Niedersächsisches Kultusministerium, 2020). At the same time, German science teacher education for secondary education is mostly discipline-specific (Neumann et al., 2017). Thus, German teacher education prepares for teaching biology, chemistry, and physics separately as single subjects (Neumann et al., 2017). Since pre-service teachers in Germany normally study two subjects, they are trained in one or two science subjects at most (Neumann et al., 2017). At the same time, it is possible that they have to teach science interdisciplinarily as teachers (see above).

Thus, interdisciplinary science – where it occurs – is taught by discipline-specific trained teachers in Germany. These conditions cause partly out-of-field teaching in the context of interdisciplinary science teaching (e.g., Dörges, 2001). Out-of-field teaching means that "teachers [are] assigned to teach subjects that do not match their training or education" (Ingersoll, 2005, p. 175). Thereby, it seems appropriate to name it partly out-of-field teaching since at least one of the subjects biology, chemistry, or physics is studied (Neumann et al., 2017). Taking into account partly out-of-field teaching, current teacher education for interdisciplinary science is inadequate (Bröll and Friedrich, 2012) and needs improvement (Dörges, 2001). After fixing the out-of-field teaching issue, teacher education would also need to train the prospective teachers, e.g., in identifying connections between biology, chemistry, and physics. Therefore, in a first step, we look at the (partly) out-of-field teaching, since this is the fundamental problem of interdisciplinary science teaching.

Since self-efficacy beliefs refer to beliefs about one's own abilities to execute concrete actions despite new challenges or difficult obstacles (Bandura, 1997; Schwarzer and Jerusalem, 2002), they are very suitable to examine how (prospective) teachers deal with this new and difficult challenge of interdisciplinary science teaching. The power of self-efficacy beliefs is illustrated by the example that science teaching self-efficacy beliefs of elementary teachers have a positive influence on their fourth- and sixth-grade students' academic achievement (Lumpe et al., 2012). In addition, Duffin et al. (2012, p. 827) summarize that in combination with pedagogical abilities and content knowledge, "educators need to be confident in their abilities to enact effective instructional practices," underlining self-efficacy beliefs' major role in teaching. Moreover, self-efficacy beliefs are also used more often to evaluate teacher education's success (Forsthuber et al., 2011).

Due to self-efficacy beliefs' importance for teaching and their suitability in the context of partly out-of-field teaching in Germany, we want to explore influencing factors. Primary science education research identified teaching experience, the number of science subjects studied, and the desire to teach interdisciplinary science as important factors for self-efficacy beliefs of interdisciplinary science teaching (e.g., Joseph, 2010; Lumpe et al., 2012; Menon and Sadler, 2016). However, the role of these factors has not been confirmed for secondary education yet. Thus, one aim of this contribution to secondary teacher education is to learn more about the impact of these factors on self-efficacy beliefs of interdisciplinary science teaching. The other aim is to investigate the yet unknown impact of studying biology, chemistry, or physics. The results of these analyses could provide starting points to improve teacher education for interdisciplinary science education.

2. Theoretical background

2.1. Self-efficacy beliefs, sources, and their importance for teaching and learning

Bandura (1997, p. 3) claims that self-efficacy beliefs are "a major basis of action." Further, he states that people without strong self-efficacy beliefs will not even try to perform the required actions (Bandura, 1997), e.g., in this case to teach interdisciplinary science. Self-efficacy beliefs vary regarding the *level* of the given task, the *generality* of the beliefs, and the *strength* of the beliefs against problems (Bandura, 1997). Thus, they vary for every specific task, scope, or difficulty and are context-specific (Tschannen-Moran et al., 1998). Therefore, they need to be examined in our specific context of interdisciplinary science teaching in secondary education rather than generally (Bandura, 1997). Bandura (1997) assumed mastery (direct) experience, vicarious (indirect) experience, verbal persuasion, and physiological and affective states as sources of self-efficacy beliefs with direct experience as the most powerful source. These assumptions were confirmed, e.g., for science self-efficacy beliefs of middle school students (Britner and Pajares, 2006).

Science teaching self-efficacy beliefs are a key factor for teachers and their students: Stronger self-efficacy beliefs of interdisciplinary science teaching result in primary teachers experiencing science as fun and interesting (de Laat and Watters, 1995). They lead to primary teachers using more hands-on activities (Appleton and Kindt, 2002). Moreover, they result in primary teachers being more willing to enhance science teaching for students and (prospective) teachers (Ramey-Gassert et al., 1996). Furthermore, they can lead to better performance of primary teachers' students in school (Lumpe et al., 2012). Recently, Bae et al. (2020) showed for middle school teachers that the greater use of motivational approaches and higher teachers' self-efficacy beliefs of interdisciplinary science teaching correspond positively with the engagement of their students and students' self-efficacy in science.

Primary education research has shown that teacher education courses have an impact on science teaching self-efficacy beliefs (e.g., Gunning and Mensah, 2011). Thus, it is important to determine factors that could have an impact on (prospective) teachers' self-efficacy beliefs of interdisciplinary science teaching (Blonder et al., 2014; Kahraman et al., 2014). Blonder et al. (2014, p. 12) pointed out the strong primary education focus of research on self-efficacy beliefs of interdisciplinary science teaching so far, stressing the "importance of conducting research beyond the elementary school level." We take up this request in the present study: We investigate factors that might influence self-efficacy beliefs of interdisciplinary science teaching in the context of secondary education.

2.2. Influencing factors of self-efficacy beliefs of interdisciplinary science teaching

For primary education, practical teaching experience of pre-service teachers turned out to be positively related with self-efficacy beliefs of interdisciplinary science teaching in a qualitative study (Gunning and Mensah, 2011). The same counts for quantitative studies with the present science teaching experience of pre- and in-service primary teachers (Lumpe et al., 2012, $\beta = 0.26$, $p < 0.01$; Riggs and Enochs, 1990, $r = 0.41$, $p < 0.01$; Velthuis et al., 2014, medium to large effects). Existing non-significant relationships of teaching experience and self-efficacy beliefs of interdisciplinary science teaching can often be traced back to inappropriate study designs, study descriptions, instruments, or samples (e.g., Yilmaz and Çavaş, 2008; Vidwans, 2016). According to our literature review, we rather assume a positive relationship between teaching experience and the self-efficacy beliefs of interdisciplinary science teaching in secondary education. This is in line with the highlighted role of direct experience by Bandura (1997).

Also, research reveals a relation between the science subjects studied and the self-efficacy beliefs of interdisciplinary science teaching. Pre-service primary school teachers with science(/mathematics) as a major in high school now hold significantly higher self-efficacy beliefs of interdisciplinary science teaching in primary education than students who had another major in high school (Bursal, 2010, $d = 0.64$). Joseph (2010) found the same relationship for pre-service primary school teachers studying science at university. In sum, research has shown that studying science in high school or at university is positively linked to the self-efficacy beliefs of interdisciplinary science teaching in primary education (Bursal, 2010; Joseph, 2010).

Another factor that may influence the self-efficacy beliefs of interdisciplinary science teaching is an individual's desire to teach interdisciplinary science. A significant correlation between such a desire and the self-efficacy beliefs of interdisciplinary science teaching was found for pre-service (Enochs and Riggs, 1990, $r = 0.58$, $p < 0.01$) and in-service primary teachers (Ramey-Gassert et al., 1996, $r = 0.44$, $p < 0.05$; Riggs and Enochs, 1990, $r = 0.57$, $p < 0.01$). Two qualitative studies expand this body of knowledge. Menon and Sadler (2016, p. 661) state that pre-service primary education teachers with high self-efficacy beliefs of interdisciplinary science teaching showed a "strong desire to teach science." Gunning and Mensah (2011, p. 180) similarly argue that the growth of self-efficacy beliefs of interdisciplinary science teaching appears "especially in terms of their desire to teach science" in primary education. Both studies support the positive relationship of the desire to teach interdisciplinary science with the self-efficacy beliefs of interdisciplinary science teaching in primary education.

3. Research questions and hypotheses

We reported on three factors influencing self-efficacy beliefs of interdisciplinary science teaching in primary education. Since interdisciplinary science teaching is taught in secondary education as well (e.g., Graube et al., 2013), we want to identify influencing factors in secondary education and extend the previous focus on primary education (Blonder et al., 2014). The results for primary education cannot be transferred to secondary education without empirical investigation due to the context-specificity of self-efficacy beliefs (Tschannen-Moran et al., 1998). In this paper, we consider ten different factors of self-efficacy beliefs of interdisciplinary science teaching. Our first aim is to determine how the influencing factors in the context of primary education can be transferred to secondary education to support prospective teachers in teaching interdisciplinary science in secondary education better. Thus, our first guiding research question is:

> *Research question 1*: Do teaching experience, the number of science subjects studied, and the desire to teach interdisciplinary science have an impact on the self-efficacy beliefs of interdisciplinary science teaching in secondary education?

