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Self-Efficacy Beliefs as well as Perceived Advantages and Challenges of Interdisciplinary Science Teaching from a Longitudinal Perspective

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Abstract: The advantages and challenges of interdisciplinary science teaching and the respective qualification of teachers are an ongoing topic of discussion, especially in countries with no or only partly interdisciplinary science teaching in secondary education. For example, German secondary science teacher education is almost exclusively discipline-specific. Up to now, research does not focus on the effect of German teacher education qualifying for interdisciplinary science teaching in secondary education from a longitudinal perspective. Thus, we were interested in the influence of current German science teacher education over time: Do (prospective) teachers believe they are capable of interdisciplinary science teaching (i.e., self-efficacy beliefs)? How do their beliefs develop during teacher education? Which advantages and challenges do they perceive regarding interdisciplinary science teaching? Do their perceptions change over time? We surveyed 271 (prospective) biology, chemistry, and physics teachers in 2019, 2020, and 2021. Examining the absolute stability (i.e., the change in the mean) of the self-efficacy beliefs showed no significant changes. Analyzing the relative stability (i.e., the change in the rank order) of the self-efficacy beliefs showed middle and positive correlations between the measurements of neighboring time points. The prospective teachers agreed in majority (>50%) with nine out of seventeen advantages and seven out of seventeen challenges of interdisciplinary science teaching. Three advantages reached over 70% approval: *Cross-linking content*, *Addressing key problems*, and *Promoting interest in science*. Four challenges reached over 70% approval: *Lack of teacher education*, *Out-of-field teaching*, *Lack of depth in content*, and *Low motivation of teachers due to low affinity to and education in the subject*. Neither do the perceptions change strongly between the time points (absolute and relative stability) nor are they very stable. Moreover, it seems that the (prospective) teachers realize the complexity of interdisciplinary science teaching, e.g., regarding experimentation or missing material, with progressing teacher education. The results, rather including no positive effect of two years of teacher education on self-efficacy beliefs, reveal obstacles for teacher education as well as starting points to support (prospective) teachers regarding interdisciplinary science teaching.

Keywords: longitudinal study; self-efficacy beliefs; interdisciplinary science teaching; teacher education; prospective teachers; advantages; challenges

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1. Introduction

In some countries such as the United States of America, STEM or even STEAM, i.e., science, technology, engineering, arts, and math, is already being discussed as an integrated subject (e.g., [1–3]). Integrative STEM education is defined by Sanders [4] (p. 21) as "teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects".

In other countries, the integration of biology, chemistry, and physics is an issue for now: There is an ongoing debate in Europe whether science should be taught in a discipline-specific or interdisciplinary way. This is shown by the fact that some European countries teach science in a discipline-specific and some teach it in an interdisciplinary way [5].

A differentiated approach is followed by Germany. In Germany, science is taught in a discipline-specific and in an interdisciplinary way, depending on the type of school, the grade level, and the federal state curricula [6,7]. At the same time, German science teacher education is almost exclusively organized in a discipline-specific way, separated into biology, chemistry, and physics [8]. Such hurdles make interdisciplinary science teaching complicated and lead in part to out-of-field teaching (e.g., [9,10]). Therefore, on the one hand, we want to know if (prospective) biology, chemistry, and physics teachers believe they are capable of interdisciplinary science teaching and if these beliefs develop over teacher education. Thus, we examine their self-efficacy beliefs of interdisciplinary science teaching; self-efficacy beliefs describe the "beliefs in one's capabilities to organize and execute courses of action required to produce given attainments" [11] (p. 3). On the other hand, we want to find out how (prospective) biology, chemistry, and physics teachers perceive the advantages and challenges of interdisciplinary science teaching over time. This investigation provides insights into the opinion of (prospective) teachers who may have to teach this subject. In sum, this paper points out whether teacher education has an influence on (prospective) teachers' self-efficacy beliefs of teaching the subject of interdisciplinary science and how they perceive teaching science interdisciplinarily.