The development of self-efficacy beliefs throughout teacher education has aroused interest (Blonder et al., 2014). Direct (and positive) experiences are the most important source of self-efficacy beliefs (Bandura, 1997). More teaching experience of pre- and in-service primary science teachers results in higher self-efficacy beliefs of interdisciplinary science teaching (e.g., Lumpe et al., 2012; Velthuis et al., 2014). Existing contrary findings are explainable and do not outweigh studies that note the positive impact of direct experiences. Prospective teachers gain teaching experience through studying progressively (including first practical trainings), acting as a trainee teacher, and finally working as an in-service teacher. Thus, we assume increasing self-efficacy beliefs in interdisciplinary science teaching as teaching experience increases. Transferring the previous results for primary education to secondary education, we derive the following hypothesis:

> *Hypothesis 1*: The self-efficacy beliefs of interdisciplinary science teaching in secondary education increase from pre-service teachers to trainee teachers to in-service teachers.

Another critical factor for self-efficacy beliefs of interdisciplinary science teaching is the number of science subjects studied. Interdisciplinary science incudes biology, chemistry, and physics. In Germany, usually one or two of these subjects are studied (Neumann et al., 2017). Primary school pre-service teachers' self-efficacy beliefs of interdisciplinary science teaching are higher in two cases: They studied science as a major earlier in high school (Bursal, 2010) or now in university (Joseph, 2010). Transferred to our context, more studied subjects out of biology, chemistry, and physics should result in higher self-efficacy beliefs of interdisciplinary science teaching, since more of the required skills should be possessed. Further extrapolating it for trainee and in-service teachers, we conclude hypothesis 2:

> *Hypothesis 2:* Pre-service, trainee, and in-service teachers for secondary education with more than one studied science subject at university have higher self-efficacy beliefs of interdisciplinary science teaching than those with one studied science subject.

In addition, researchers report a relationship of the self-efficacy beliefs of interdisciplinary science teaching with the desire to teach interdisciplinary science of primary pre- and in-service-teachers (e.g., Enochs and Riggs, 1990; Menon and Sadler, 2016). We assume the same positive relationship for (prospective) teachers in secondary education. In this study, we particularly focus on the predictive potential of the desire to teach interdisciplinary science, since we want to investigate influencing factors to foster these self-efficacy beliefs in teacher education (research question 1). Thus, we hypothesize the following:

> *Hypothesis 3:* The desire to teach interdisciplinary science positively predicts the self-efficacy beliefs of interdisciplinary science teaching in secondary education.

Research question 1 and the hypotheses 1–3 focus the transfer of primary education results to secondary education. Besides theses investigations, our second aim is to identify the so far unknown individual influence of the three single science subjects studied on self-efficacy beliefs of interdisciplinary science teaching. Previous research has focused on the impact of the number of science subjects studied (see hypothesis 2). We want to shed light on how biology, chemistry, and physics contribute differently to self-efficacy beliefs of interdisciplinary science teaching. Thus, the second major research question addresses the impact of the three single science subjects studied:

> *Research question 2*: What impact do the individual science subjects studied (biology, chemistry, and physics) have on the self-efficacy beliefs of interdisciplinary science teaching?

4. Materials and methods

4.1. Sample

The aim of the study was to investigate influencing factors of the discipline-specific trained (prospective) teachers' self-efficacy beliefs of interdisciplinary science teaching. Interdisciplinary science teaching is more and more demanded in German secondary education (e.g., Graube et al., 2013). In our study ($n = 589$), pre-service, trainee, and in-service teachers from five German federal states participated. The pre-service teachers studied at eight German universities. The trainee teachers came from three teacher education institutions in Lower Saxony. The teachers worked at grammar and comprehensive schools in Lower Saxony. The pre-service teachers were recruited from three different study programs: bachelor (undergraduates, usually six semesters of the studies), master of education (graduates, usually four semesters of the studies), and state examination (usually eight to ten semesters). Since not all universities completed the switch from the state examination to the bachelor's/master's program, there are still pre-service teachers in the state examination program. Trainee teachers are from the second phase of teacher education. In this phase, the trainee teachers are trained in teacher education institutions and teach at a school at the same time. The second phase of teacher education normally lasts 1.5 years. The trainee teachers get a (reduced) wage for their teaching at school because they are still in a qualification phase before becoming a teacher.

We conducted a paper-pencil questionnaire study with a cross-sectional study design from December 2017 to December 2018. The study was part of a nationwide German program, called "Qualitätsoffensive Lehrerbildung" (QLB), in order to further develop German teacher education quality. Within the QLB several surveys took place at the same time throughout Germany. Therefore, we had to recruit participants due to availability.

In the sample, we considered all three science subjects, all phases of teacher education as well as in-service teachers. Furthermore, we selected participants from different federal states. We wanted to consider especially participants from Lower Saxony (79.5%). This is due to the following reason: One starting point of the measurement development (Handtke and Bögeholz, 2019a) was science (teacher) education in Lower Saxony, since our research project within the QLB was of an university in Lower Saxony. It has to be considered that school education in Germany is under federal state responsibility. Thus, the curricula have slightly federal state-specific content designs. Teacher education responds to federal state framings. Apart from such slightly specific content designs, the requirements are very similar. Thus, we integrated four further federal states into the sample (7.1, 6.8, 4.1, and 2.5%). The majority of the sample was female (57.6%, males: 41.9%; no indication: 0.5%). The participants were pre-service, trainee, and in-service teachers studying mostly one or two of the three science subjects. There are only two exceptions: one with all three science subjects studied and one with a very rare interdisciplinary science focus (see Table 1). For further details of the sample composition regarding the studied science subjects, see Table 1.

Almost half of the participants were undergraduate students (48.7%; on average in semester 4.30; standard deviation of 2.49). A fourth were in a master's program for teacher education (23.1%; on average in semester 2.40; standard deviation of 1.38). Only some participants were in the state examination program (7.1%; on average

TABLE 1 Summary of the science subjects studied indicated by the participants ($n = 589$).

Subject(s)	Absolute number	Percentages (rounded)
Biology	170	28.9%
Chemistry	138	23.4%
Physics	99	16.8%
Biology and chemistry	143	24.3%
Biology and physics	7	1.2%
Chemistry and physics	30	5.1%
Biology, chemistry, and physics	1	0.2%
Science	1	0.2%

in semester 6.88; standard deviation of 2.80). Around one-sixth were trainee and in-service teachers (trainee: 11.5%; in-service: 6.5%). Two participants finished their studies recently, 16 made no indication. The clear majority of the sample studied to teach in secondary education (a grammar or comprehensive school; 88.5%, $n = 521$). The remaining 68 participants (including 25 with no indication) can be assigned to secondary education (in their current position) as well, and thus are not excluded. For example, 17 participants are lateral entrants into teaching profession without teaching experience in their previous studies. Our sample contains no participants who specialized in primary education. Of the in-service teachers, 15 were teaching at a grammar school (mostly discipline-specific science taught) and 22 at a comprehensive school (mostly interdisciplinary science taught). One in-service teacher made no indication. Thirty-one of the in-service teachers already taught interdisciplinary science or were doing it during the time of the study for 0.5 to 25 years (mean = 4.68, standard deviation = 5.66).

Table 2 shows the teaching experience of all participants of all phases of teacher education in taught lessons (pre-service and trainee teachers) and in years at school (in-service teachers). The teaching experience increases with progressing teacher education (bachelor/state examination – master of education – trainee teachers) and is the highest in the group of in-service teachers. The pre-service teachers (bachelor, master of education, and state examination as one group) have taught 5.5 lessons in a science subject (biology, chemistry, physics, or science) on average, with a standard deviation of 17. Despite the discipline-specific teacher education, teaching experience in interdisciplinary science is possible. For example, pre-service and trainee teachers could (be forced to) complete their internship at a comprehensive school with interdisciplinary science. The desire to teach interdisciplinary science (hypothesis 3, independent variable) was measured by a single item: (translated) "If I have the opportunity, I will teach science interdisciplinarily." We used the same four-point response scale "Is not right" (1), "Is a little right" (2), "Is rather right" (3), and "Is exactly right" (4) as for the SElf-ST instrument (Handtke and Bögeholz, 2019a, p. 8). The desire to teach interdisciplinary science is close to the middle of the scale of 2.5 for all groups, including pre-service teachers as one group (see above; mean = 2.64, standard deviation = 1.0). The standard deviations of the teaching experience and the desire to teach interdisciplinary science indicate widely diversified values.

4.2. Measurement instrument

We investigated self-efficacy beliefs of interdisciplinary science teaching in secondary education in this study. We applied – inspired by Bandura (1997) – a multidimensional and a theory-based approach to design our instrument for secondary science education: the Self-Efficacy Beliefs of Interdisciplinary Science Teaching (SElf-ST) instrument (Handtke and Bögeholz, 2019a, 2020a). The SElf-ST instrument is innovative due to the theory-driven integration of multiple facets of science teaching (Handtke and Bögeholz, 2019a). We operationalized the pentagon model of pedagogical content knowledge (PCK) for teaching science (Park and Chen, 2012; Handtke and Bögeholz, 2019a) in our SElf-ST instrument. Previous exploratory factor analysis ($n = 114$) indicates that the items covered ten different factors (Handtke and Bögeholz, 2019a).