2. Theoretical Background

2.1. Interdisciplinary Science Teaching and German Teacher Education

In Europe, science is taught in a discipline-specific or interdisciplinary way in lower secondary education, depending on the specific country [5]. In Germany, grammar schools and comprehensive schools are the main school types for lower secondary education. While science is taught interdisciplinarily exclusively in some 5./6. classes of the grammar school [6], interdisciplinary science teaching has its origin and is mainly taught in the comprehensive schools in Germany [12]. For example, interdisciplinary science is taught from classes 5 to 10 in comprehensive schools in Lower Saxony, which is one of the German federal states [7].

At the same time, (prospective) teachers in Germany go through three stages of teacher education before becoming an in-service teacher at school: Bachelor program for teaching profession (three years), Master of Education program (two years), and traineeship (from 18 months to two years) [8]. We summarize all individuals in these three stages of teacher education and the in-service teachers at school with the term *(prospective) teachers*. This paper uses the following wording: *pre-service teachers* focuses on Bachelor and Master of Education students, *trainee teachers* relates to those in traineeship, and *in-service teachers* are professional teachers at school.

In contrast to the (partial) integration of interdisciplinary science in German schools, German science teacher education has remained mainly discipline-specific for grammar and comprehensive schools [8]. Since German pre-service teachers usually study two subjects [8], this type of teacher education has to result in at least partly out-of-field teaching (e.g., [9,10]). Some universities try to react to this issue by implementing new additional qualifications for science teachers: At the University of Göttingen, a voluntary certificate program regarding interdisciplinary teaching, including one focus on interdisciplinary science teaching (limited to 16 credits), was developed; it can even be studied within the regular discipline-specific teacher education program (optional area) [13]. Pre-service teachers are trained in content knowledge and pedagogical content knowledge (PCK) of the unstudied science subjects [13]. In the concluding module of the certificate focus, they engage in mastery experience in interdisciplinary science teaching at a school [13].

2.2. Self-Efficacy Beliefs of Interdisciplinary Science Teaching in Longitudinal Studies

Self-efficacy beliefs refer to the beliefs in one's own capacities to execute actions to achieve specific results [11]. A person who does not believe to be able to accomplish a result, will rather not even try to do so; thus, self-efficacy beliefs are of great importance [11]. For example, in science teaching, self-efficacy beliefs are important since they have a positive influence on the students' performance [14]. Since self-efficacy beliefs are a context-specific construct, they have to be examined specifically for different situations (e.g., teaching science vs. teaching English) [15]. Previous cross-sectional research on self-efficacy beliefs of interdisciplinary science teaching has shown that there was a focus on primary education, on the Science Teaching Efficacy Belief Instrument (STEBI; [16,17]), and on rather less differentiated measurement instruments [18].

In this paper, we want to look at previous quantitative longitudinal studies considering interdisciplinary science teaching over a longer course of time. Due to the focus on primary education in cross-sectional settings [18], the focus on primary education in longitudinal studies seems expectable. To the best of our knowledge, there is no longitudinal study investigating self-efficacy beliefs of interdisciplinary science teaching in secondary education. Thus, we provide an overview about this research regarding primary education as a neighboring research field with some illustrating examples.

In 2019, Thomson et al. [19] stated that there were only three longitudinal studies looking at self-efficacy beliefs of interdisciplinary science teaching. These three studies all surveyed pre-service primary teachers [20–22]. Only one of the three studies focused on more than one science methods course over one semester [20]. In addition to the studies named by Thomson et al. [19], we found further studies described in the following. Ginns and Watters [23] asked 72 pre-service primary teachers about their self-efficacy beliefs of interdisciplinary science teaching at the beginning and in the middle of their Bachelor program in teacher education (after three semesters), measured by the STEBI [17]. They found no significant difference between both time points, despite a science content course and a science methods course in this period [23]. The science methods course also contained practical experience with children and the development of teaching units [23].

Wingfield et al. surveyed 131 pre-service primary teachers with the STEBI-B [17] before and after participation in a preparation program and 31 of them as in-service teachers after teaching for one year (follow-up) [24]. They found a significant increase in the self-efficacy beliefs of interdisciplinary science teaching during the site-based preparation program [24]. However, no change was found from after participation to after one year of teaching [24].

Andersen et al. surveyed 39 first-year in-service primary teachers three times over a period of one year (summer 2000, winter 2000/01, spring 2001) with a Danish version of the STEBI-B [25,26]. They revealed a significant decrease between time points 1 and 2 and no change between time points 2 and 3 [26].

Settlage et al. [20] surveyed 46 pre-service primary teachers over the course of nine months and three time points (including a science methods course and student teaching) with the STEBI-B [17] and the Self-Efficacy Beliefs about Equitable Science Teaching instrument (SEBEST; [27]). They [20] observed a significant gain in self-efficacy beliefs of interdisciplinary science teaching measured by the STEBI between the start and end of the science methods course. After student teaching, there was a decrease; however, there was an overall positive trend [20]. Regarding the subscales Language Personal Efficacy and Socioeconomic Personal Efficacy of the SEBEST [27], they found a similar pattern, with a gain over the methods course and a loss due to student teaching [20]. This resulted in an overall positive development in the Language Personal Efficacy and no significant change in the Socioeconomic Personal Efficacy [20].

Thomson et al. [19] surveyed 245 pre-service primary teachers six times from the start of the freshman year of STEM-focused teacher preparation to the end of the second year of teaching with the STEBI-B (five-point Likert scale from 1 to 5, standardized Rasch scores used) [17]. They found significant gains in the self-efficacy beliefs of interdisciplinary science teaching from −0.21 to 0.08 between time points 2 and 3 (time of science methods courses) and from 0.08 to 0.35 between time points 3 and 4 (beginning and end of the senior year, including methods courses and practical teaching experience) [19]. From the end of pre-service teachers' teaching preparation program (time point 4) to the end of the first year of teaching (time point 5), there was a significant loss from 0.35 to −0.06 in the self-efficacy beliefs of interdisciplinary science teaching [19].

In addition, Deehan et al. [28] investigated data of 44 study participants. They [28] surveyed them four times during their time as pre-service primary teachers and one time as in-service teachers; the data were collected with the STEBI-A for in-service [16] and STEBI-B for pre-service teachers [17]. Deehan et al. [28] found a positive development in the pre-service teachers' self-efficacy beliefs of interdisciplinary science teaching during their university studies that remained stable even with the transition to teaching in school (effect size from first to final time point: $d = 1.33$).

Deehan et al. [29] conducted a further study with 112 (first time point)/56 (last time point) pre-service primary teachers in a Bachelor of Education program. The pre-service teachers were surveyed weekly with the STEBI-B [17] during two science PCK courses (12 time points in the one and 10 time points in the other course) [29]. There were four more time points before and after practical experience in school, resulting in 26 time points [29]. The self-efficacy beliefs increased moderately during both courses ($d = 0.41$ and 0.65) [29]. Thereafter, the self-efficacy beliefs of interdisciplinary science teaching remained stable in the context of no formal science intervention in the first year after the interventions. In addition, the self-efficacy beliefs of interdisciplinary science teaching increased in the second year in the context of practical experiences at school ($d = 0.26$) [29].

In sum, research regarding primary education revealed possible occasions of changes in self-efficacy beliefs of interdisciplinary science teaching (e.g., [19,20]). As there are only studies regarding primary education, to the best of our knowledge, there is a lack of a longitudinal study of self-efficacy beliefs of interdisciplinary science teaching in secondary education.

2.3. Perceived Advantages and Challenges of Interdisciplinary Science Teaching

Besides the issue of out-of-field teaching (e.g., [9,10]) there is a discussion regarding interdisciplinary science teaching in Germany about its establishment and its advantages and challenges [30]. In this paper, interdisciplinary science teaching is defined as teaching biology, chemistry, and physics as one joint subject by one teacher [31,32]. Many advantages and challenges of this type of subject have been discussed in Germany (see Tables 1 and 2). In addition, we describe further international arguments that focus on the integration of STE(A)M, and partly on interdisciplinary science, as well (Table 3).

Table 1. Advantages of interdisciplinary science teaching (17 selected arguments).