All items were introduced with the same item stem "Even in science teaching, I can…" (for items see Supplementary Material S1 Measure, Table A, Handtke and Bögeholz, 2019a, 2020a). German teachers are almost always not trained interdisciplinarily or in all three science subjects (Neumann et al., 2017). Nevertheless, interdisciplinary science teaching is demanded more and more often (e.g., Graube et al., 2013). Thus, teaching interdisciplinary science is a content-related standardized obstacle for the German participants as called for by Bandura (1997). The items continued by including different assertions. They pertained to various aspects of self-efficacy beliefs of interdisciplinary science teaching regarding the PCK model (Park and Chen, 2012; Handtke and Bögeholz, 2019a). One example is "Even in science teaching, I can take into account difficulties of students regarding ethically complex questions (e.g., regarding the topics animal testing, climate change, nuclear power)." (see Supplementary Material S1 Measure, Table A, Handtke and Bögeholz, 2019a, 2020a). The participants had four options for responding: "Is not right" (1), "Is a little right" (2), "Is rather right" (3), and "Is exactly right" (4) (Handtke and Bögeholz, 2019a,

TABLE 2 Means, medians, and standard deviations of the teaching experience and desire to teach interdisciplinary science.

Actual status	Taught lessons in biology, chemistry, physics, or science (45 min)	Years of teaching biology, chemistry, physics, or science at school	Desire to teach interdisciplinary science
Bachelor students ($n = 287$)	2.9 (18.9) (median: 0)	–	2.7 (1.0)
Master of education students ($n = 136$)	12.0 (13.6) (median: 7.5)	–	2.5 (1.0)
State examination students ($n = 42$)	3.9 (8.9) (median: 0)	–	2.7 (1.1)
Trainee teachers ($n = 68$)	164.1 (296.0) (median: 55)	–	2.6 (1.0)
In-service teachers ($n = 38$)	–	9.9 (9.2) (median: 8)	2.8 (1.1)

Pre-service teachers come from the study programs bachelor, master of education, and state examination. The teaching experience of the in-service teachers was measured in years teaching at a school with some teaching discipline-specific science and some teaching interdisciplinary science. Pre-service and trainee teachers estimated how many lessons (45 min) they had taught in biology, chemistry, physics, or science. The desire to teach interdisciplinary science is measured on a Likert scale from 1 to 4: "Is not right" (1), "Is a little right" (2), "Is rather right" (3), and "Is exactly right" (4).

p. 8). The instrument was administered in German to the participants and translated afterwards into English for this paper.

4.3. Administration of the survey and ethics statement

All participants gave their written informed consent to be part of the study. We conducted the paper-pencil-test in line with the Declaration of Helsinki. The personal data were recorded pseudo-anonymously and will be anonymized as soon as possible. Since all data are treated in accordance with the General Data Protection Regulation and the participants did not have to fear any negative consequences, no approval of the Ethics Committee was necessary. We provide a strictly anonymized dataset in the supporting information (see Supplementary Material S4 Dataset). The characteristics of two persons regarding the studied subjects had to be deleted in this dataset due to anonymization. The participants indicated personal data (e.g., science subjects studied, actual status as a pre-service, trainee, or in-service teacher) and their desire to teach interdisciplinary science at the beginning of the survey. The category gender (female/male/no indication) was only used for sample description at group level. Then, we applied the SElf-ST instrument (Handtke and Bögeholz, 2019a, 2020a and Supplementary Material S1 Measure, Table A). We monetarily rewarded 135 pre-service teachers (and one participant that finished the studies recently) for their participation during breaks in courses or beyond courses (e.g., appointment in their free time). Remaining pre-service teachers took part in courses without monetary reward. The entire group of trainee teachers received monetary compensations, while in-service teachers were not rewarded.

4.4. Analyses

To identify factors influencing the self-efficacy beliefs of interdisciplinary science teaching in secondary education, we applied structural equation modeling. The alpha-level was set to $p < 0.05$ for all statistical analyses. We used RStudio with the *lavaan* (version 0.6–3) package (Rosseel et al., 2020), the *ggplot2* (version 3.3.3) package (Wickham et al., 2021), the *sjmisc* (version 2.8.7) package (Lüdecke et al., 2021), the *patchwork* (version 1.1.1) package (Pedersen, 2020), and the *psych* (version 2.0.12) package (Revelle, 2021) as implemented in R for our analyses. We used PowerPoint to create the figures of the confirmatory factor analysis and the schematic structural equation model. We completed the data computation of the self-efficacy beliefs of interdisciplinary science teaching in ordinal values.

We checked the self-efficacy beliefs of interdisciplinary science teaching for possible outliers. No mistyped values occurred. All answers were permitted and all participants were part of the target sample, since they studied at least one science subject with the aim of becoming a teacher. Therefore, we deleted no possible outliers that were shown by boxplots (Flora et al., 2012). Since our sample is relatively large, it is less susceptible to the effect of possible outliers (Brown, 2006). The histograms and Shapiro–Wilk tests showed no normal distribution for all items of the self-efficacy beliefs of interdisciplinary science teaching and the item regarding the desire to teach interdisciplinary science.

Due to only approximately 1% missing values, we applied pairwise deletion (Rosseel et al., 2020). Because of non-normality and ordinal values we used the weighted least squares means and variance adjusted (WLSMV) estimator (Brown, 2006). In addition, the WLSMV estimator has less restrictive requirements regarding the sample size, e.g., compared with the WLS estimator (Brown, 2006). According to Little (2013), the sample size was suitable, since far more than 120 participants were part of the sample. To evaluate the fit of our models, we applied the following more liberal guidelines from Wheaton et al. (1977) and Little (2013) as minimum requirements: χ^2/degrees of freedom ≤ 5, comparative fit index (CFI) > 0.90, Tucker-Lewis index (TLI) > 0.90, root mean square error of approximation (RMSEA) < 0.10.

Before identifying influencing factors, we checked the stability of the subscales of the SElf-ST and ensured that they can be replicated in a larger and more diverse sample ($n = 589$) with a confirmatory factor analysis (Conway and Huffcutt, 2003). The theoretically expected model with ten latent factors (Figure 1) showed a very good fit: CFI = 0.95, TLI = 0.95, RMSEA = 0.06, 90% confidence interval = 0.05–0.06 (*cf.* Handtke and Bögeholz, 2019b, 2020a; 590 participants included in the validation study, but 589 could be used for the confirmatory factor analysis). In addition, the ratio of chi-square to degrees of freedom (2.87) supports this classification. The χ^2-statistic was significant: $\chi^2(734) = 2103.18$, $p < 0.001$. However, the chi-square test is sensitive to a moderately large sample and tests for an exact fit; thus, the chi-square statistic should be neglected (Little, 2013).

The standardized loadings of the 41 items ranged from 0.62 to 0.89, and only eight items had loadings under 0.7 (see Supplementary Material S1 Measure, Table A). According to Moosbrugger and Kelava (2012), the reliability of all subscales ranging from 0.72 to 0.88 was satisfactory (see Supplementary Material S1 Measure, Table A; *cf.* Handtke and Bögeholz, 2019b, 2020a). The shortened names of the ten subscales are in Figure 1 and the full names of the factors are in Tables 3–6 and in Supplementary Material S1 Measure, Table A. The intercorrelations between the different subscales are reported in Supplementary Material S2 Intercorrelations, Table B and the model-implied correlation matrix of the observed variables is presented in Supplementary Material S3 Inter-item correlations, Tables C1, C2. According to Handtke and Bögeholz (2019a), *Applying Media* (F2) and *Applying Methods of Evaluation* (F7) are rather generic subscales, while *Including Science-Specific and General Instructional Strategies* (F9) is partly science-teaching-specific and partly generic. The other seven factors are science-teaching-specific (Handtke and Bögeholz, 2019a). The confirmatory factor analysis indicated the SElf-ST to be appropriate for identifying influencing factors on the self-efficacy beliefs. Handtke and Bögeholz (2020a) already presented arguments for construct validity of the SElf-ST.

We used structural equation modeling to test the hypotheses 1–3 (research question 1) and research question 2 with the ten factors of self-efficacy beliefs of interdisciplinary science teaching as the dependent variables. Figure 2 shows the schema of the four different structural equation models only including different numbers and types of predictors as independent variables.

Considering other studies investigating the impact of different factors on science teaching self-efficacy beliefs (e.g., Lumpe et al., 2012),

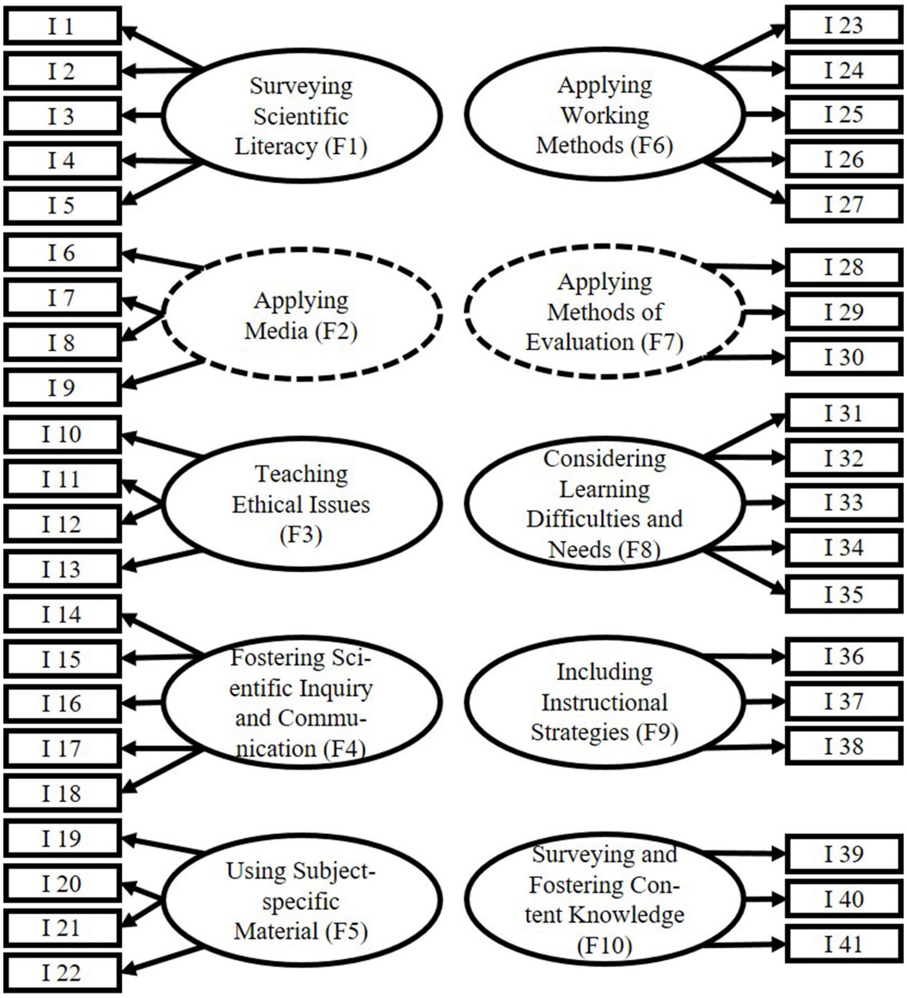

FIGURE 1
Measurement model of the self-efficacy beliefs of interdisciplinary science teaching. The computed correlations between the ten factors are not shown, so that the illustration remains clear. They are reported in Supplementary Material S2 Intercorrelations, Table B of the factors. Factor 2 and 7 are generic and thus dashed. The items and full factor names can be found in Supplementary Material S1 Measure, Table A. F, factor; I, item.

TABLE 3 Structural equation model of the teaching experience on the self-efficacy beliefs of interdisciplinary science teaching ($n = 587$).

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Trainee teachers (predictor 1)										
β	**0.09**	0.04	−0.01	0.06	0.06	0.02	−0.02	−0.05	0.04	0.01
CI-95%	0.01 – 0.17	−0.05 – 0.14	−0.10 – 0.08	−0.03 – 0.14	−0.04 – 0.15	−0.06 – 0.10	−0.10 – 0.07	−0.14 – 0.04	−0.05 – 0.13	−0.07 – 0.10
SE	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.05	0.04
Value of *p*	0.039	0.359	0.823	0.177	0.223	0.633	0.714	0.261	0.395	0.782
In-service teachers (predictor 2)										
β	**0.16**	**0.10**	**0.16**	**0.17**	**0.15**	**0.18**	**0.15**	**0.13**	**0.24**	0.07
CI-95%	0.07 – 0.25	0.01 – 0.18	0.08 – 0.24	0.09 – 0.25	0.07 – 0.23	0.09 – 0.27	0.06 – 0.23	0.04 – 0.22	0.15 – 0.33	−0.01 – 0.16
SE	0.05	0.05	0.04	0.04	0.04	0.05	0.04	0.05	0.05	0.04
Value of *p*	< 0.001	0.034	< 0.001	< 0.001	< 0.001	< 0.001	0.001	0.004	< 0.001	0.099

Two dummy coded variables (predictor 1 and 2, see Figure 2) for pre-service, trainee, and in-service teachers. The pre-service teachers are the reference group. β, standardized regression coefficient; CI-95%, 95% confidence interval; SE, standard error. Bold values are significant ($p < 0.05$). F1, Surveying Dimensions of Scientific Literacy; F2, Applying Media; F3, Teaching Ethically Relevant Issues of Applied Science; F4, Differentiated Fostering of Scientific Inquiry and Communication in Science; F5, Using Subject-Specific Materials in Science; F6, Applying Natural Scientific Working Methods; F7, Applying Methods of Evaluation; F8, Considering Learning Difficulties and Needs of Students in Science; F9, Including Science-Specific and General Instructional Strategies; F10, Surveying and Fostering Natural Scientific Content Knowledge.

TABLE 4 Structural equation model of the number of studied science subjects on the self-efficacy beliefs of interdisciplinary science teaching (*n* = 589).

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Number of science subjects studied (predictor 1)										
β	**0.13**	−0.02	**0.10**	**0.14**	**0.13**	**0.18**	0.05	**0.20**	**0.11**	**0.16**
CI-95%	0.04 – 0.21	−0.12 – 0.07	0.02 – 0.19	0.06 – 0.23	0.05 – 0.22	0.10 – 0.27	−0.04 – 0.14	0.11 – 0.29	0.02–0.20	0.07 – 0.24
SE	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.04
Value of *p*	0.003	0.608	0.017	0.001	0.003	< 0.001	0.256	< 0.001	0.020	< 0.001

One dummy coded variable (predictor 1, see Figure 2) for one or minimum two science subjects. β, standardized regression coefficient; CI-95%, 95% confidence interval; SE, standard error. Bold values are significant ($p < 0.05$). F1, Surveying Dimensions of Scientific Literacy; F2, Applying Media; F3, Teaching Ethically Relevant Issues of Applied Science; F4, Differentiated Fostering of Scientific Inquiry and Communication in Science; F5, Using Subject-Specific Materials in Science; F6, Applying Natural Scientific Working Methods; F7, Applying Methods of Evaluation; F8, Considering Learning Difficulties and Needs of Students in Science; F9, Including Science-Specific and General Instructional Strategies; F10, Surveying and Fostering Natural Scientific Content Knowledge.

TABLE 5 Structural equation model of the desire to teach interdisciplinary science on the self-efficacy beliefs of interdisciplinary science teaching (*n* = 574).

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Desire to teach interdisciplinary science (predictor 1)										
β	**0.16**	**0.10**	**0.15**	**0.18**	**0.37**	**0.28**	**0.10**	**0.29**	**0.20**	**0.28**
CI-95%	0.08 – 0.25	0.01 – 0.20	0.07 – 0.23	0.10 – 0.27	0.31 – 0.44	0.20 – 0.35	0.01 – 0.18	0.21 – 0.37	0.11 – 0.28	0.21 – 0.36
SE	0.04	0.05	0.04	0.04	0.03	0.04	0.05	0.04	0.05	0.04
Value of *p*	< 0.001	0.032	< 0.001	< 0.001	< 0.001	< 0.001	0.031	< 0.001	< 0.001	< 0.001

One Likert-Scale item (predictor 1, see Figure 2) about the desire to teach interdisciplinary science. β, standardized regression coefficient; CI-95%, 95% confidence interval; SE, standard error. Bold values are significant ($p < 0.05$). F1, Surveying Dimensions of Scientific Literacy; F2, Applying Media; F3, Teaching Ethically Relevant Issues of Applied Science; F4, Differentiated Fostering of Scientific Inquiry and Communication in Science; F5, Using Subject-Specific Materials in Science; F6, Applying Natural Scientific Working Methods; F7, Applying Methods of Evaluation; F8, Considering Learning Difficulties and Needs of Students in Science; F9, Including Science-Specific and General Instructional Strategies; F10, Surveying and Fostering Natural Scientific Content Knowledge.

TABLE 6 Structural equation model of the individual science subjects studied on the self-efficacy beliefs of interdisciplinary science teaching (*n* = 589).