Advantage	Reference
Addressing key problems (climate change, energy transition, etc.)	[33]
Promoting interest in science	[10,30,34–36]
Cross-linking content (e.g., interrelationships in nature)	[9,30,37]
Scientific and vocational propaedeutics as well as competence-oriented learning	[30]
Promoting generic competencies	[30]
Learning in projects and through experimentation	[30]
Gender-responsive teaching	[30]
More experiments possible	[9,10]
Promoting scientific competence	[30,35,36]
Working interdisciplinarily	[9]
Teaching more hours per week in the same class	[9,34]
Higher motivation	[9]
Increased willingness to cooperate among teachers	[9]
Practicing general methods of scientific inquiry	[34]
Supply of teaching staff simplified through merging	[10]
Fun for teachers through the preparation of new subject areas	[10,38]
Easier organization of excursions	[10,34]

Table 2. Challenges of interdisciplinary science teaching (17 selected arguments).

Challenge	Reference
Lack of depth in content	[9,34,39]
Little possibility of own "research" (e.g., in problem-based learning)	[34]
Perspective of the single subjects is lost	[32,34,40]
High time and effort required	[9,10,35,41]
Out-of-field teaching	[9,10]
Little or missing material	[9,10,42]
Too little scientific or systematic work/learning in the single science subjects	[9]
Possibility of never having contact with specifically trained subject teachers throughout school, since they all teach everything	[34]
Complex subject logic, especially from grade 8 (e.g., thinking in models)	[34]
Criticism/Thematization of everyday ideas come too short	[34]
Lack of teacher education (content knowledge, pedagogical content knowledge)	[10,34,39]
Low motivation of teachers due to low affinity to and education in the subject (e.g., physics/technology)	[10,34]
Fewer lessons in the single subjects	[43]
Lack of experience in (dangerous) experiments and with equipment	[10,34]
Interested students could be ahead of teachers in terms of content	[10]
Transition to discipline-specific higher secondary education	[34]
Lack of collegial cooperation	[10,36,41,42]

Table 3. Advantages and challenges of STEM education with an international focus.

Advantage	Reference
Motivating to students	[1]
Promoting interest	[44]
Beneficial to student learning	[1,45]
New perspective	[45]
Well-being, joy of learning	[44,45]
Student-centered	[44,45]
Integrity of knowledge/interconnected nature	[45]
21st century skills	[44,46,47]
Challenge	
Structural challenges (school structures)	[1,45,46]
Lack of (planning) time	[1,45]
Lack of knowledge of STEM disciplines	[1,45–47]
Lack of teaching material	[44,45,47]
More laborious	[44,45]
Difficult collaboration with other teachers	[1,45]
Student concerns	[1,44,45]
Lack of teacher education	[44,46,48,49]
Out-of-field teaching	[48]

Since STE(A)M includes the teaching of interdisciplinary science [4], the arguments in Table 3 are of interest. Some of the international arguments are mentioned to obtain an impression in this context as well. It becomes clear that there are numerous overlaps with the German arguments/perceptions (Tables 1 and 2).

Considering previous research, the perceived advantages and challenges of interdisciplinary science teaching were investigated at one time point (see studies mentioned in the following tables). Up to now, there is a lack of longitudinal views regarding the development of these perceptions of interdisciplinary science teaching's advantages and challenges.

3. Research Questions

Considering previous longitudinal studies on self-efficacy beliefs of interdisciplinary science teaching, there is a clear focus on primary education (e.g., [19,29]). In sum, there is no longitudinal study considering the self-efficacy beliefs of interdisciplinary science teaching in (German) secondary education, to the best of our knowledge. Research regarding primary education revealed possible occasions of changes in self-efficacy beliefs of interdisciplinary science teaching, e.g., science methods courses or practical teaching experience (e.g., [19,20]). However, there is a lack of clear, consistent results even in primary education, since sometimes teaching experiences lead to an increase [29], sometimes to no change [23,24,26,28], and sometimes to a decrease [19,26] in self-efficacy beliefs of interdisciplinary science teaching. In addition, self-efficacy beliefs are context-specific [15], and secondary teacher education has to face different challenges to primary teacher education. Thus, there is need for a study on the development of self-efficacy beliefs of interdisciplinary science teaching during secondary teacher education:

Research Question 1: How time-stable are self-efficacy beliefs of interdisciplinary science teaching during teacher education?