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Studied biology (predictor 1)										
β	0.10	−0.05	**0.21**	**0.14**	0.09	**0.17**	0.07	**0.21**	0.12	0.11
CI-95%	−0.01 – 0.21	−0.18 – 0.07	0.09 – 0.32	0.02 – 0.26	−0.04 – 0.21	0.05 – 0.29	−0.05 – 0.19	0.08 – 0.33	−0.01 – 0.24	−0.01 – 0.23
SE	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Value of *p*	0.074	0.418	< 0.001	0.025	0.168	0.005	0.271	0.001	0.066	0.073
Studied chemistry (predictor 2)										
β	**0.16**	0.00	0.05	**0.16**	**0.17**	**0.22**	0.05	**0.22**	**0.13**	**0.20**
CI-95%	0.06 – 0.26	−0.11 – 0.11	−0.05 – 0.15	0.06 – 0.27	0.06 – 0.27	0.11 – 0.32	−0.06 – 0.15	0.11 – 0.33	0.02 – 0.24	0.10 – 0.31
SE	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.05
Value of *p*	0.002	0.995	0.332	0.002	0.002	< 0.001	0.390	< 0.001	0.025	< 0.001
Studied physics (predictor 3)										
β	0.10	0.03	0.07	0.04	**0.14**	**0.19**	0.03	**0.14**	0.10	0.03
CI-95%	−0.02 – 0.22	−0.10 – 0.17	−0.05 – 0.19	−0.08 – 0.17	0.02 – 0.27	0.07 – 0.32	−0.09 – 0.15	0.01 – 0.27	−0.04 – 0.23	−0.10 – 0.15
SE	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.06
Value of *p*	0.086	0.652	0.278	0.498	0.025	0.002	0.628	0.033	0.157	0.680

Three effect-coded variables (predictor 1, 2, and 3, see Figure 2) for biology, chemistry, and physics as the studied subjects. β, standardized regression coefficient; CI-95%, 95% confidence interval; SE, standard error. Bold values are significant ($p < 0.05$). F1, Surveying Dimensions of Scientific Literacy; F2, Applying Media; F3, Teaching Ethically Relevant Issues of Applied Science; F4, Differentiated Fostering of Scientific Inquiry and Communication in Science; F5, Using Subject-Specific Materials in Science; F6, Applying Natural Scientific Working Methods; F7, Applying Methods of Evaluation; F8, Considering Learning Difficulties and Needs of Students in Science; F9, Including Science-Specific and General Instructional Strategies; F10, Surveying and Fostering Natural Scientific Content Knowledge.

we assume a significant standardized regression coefficient of ≥ 0.1 to be relevant. The predictors for hypotheses 1 and 2 were dummy coded (Cohen et al., 2003). Regarding hypothesis 1 (teaching experience), we used two independent dummy variables (predictor 1 and 2) due to three groups of interest: pre-service teachers, trainee teachers, and in-service teachers. The pre-service teachers were the reference group for

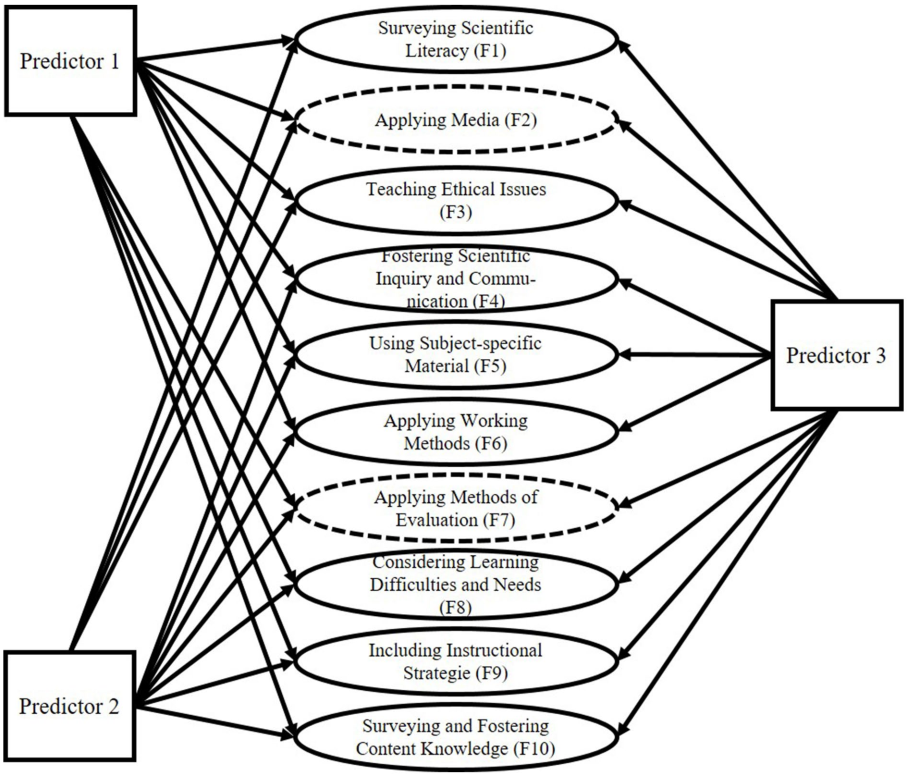

FIGURE 2
Theoretical schema of the structural equation models (hypotheses 1, 2, 3, and research question 2). The structural equation models regarding hypothesis 2 and 3 contain one predictor each, the structural equation model for hypothesis 1 integrates two predictors, and the structural equation model for research question 2 comprises three predictors. The full factor names can be found in Supplementary Material S1 Measure, Table A.

both variables, since we wanted to investigate the influence of the growing teaching experience. Thus, pre-service teachers were always coded 0. One predictor was coded 1 for being a trainee teacher and 0 for in-service teachers; the other predictor was coded 1 for being an in-service teacher and 0 for trainee teachers. In addition, we want to describe the different groups of teacher education and in-service teachers and their absolute level of self-efficacy beliefs. Thus, we additionally display the means of all factors in Figure 3. The use of means seemed acceptable after checking the factor structure more severely with ordinal values. Thus, we also provide factors' and items' means of the total sample in Supplementary Material S1 Measure, Table A. Regarding hypothesis 2 (studied subjects), we used one independent dummy variable (predictor 1) with two groups (0 = one science subject studied vs. 1 = at least two science subjects studied). Regarding hypothesis 3 (desire to teach interdisciplinary science), we used a single item with a four-point response scale as the independent variable (predictor 1). We used one item, since we wanted to implement the desire as a briefly surveyed predictor without burdening the participants.

The subjects for research question 2 were computed with effects coding (Cohen et al., 2003). Since we want to know the effect of each subject out of biology, chemistry, and physics, we cannot determine one of these groups as the reference group. Thus, we cannot use dummy coding for research question 2. In order to use effects coding, we calculated one independent variable for each subject out of biology, chemistry, and physics (predictor 1, 2, and 3) with two forms each. For example, for the biology variable, if biology in any combination was studied, it was coded 1, and −1 if not. This results in a comparison of persons studying biology as one subject to the mean of the whole sample (Cohen et al., 2003). We also conducted this approach for chemistry and physics. Thus, the three effects were controlled by each other in the structural equation model of research question 2. This is necessary due to at least two studied subjects per participant. The variables represent the effects of studying the individual subjects in comparison to the whole sample.

5. Results

5.1. Research question 1: influencing factors on self-efficacy beliefs of interdisciplinary science teaching

5.1.1. Hypothesis 1 regarding teaching experience

First, we want to provide absolute levels of self-efficacy beliefs – specified for ten factors – with regard to different amounts of teaching experience. Thus, we display the boxplots and means of the factors for the three groups pre-service, trainee, and in-service teachers in Figure 3. The means for pre-service teachers ranged from 2.82 to 3.31, for trainee teachers from 2.85 to 3.38, and for in-service teachers from 3.11 to 3.50.

Concerning hypothesis 1 ($n = 587$, $\chi^2/df = 2.76$, CFI = 0.96, TLI = 0.95, RMSEA = 0.06, 90% confidence interval = 0.05–0.06), Table 3

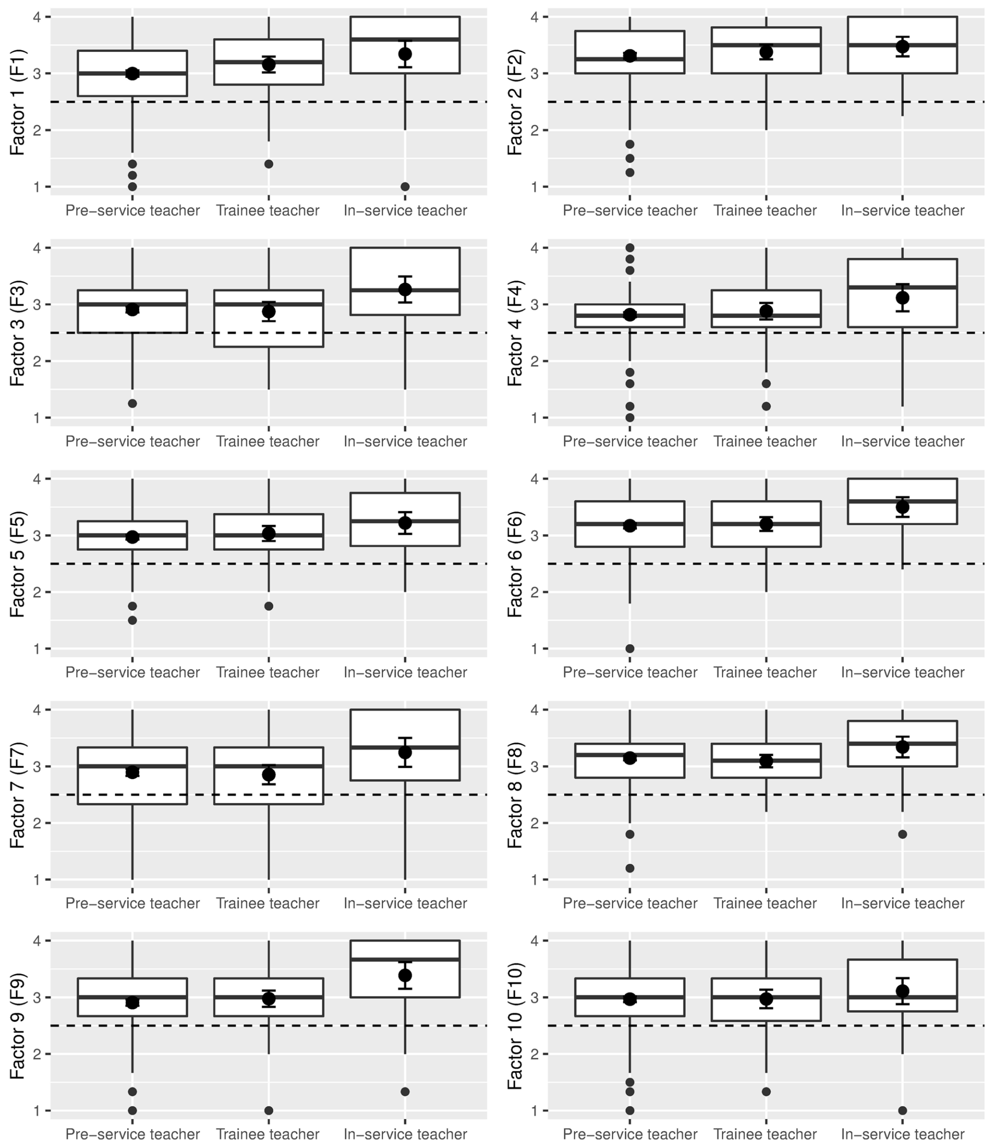

FIGURE 3
Self-efficacy beliefs of interdisciplinary science teaching of the pre-service, trainee, and in-service teachers (n = 587). Boxplots, means, and error bars (95% confidence interval). Measured on a four-point Likert scale: "Is not right" (1), "Is a little right" (2), "Is rather right" (3), and "Is exactly right" (4) (Handtke and Bögeholz, 2019a, p. 8). The dashed cross line indicates the scale's middle of 2.5. F1, Surveying Dimensions of Scientific Literacy; F2, Applying Media; F3, Teaching Ethically Relevant Issues of Applied Science; F4, Differentiated Fostering of Scientific Inquiry and Communication in Science; F5, Using Subject-Specific Materials in Science; F6, Applying Natural Scientific Working Methods; F7, Applying Methods of Evaluation; F8, Considering Learning Difficulties and Needs of Students in Science; F9, Including Science-Specific and General Instructional Strategies; F10, Surveying and Fostering Natural Scientific Content Knowledge.

shows that the trainee teachers only have an advantage in *Surveying Dimensions of Scientific Literacy* (F1; β = 0.09, p < 0.05) when compared to the pre-service teachers. However, the size of the standardized regression coefficient is rather irrelevant according to our benchmark of 0.1 (see Analyses section). The other latent factors show no differences for trainee teachers.

In contrast, in-service teachers had higher self-efficacy beliefs than pre-service teachers on nine of the ten factors (Table 3; F1–9; β = 0.10–0.24, p < 0.05). Only *Surveying and Fostering Natural Scientific Content Knowledge* (F10) indicates no difference. These values fit the absolute means in Figure 3, demonstrating nearly no difference between pre-service and trainee teachers and stronger self-efficacy beliefs for in-service teachers.

5.1.2. Hypothesis 2 regarding number of studied science subjects

With respect to hypothesis 2 (n = 589, χ^2/df = 2.76, CFI = 0.95, TLI = 0.95, RMSEA = 0.06, 90% confidence interval = 0.05–0.06), the number of studied science subjects showed differences for eight science-teaching-specific out of ten factors of self-efficacy beliefs of interdisciplinary science teaching (Table 4; β = 0.10–0.20, p < 0.05). Only the generic teaching factors *Applying Media* (F2) and *Applying*

Methods of Evaluation (F7) are not influenced by the number of studied science subjects ($p > 0.05$).

5.1.3. Hypothesis 3 regarding desire to teach interdisciplinary science

Concerning hypothesis 3 ($n = 574$, χ^2/df = 2.10, CFI = 0.96, TLI = 0.96, RMSEA = 0.04, 90% confidence interval = 0.04–0.05), the desire to teach interdisciplinary science has a statistically significant effect on each of the ten factors of the self-efficacy beliefs of interdisciplinary science teaching (Table 5; $\beta = 0.10–0.37$, $p < 0.05$). Among these factors, the generic teaching factors *Applying Media* (F2) and *Applying Methods of Evaluation* (F7) are influenced rather low (dashed factors in Figure 2; $\beta = 0.10$, $p < 0.05$).

5.2. Research question 2: impact of individual science subjects studied (biology, chemistry, or physics) on self-efficacy beliefs of interdisciplinary science teaching

The results of research question 2 regarding the individual impact of studying biology, chemistry, or physics show a more complex structure (Table 6; χ^2/df = 2.40, CFI = 0.96, TLI = 0.96, RMSEA = 0.05, 90% confidence interval = 0.05–0.05). The generic teaching factors *Applying Media* (F2) and *Applying Methods of Evaluation* (F7) are not specifically influenced by studying biology, chemistry, or physics. *Teaching Ethically Relevant Issues of Applied Science* (F3) is only impacted by studying biology ($\beta = 0.21$, $p < 0.01$). The science-teaching-specific factors *Applying Natural Scientific Working Methods* (F6) and *Considering Learning Difficulties and Needs of Students in Science* (F8) are positively associated with studying each of the three science subjects ($\beta = 0.14–0.22$, $p < 0.05$). The other factors (F1, 4, 5, 9, and 10) are influenced by studying one or two science subjects in different combinations of impact patterns. However, studying chemistry influenced seven of the eight science-teaching-specific factors. The exception is *Teaching Ethically Relevant Issues of Applied Science* (F3). *Surveying Dimensions of Scientific Literacy* (F1), *Including Science-Specific and General Instructional Strategies* (F9), and *Surveying and Fostering Natural Scientific Content Knowledge* (F10) are influenced by studying chemistry exclusively ($\beta = 0.13–0.20$, $p < 0.05$).

6. Discussion

This paper explores the possible impact of influencing factors such as teaching experience, science subjects studied, and the desire to teach interdisciplinary science on the self-efficacy beliefs of interdisciplinary science teaching in secondary education. On the one hand, previous results transferred from primary education were examined for secondary education (research question 1 and hypotheses 1–3). On the other hand, we focused on the so far unknown individual impact of studying biology, chemistry, or physics on the self-efficacy beliefs of interdisciplinary science teaching (research question 2). Identifying the role of these influencing factors could provide starting points for improving teacher education and (prospective) teachers' self-efficacy beliefs for teaching the new and difficult subject interdisciplinary science.

With regard to teaching experience, being a trainee teacher made nearly no difference compared to being a pre-service teacher. Those having teaching experience as an in-service teacher had higher self-efficacy beliefs of interdisciplinary science teaching than pre-service teachers in almost all factors. The number of science subjects studied and the desire to teach interdisciplinary science particularly influenced the eight science-teaching-specific factors of the self-efficacy beliefs of interdisciplinary science teaching. Thus, the first major contribution of this paper is the empirical evidence that the findings of previous research in primary education seem to be transferable to the context of secondary education. In addition, we revealed a possible exception for trainee teachers' teaching experience. The second major contribution of this paper is the so far unknown impact of biology, chemistry, and physics on the self-efficacy beliefs of interdisciplinary science teaching in secondary education. The results indicate that all science subjects have some kind of an impact. However, studying chemistry influenced seven of the eight science-teaching-specific factors, among them three factors exclusively.

6.1. Research question 1: influencing factors on self-efficacy beliefs of interdisciplinary science teaching

6.1.1. Hypothesis 1 regarding teaching experience

The impact of the teaching experience (comparing pre-service, trainee, and in-service teachers) shows clear patterns. The in-service teachers had the strongest self-efficacy beliefs of interdisciplinary science teaching in secondary education, while the pre-service teachers and trainee teachers were at a similar lower level, with one exception each: The weak impact of trainee teachers' teaching experience on *Surveying Dimensions of Scientific Literacy* (F1) indicates that trainee teachers perhaps are a little more familiar with scientific literacy than pre-service teachers. The missing impact of in-service teachers' teaching experience on *Surveying and Fostering Natural Scientific Content Knowledge* (F10) could be explained by content knowledge being the main focus when studying at university as a pre-service teacher (Kleickmann et al., 2013).