A lot of arguments for and against interdisciplinary science teaching have been discussed in research (e.g., [30]). In previous research, we identified many nationally and internationally discussed advantages and challenges of interdisciplinary science teaching (see Tables 1–3). On the one hand, we want to know the advantages and challenges of interdisciplinary science teaching perceived by the (prospective) teachers. On the other hand, since previous research was only cross-sectional (see Tables 1–3), we focus on the development over time. Thus, our second research question was:

Research Question 2: How time-stable are the perceived advantages and challenges of interdisciplinary science teaching during teacher education?

4. Materials and Methods

4.1. Study Design and Sample

Our longitudinal study started in the winter semester of 2019 at nine German universities (online) and was repeated with the same cohort in the winter semesters of 2020 and 2021 [50]. Thus, we surveyed a span of two years of teacher education in our study. In addition to the study participants from the nine universities, we asked 90 study participants of a previous study to participate in our longitudinal study now [50]. However, we are not able to say how many of these 90 requested previous study participants were part of our present longitudinal study. The allocation of the data from the previous study to the present longitudinal data was not allowed, since this was not part of the research purpose in the informed consent of the previous study. Thus, there are some trainee teachers at time point 1 as well [50]. We used the same sample and study as in Handtke and Bögeholz [50] regarding the analyses of self-rated content knowledge. Thus, the description of the study design and the sample are very similar. However, in this paper, we take a look at the self-efficacy beliefs of interdisciplinary science teaching and the perceived advantages and challenges of interdisciplinary science teaching at three time points. The investigation period of two years should allow us to draw conclusions about teacher education, since after two years, many study participants should have transitioned from the Bachelor program to the Master of Education program or from the Master of Education program to the traineeship or from the traineeship to being an in-service teacher [50]. The sample of 271 (prospective) teachers is described in Table 4 at all three time points.

Table 4. Sample description (see [50], n = 271). Relative values are always shares of the 271 study participants. Sometimes values are missing. Thus, the sum of values is not always 271. The federal state and the studied school type are only indicated by pre-service teachers. Thus, the missing values become larger with the increasing duration of the survey.

Variable	Time Point 1		Time Point 2		Time Point 3	
	Absolute Value	Relative Value	Absolute Value	Relative Value	Absolute Value	Relative Value
Sex						
Female	170	62.7%	171	63.1%	170	62.7%
Male	100	36.9%	98	36.2%	99	36.5%
Federal state (universities)						
Lower Saxony	161	59.4%	149	55.0%	127	46.9%
Others	105	38.8%	100	36.9%	85	31.4%
Phase of teacher education						
Bachelor	169	62.4%	120	44.3%	55	20.3%
Master	98	36.2%	130	48.0%	157	57.9%
Trainee teachers	4	1.5%	19	7.0%	49	18.1%
In-service teachers	0	0%	2	0.7%	10	3.7%
School type studied						
Grammar and comprehensive school (class 5–13)	265	97.8%	250	92.3%	212	78.2%
Others (e.g., primary school)	2	0.7%	0	0%	0	0%
Subjects studied at university (to teach)						
Biology	147	54.2%	145	53.5%	145	53.5%
Chemistry	36	13.3%	36	13.3%	36	13.3%
Physics	42	15.5%	42	15.5%	42	15.5%
Biology and chemistry	33	12.2%	34	12.5%	34	12.5%
Biology and physics	6	2.2%	6	2.2%	6	2.2%
Chemistry and physics	6	2.2%	6	2.2%	6	2.2%
Biology, chemistry, and physics	1	0.4%	2	0.7%	2	0.7%

In sum, 271 (prospective) teachers participated at all three time points of our study [50]. We register a panel attrition of 43.70% between time points 1 and 2 and 27.74% between time points 2 and 3 [50]. The reason for the rather high panel attrition between time points 1 and 2 is that only 515 of 698 study participants left their e-mail address for us to contact them for the next time point one year later [50]. Nevertheless, the study participants who dropped out did not show specific characteristics (e.g., studied subjects at university or age) [50]. Thus, these missing participants seem to be random [50].

First, the study participants' distribution regarding the phase of teacher education at all three time points represents the progression of the (prospective) teachers during teacher education. We started with nearly only pre-service teachers, with a majority in the Bachelor program [50]. At this point, it has to be underlined that the study participants did not all start in the same semester or even the same phase of teacher education. However, in the following, we take a look at two years of (prospective) teachers' professional development, including teacher education and traineeship.

A majority studied in Lower Saxony. However, we were able to recruit study participants in other federal states of Germany. In Germany, teacher education at university is aimed at teaching at a specific type of school—mostly from the beginning of pre-service teachers' studies. Besides study programs for grammar and comprehensive school (class 5–13), there are also other school types addressed, such as vocational or primary school. Only two study participants did not study to teach in secondary education (grammar/comprehensive school) at the first time point [50]. However, these two pre-service teachers changed paths and studied to teach at secondary school at the following time points [50]. Thus, our sample represents teaching in secondary education very well. According to the much larger number of pre-service biology teachers in Germany compared to pre-service teachers in other science subjects [51], our sample contains over half (prospective) biology teachers [50]. Studying chemistry, studying physics, and studying biology and chemistry together all accounted for around 12–15% each. All other combinations are rather negligible.

At the beginning of our longitudinal study, the pre-service teachers in the Bachelor program were in semester 4.21 (SD = 2.13) on average [50]. The pre-service teachers in the Master of Education program were in semester 2.51 (SD = 1.66) on average [50].

4.2. Measurement Instruments and Survey

We used two measurement instruments in this study that we present in the following two subsections.

4.2.1. Self-Efficacy Beliefs of Interdisciplinary Science Teaching Instrument

First, we used the *Self-Efficacy Beliefs of Interdisciplinary Science Teaching* (SElf-ST) instrument, described by Handtke and Bögeholz [18,52]. This multifaceted, valid, and reliable instrument contains ten factors, based on the subcategories of the PCK model from Park and Chen [18,52,53]. It is the first literature-based, curricular-valid, and theory-based measurement instrument for self-efficacy beliefs of interdisciplinary science teaching in secondary education [18]. The measurement instrument contains some generic, but mostly science-specific factors [18]. The ten factors are described by their respective number of items and their characteristics of being generic or science-specific in Table 5.

Table 5. Self-Efficacy Beliefs of Interdisciplinary Science Teaching (SElf-ST) instrument. Description of its ten factors (label, specificity, number of items) (see also [18]).

Factor (F) of Self-Efficacy Beliefs of Interdisciplinary Science Teaching	Science-Specific/ Generic	Number of Items
F1: Surveying Dimensions of Scientific Literacy	Science-specific	5
F2: Applying Media	Generic	4
F3: Teaching Ethically Relevant Issues of Applied Science	Science-specific	4
F4: Differentiated Fostering of Scientific Inquiry and Communication in Science	Science-specific	5
F5: Using Subject-Specific Materials in Science	Science-specific	4
F6: Applying Scientific Working Methods	Science-specific	5
F7: Applying Methods of Evaluation	Generic	3
F8: Considering Learning Difficulties and Needs of Students in Science	Science-specific	5
F9: Including Science-Specific and General Instructional Strategies	Science-specific/ Generic	3
F10: Surveying and Fostering Science Content Knowledge	Science-specific	3

Considering Table 5, the SElf-ST instrument contains 41 items in total [18]. All items start with science (teaching) as an obstacle [18]. The actions required by the PCK model [53] were followed by illustrating examples of all three science subjects if possible [18]. One exemplary item is: Even in science teaching, I can initiate systematical observations conducted by students (e.g., the behavior of living organisms, chemical reactions, field observations such as partial solar eclipses). The four-point Likert scale contained options 1: “Is not right”, 2: “Is a little right”, 3: “Is rather right”, and 4: “Is exactly right” [18] (p. 8).

4.2.2. The Perceived Advantages and Challenges of Interdisciplinary Science Teaching

The second measurement instrument contained two lists: one with 17 possible advantages and one with 17 possible challenges of interdisciplinary science teaching. The advantages and challenges were all derived from the literature (see Tables 1 and 2). To avoid bias, we used 17 items for advantages and challenges. The study participants had to indicate which advantages and challenges they agree with. More precisely, we used one dichotomous variable for each advantage and challenge of interdisciplinary science teaching at each time point. In addition, all study participants had the possibility to indicate further advantages or challenges in addition to our lists.