Due to increasing teaching experience, we expected higher self-efficacy beliefs of interdisciplinary science teaching for trainee teachers in comparison to pre-service teachers. This was not the case. Rather, we found no difference between pre-service teachers' and trainee teachers' self-efficacy beliefs of interdisciplinary science teaching. We assume several possible reasons for this unexpected result:

1. The group of trainee teachers consisted of 25% lateral entrants to the teaching profession without any teaching experience before the traineeship. This missing teaching experience possibly results in lower self-efficacy beliefs of interdisciplinary science teaching.
2. Another possible reason is whether the teaching experience is positive or negative (Bandura, 1997). Negative teaching experiences could weaken the self-efficacy beliefs of interdisciplinary science teaching (Bandura, 1997). A certain number of trainee teachers could have negative teaching experiences because of the so-called "reality shock." For example, as they are confronted the first time with the everyday life of being a school teacher, they could realize the complexity of teaching (Veenman, 1984; Tschannen-Moran et al., 1998). Thus, trainee teachers, perhaps, simply have a (more) realistic view of their abilities.

3. In line with that argument, it seems possible that pre-service teachers with little or no teaching experience overestimate their abilities (Settlage et al., 2009; Kazempour, 2013). They could have limited expectations of the skills needed for interdisciplinary science teaching (*cf.* for biology: Mavrikaki and Athanasiou, 2011) or underestimate the difficulty and complexity of required tasks (Hoy and Spero, 2005). These reasons could result in pre-service teachers' inflated self-efficacy beliefs of interdisciplinary science teaching. Our sample could be skewed by this issue, since the bachelor students (48.7% of the sample) had only taught 2.9 lessons in a science subject, on average, with a median of 0 (see Table 2).

In contrast, we expected in-service teachers to be those with the highest self-efficacy beliefs of interdisciplinary science teaching. This is supported by the highest mean of all groups. The in-service teachers of our sample were rather experienced as they had conducted 9.9 years of teaching at a school on average (median = 8), probably including more and more positive teaching experiences over time. Thus, we can assume that – in contrast to the potentially "shocked" trainee teachers – they have the abilities required and know the obstacles to overcome in everyday teaching. This argument is supported by the fact that 31 of the 38 in-service teachers already taught interdisciplinary science or were doing it at the time of the study. The intensive direct experience expressed via years of teaching (discipline-specific and interdisciplinary science) probably resulted in higher self-efficacy beliefs (Bandura, 1997). Mavrikaki and Athanasiou (2011, p. 207) support this assumption, stating for biology: "As the years of teachers' experience increase, so does their self-efficacy beliefs."

In sum, our results indicate that teaching experience could play a critical role in self-efficacy beliefs. Teaching experience could increase self-efficacy beliefs of interdisciplinary science teaching (e.g., Lumpe et al., 2012) - at least for "experts" of in-service teaching (teachers with approximately 10 years of experience on average). Based on our cross-sectional data, it does not seem to be reasonable to assume a straightforward linear growth of the self-efficacy beliefs of interdisciplinary science teaching with increasing teaching experience. Trainee teachers could suffer from a "reality shock" (Veenman, 1984; Tschannen-Moran et al., 1998), negatively influencing the perception of their teaching abilities.

6.1.2. Hypothesis 2 regarding number of studied science subjects

Another influencing factor having an impact on the self-efficacy beliefs of interdisciplinary science teaching was the number of science subjects studied. The greater the number of science subjects studied (i.e., more parts of interdisciplinary science), the higher the self-efficacy beliefs about science-teaching-specific factors. These results are in line with previous findings that pre-service primary teachers with science as a major hold higher self-efficacy beliefs of interdisciplinary science teaching than those with other majors (Joseph, 2010). The results plausibly did not account for the generic teaching factors *Applying Media* (F2) and *Applying Methods of Evaluation* (F7). As the factors' contents include beliefs about generic teaching, teacher studies for all subjects contribute to these topics. Thus, generic teaching self-efficacy beliefs do not especially benefit from more studied science subjects in contrast to other subjects. In sum, the results clearly underline the important role of studying multiple science subjects for the science-teaching-specific factors of self-efficacy beliefs of interdisciplinary science teaching during teacher education.

6.1.3. Hypothesis 3 regarding desire to teach interdisciplinary science

The third influencing factor investigated was the desire to teach interdisciplinary science. It had an impact on each factor of the self-efficacy beliefs of interdisciplinary science teaching. This result is plausible and extends the relationship of the desire to teach interdisciplinary science with the ten factors of self-efficacy beliefs of interdisciplinary science teaching (e.g., Enochs and Riggs, 1990; Menon and Sadler, 2016) to a prediction by the desire. However, the generic teaching factors *Applying Media* (F2) and *Applying Methods of Evaluation* (F7) are only influenced to a relatively small extent. An effect on generic teaching factors is plausible, since they are a part of teaching science as well. However, the subject-specific desire to teach interdisciplinary science should especially impact science-teaching-specific factors due to the context-specificity of self-efficacy beliefs (Tschannen-Moran et al., 1998; Park and Oliver, 2008), resulting in a stronger impact than on generic teaching factors. Overall, our investigation reveals the significant role of the desire to teach interdisciplinary science for the self-efficacy beliefs of interdisciplinary science teaching in secondary education.

6.2. Research question 2: impact of individual science subjects studied (biology, chemistry, or physics) on self-efficacy beliefs of interdisciplinary science teaching

The novel examination of the impact of the individual science subjects (biology, chemistry, or physics) on the self-efficacy beliefs of interdisciplinary science teaching uncovered a diverse image. Reasonably, the generic teaching factors *Applying Media* (F2) and *Applying Methods of Evaluation* (F7) are not influenced by one specific science subject due to the context-specificity of self-efficacy beliefs (Tschannen-Moran et al., 1998; Park and Oliver, 2008). In contrast, the science-teaching-specific factors *Applying Natural Scientific Working Methods* (F6) and *Considering Learning Difficulties and Needs of Students in Science* (F8) are positively influenced by studying all three science subjects. This is believable, since with working methods and learning difficulties these factors contain topics relevant to all science subjects. Moreover, *Teaching Ethically Relevant Issues of Applied Science* (F3) is understandably only impacted by studying biology. Compared to other science subjects, biology in particular addresses multiple topics to foster socioscientific reasoning and decision-making in school, such as different aspects of health, sexual self-determination, or livestock farming (Niedersächsisches Kultusministerium, 2015). Regarding the curriculum for physics, the options to foster socioscientific reasoning and decision-making are more limited (Niedersächsisches Kultusministerium, 2015).

The remaining factors (F1, F4, F5, F9, and F10) indicate different patterns concerning the impact of science subjects. *Surveying Dimensions of Scientific Literacy* (F1), *Including Science-Specific and General Instructional Strategies* (F9), and *Surveying and Fostering Natural Scientific Content Knowledge* (F10) are only influenced by studying chemistry. *Differentiated Fostering of Scientific Inquiry and Communication in Science* (F4) and *Using Subject-Specific Materials in Science* (F5) show the impact of two science subjects studied (F4: biology and chemistry, F5: chemistry and physics). Thus, the diverse patterns suggest that all science subjects have an impact on the self-efficacy beliefs of interdisciplinary science teaching.

In particular, studying chemistry had an impact on seven of the ten factors. Ignoring the generic teaching factors without any impact, only *Teaching Ethically Relevant Issues of Applied Science* (F3) does not especially benefit from chemistry studies. Overall, nearly all science-teaching-specific factors are influenced by studying chemistry, four by studying biology, and three by studying physics. Moreover, three factors are positively influenced exclusively by studying chemistry.

On the one hand, these findings reveal that all science subjects studied are important for the self-efficacy beliefs of interdisciplinary science teaching. On the other hand, biology, chemistry, and physics contribute to varying extents. Among them, studying chemistry could be important providing content that influences science-teaching-specific self-efficacy beliefs. Perhaps in interdisciplinary science teaching, chemistry content serves as a basis for certain biology and physics topics. For example, regarding lower secondary education, topics of biology such as cell respiration and neurophysiology and topics of physics such as thermodynamics or atomic physics show links to chemistry. In comparison, topics of biology and physics probably provide fewer links between each other. This could be a hint that studying chemistry prepares one more for the other unstudied science subjects than does studying biology or physics. Thus, chemistry could better prepare one for interdisciplinary science teaching in secondary education.

6.3. Limitations

Overall, the main limitations of our study are related to the sample used. This study focused mainly on pre-service teachers. Pre-service teachers were easy to access for the study and they were the most important target group of the "Qualitätsoffensive Lehrerbildung" (QLB). The QLB aims to advance German teacher education at universities. Nevertheless, the inclusion of even more trainee and in-service teachers in a sample would be desirable. It would allow, e.g., to investigate hypothesis 2 and research question 2 differentiated by the phase of teacher education. The sizes of the sub-samples of trainee (n = 68) and in-service teachers (n = 38) also do not allow the investigation of measurement invariance, e.g., for the different phases of teacher education (hypothesis 1). This has to be considered regarding the robustness of the results. A larger sample size also could allow the usage of all predictors in one structural equation model to consider possible effects between these predictors. In addition, the number of participants studying physics with a second science subject was limited. However, one explanation is that there are, in total, more biology and chemistry than physics pre-service teachers at German universities. For example, in the winter semester 2018/2019 at German universities 12,005 pre-service teachers studied biology, 5,369 chemistry, and 2,818 physics (and astronomy) in the first semester (Statistisches Bundesamt, 2019). However, it has to be stated that the distribution of the studied science subjects was not identical for pre-service, trainee, and in-service teachers. Especially the ones studying chemistry or physics with a non-science subject were different across the phases of teacher education. 25.8% of the pre-service teachers, 11.8% of the trainee teachers, and 15.8% of the in-service teachers studied chemistry with a second non-science subject. 15.2% of the pre-service teachers, 32.4% of the trainee teachers, and 7.9% of the in-service teachers studied physics with a second non-science subject. These distributions could also be improved in a future study.

Furthermore, the diverse distribution of teaching experience in and between the pre-service, trainee, and in-service teachers has to be considered. A large number of pre-service teachers in the Bachelor had no teaching experience at all (indicated by a median of 0). At the same time, some pre-service teachers had relatively often taught lessons in a science subject, resulting in an overall mean of 5.5 lessons for the pre-service teachers (standard deviation = 17). The group of trainee teachers consisted of 25% lateral entrants to the teaching profession without any teaching experience before the traineeship. This condition resulted in a broad distribution of teaching experience in the group of trainee teachers as well (mean = 164.1 lessons, standard deviation = 296). The in-service teachers' group also has a broad distribution of teaching experience (from 0.5 to 39 years). The mean and standard deviation (mean = 9.9 years, standard deviation = 9.2) also indicate that the group contains beginners and experienced in-service teachers. The presented values reveal an extremely heterogeneous distribution of teaching experience within and between the three groups. On the one hand, many different levels of teaching experience are integrated, ensuring the representativeness of the sample. On the other hand, this distribution leads to extreme comparisons of pre-service teachers with zero experience and in-service teachers with decades of teaching experience (maximum = 39 years). In addition to the cross-sectional design, these characteristics of our sample must be kept in mind when looking at the differences in the self-efficacy beliefs of interdisciplinary science teaching.

Another issue could be a possible confoundation of the predictors of actual status of teaching experience and the studied science subjects. The distribution of the studied science subjects in the group of in-service teachers rather denies such a confoundation. Biology (single and in combination) is studied by 27 in-service teachers and chemistry (single and in combination) is studied by 23 in-service teachers. That the teaching experience is responsible for the influence of the individual science subjects in the whole sample is unlikely, since the sample only contains 6.5% in-service teachers.

Further, the investigation of teaching experience only made sense indirectly by the groups of participants classified as pre-service teachers, trainee teachers, or in-service teachers. A regression analysis or structural equation model with teaching experience as the independent variable was not reasonable due to several reasons. While we asked pre-service and trainee teachers to indicate how many lessons they have taught in science subjects so far, we asked the in-service teachers to indicate the years they taught at school (e.g., 39 years). Therefore, a structural equation model with a common predictor was hardly possible. Even for trainee teachers, the indication of the number of taught lessons was hardly reasonable (e.g., more than 1,000 lessons). Furthermore, they were less reliable due to the estimation of taught lessons. In addition, we do not know if the experience (i.e., the taught lessons) was judged as positive or negative. Also, we cannot determine, whether the discipline-specific or interdisciplinary teaching experience of in-service teachers leads to the higher self-efficacy beliefs in comparison to pre-service and trainee teachers. Moreover, the group of in-service teachers only teaching discipline-specific science was too small for such a comparison.

Finally, the overall impact of the reimbursement can be disregarded (Handtke and Bögeholz, 2020a). When we investigated the effect with a structural equation model dummy coded (0 = *no reimbursement*, 1 = *reimbursement*), only one factor showed an effect: *Applying Media* was positively influenced by the variable for reimbursement ($\beta = 0.15$, $SE = 0.04$, $p < 0.01$) to some extent (Handtke and Bögeholz, 2020a).

7. Future research and conclusion

Future research should further explore the development of (prospective) teachers' self-efficacy beliefs through the years of teacher education and teaching at a secondary school in longitudinal studies. These studies could, e.g., also further investigate the existence and role of the so-called "reality shock" (Veenman, 1984; Tschannen-Moran et al., 1998) and the effect of discipline-specific (or general teaching) and interdisciplinary science teaching experience in comparison. In addition, an examination of the effect of negative teaching experience on the self-efficacy beliefs is of interest as well.

In the context of self-rated content knowledge of biology, chemistry, and physics, we already revealed a positive effect of studying the subject of the self-rated content knowledge in question or multiple science subjects (Handtke and Bögeholz, 2020b, 2022). Regarding non-corresponding science subjects studied, only studying chemistry had a positive effect on the self-rated content knowledge in physics (Handtke and Bögeholz, 2020b, 2022). In addition, only the self-rated content knowledge of chemistry has not only no negative correlations with the self-rated content knowledge of biology and physics, but also a positive correlation with physics (Handtke and Bögeholz, 2020b, 2022). In the paper at hand, we identified the advantage of studying more than one science subject for the self-efficacy beliefs of interdisciplinary science teaching. These results indicate that more training in previously unstudied science subjects could support (prospective) teachers for teaching interdisciplinary science. Furthermore, the findings point to the possibility that studying chemistry could be crucial for interdisciplinary science in secondary education to some degree. Combining these results, it could be reasonable to suggest to policy-makers and teacher educators that prospective pre-service teachers for secondary education should study science subjects such as biology or physics in combination with chemistry. Corresponding mandatory subject combinations could be one option for future prospective teachers. However, the apparent special status of chemistry needs more investigation. Although we focused on PCK with the SElf-ST (Handtke and Bögeholz, 2019a) and on content knowledge with the self-rated content knowledge (Handtke and Bögeholz, 2020b, 2022), further research could focus the specifics of chemistry for interdisciplinary science teaching regarding both aspects. Perhaps there are other reasons such as that chemistry contains concepts that are helpful to identify connections between the three science subjects. In addition, evaluation studies are necessary to find out more about the specific effect of studying more subjects in emerging study programs such as certificates for teaching interdisciplinary science (e.g., Eggert et al., 2018). First results revealed positive effects of a biology content course on the self-rated content knowledge of biology of pre-service chemistry and physics teachers (Handtke and Bögeholz, 2022).

Since the desire to teach interdisciplinary science could be a factor influencing the self-efficacy beliefs of interdisciplinary science teaching in secondary education, the origins and sources of a strong desire to teach interdisciplinary science should be further explored. What constitutes the desire to teach interdisciplinary science? What are the settings, conditions, and measures to foster the desire to teach interdisciplinary science? These questions need further (qualitative) research to broaden the knowledge base regarding the desire to teach interdisciplinary science. Based on the results of such research, teacher education researchers and teacher educators could adopt teacher education.

In sum, this paper makes a valuable contribution to the field by providing starting points to improve teacher education for interdisciplinary science education. We present empirical hints that teaching experience (comparing pre-service, trainee, and in-service teachers), the number of science subjects studied, and the desire to teach interdiscplinary science could play an important role for the self-efficacy beliefs of interdisciplinary science teaching in secondary education. Our work adds results to the so far neglected body of research regarding interdisciplinary science teaching in secondary education and extends it beyond primary education (Blonder et al., 2014). This includes the three influencing factors transferred from primary education and the so far unexplored impact of the individual science subjects studied. Our results provide hints for policy-makers and teacher educators to possibly improve teacher education to help prospective teachers to better tackle the new and difficult challenge of interdisciplinary science teaching. The use of the theory-based and multidimensional measurement instrument SElf-ST in the context of secondary education ensured the consideration of the most recent requirements of science teacher education in our study.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

Ethical approval was not required for the studies involving humans because it is voluntary at the University of Göttingen and we identified no critical or problematic ethical aspects in our study. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SB, KvK, and SaSc: conceptualization and methodology. KvK: data curation, formal analysis, investigation, and writing – original draft preparation. SB: funding acquisition, project administration, and supervision. SB and KvK: visualization. SB and SaSc: writing – review and editing. All authors contributed to the manuscript revision, read, and approved the submitted version.

Funding

This project is part of the "Qualitätsoffensive Lehrerbildung," a joint initiative of the Federal Government and the *Länder,* which aims to improve the quality of teacher training. The program was funded by the Federal Ministry of Education and Research (reference number SPL first phase: 01JA1617, SPL second phase: 01JA1917). The authors are responsible for the content of this publication.

SPONSORED BY THE

Federal Ministry of Education and Research

Acknowledgments

The authors thank all participants who were part of this study. We also want to express special thanks to Monika Oberle for her valuable input during the development of the measurement. Parts of this manuscript (in a previous manuscript version) are part of the publication-based dissertation of the corresponding author Handtke (2021). We acknowledge support by the Open Access Publication Funds of the Göttingen University.

Conflict of interest

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

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2023.1147441/full#supplementary-material

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