4.2.3. The Administration of the Survey

The study participants were surveyed online via LimeSurvey. Regarding this paper, they were asked about personal data, self-efficacy beliefs of interdisciplinary science teaching [18,52], and the perceived advantages and challenges of interdisciplinary science teaching. The part about the self-efficacy beliefs of interdisciplinary science teaching was obligatory to receive a participation fee. The part about the perceived advantages and challenges of interdisciplinary science teaching was at the end of the survey and not necessary to gain the reward. Each participant received a participation fee of 5€ each time. In addition, there was the chance to be part of a drawing of 20 vouchers worth 25€ in 2019 and 2020. In 2021, the 25€ had to be paid in cash due to new regulations of the University of Göttingen.

4.3. Analysis

We used SPSS 28 and RStudio with the lavaan [54] package (0.6–3) and PowerPoint for the figures. The robust maximum likelihood estimator (MLR) was used to compute the models due to its robustness against non-normality, under the assumption of our data being metric [55]. Using only full data with listwise deletion seemed to be allowed, since no specific reason for panel attrition appeared (see Section 4.1).

We tested measurement invariance [56] for all ten factors of the Self-Efficacy Beliefs of Interdisciplinary Science Teaching instrument. Scalar invariance was needed to compare the means of the different time points [57]. We used the structural equation modeling framework [56]. All autocorrelations (unstructured) were applied to allow the computation between all three time points. Configural invariance was tested with absolute fit, and the other steps were tested with the differences between the model fits of two sequential invariance steps [56]. We rather focused on the use of goodness-of-fit indices: Comparative Fit Index (CFI) and Root Mean Square Error of Approximation (RMSEA) [58,59]. There are doubts on (only) using the chi-square difference test, since it is prone to sample size issues and violations of the normality assumption [59]. Thus, we focused on CFI, RMSEA, Akaike Information Criterion (AIC) [60], and Bayesian Information Criterion (BIC) [61]. In absolute terms, guidelines for CFI and RMSEA are: (robust) CFI > 0.90 and (robust) RMSEA < 0.10 [57].

The guidelines for comparatively testing the next step of measurement invariance are: non-significant ($p > 0.05$) chi-square difference test [62], ΔCFI < 0.005, ΔRMSEA < 0.01 [59], and smaller values for AIC and BIC are better [63]. In the Appendix A (Tables A1–A9), the results regarding testing configural, metric, scalar, and residual invariance of nine of the ten factors are presented. At this point, we provide an impression of the information presented in Appendix A by showing the results for the measurement invariance of Factor 1 as an example in Table 6.

Table 6. Fit indices of the measurement invariance steps of Factor 1: Surveying Dimensions of Scientific Literacy ($n = 270$). The following guidelines approve the next step of invariance: ΔCFI < 0.005, ΔRMSEA < 0.01 [59], smaller values for AIC and BIC [63], non-significant ($p > 0.05$) chi-square difference test [62]. All values indicate invariance.

Factor 1	Configural	Metric	Scalar	Residual
Robust X^2/df (p-value)	122.39/72 (<0.001)	131.94/80 (<0.001)	146.28/88 (<0.001)	160.43/98 (<0.001)
X^2-difference/df-difference (p-value)	-	7.92/8 (0.442)	14.43/8 (0.071)	14.09/10 (0.169)
Robust CFI (ΔCFI)	0.972 (-)	0.972 (-)	0.969 (−0.003)	0.967 (−0.002)
AIC	7256.75	7246.91	7245.40	7240.22
BIC	7483.45	7444.82	7414.53	7373.36
Adjusted BIC	7283.70	7270.44	7265.51	7256.05
Robust RMSEA (ΔRMSEA)	0.054 (-)	0.051 (−0.003)	0.052 (+0.001)	0.050 (−0.002)

In sum, all factors reached scalar invariance at least, since overall, only a few values and at most one per factor indicated non-invariance up to this step (Tables 6 and A1–A9). Thus, we were able to compute latent change models for all factors. Including metric invariance, we were able to compare the latent correlations as well [57].

To investigate time stability, we used absolute and relative stability [63]. While absolute stability describes the stability of the absolute values such as means, relative stability describes the stability of the rank order, e.g., examined with correlations over time [63]. Regarding our dichotomous variables, we used the percentages of approval as the indicator of absolute stability. For relative stability of the single perceived advantages and challenges of interdisciplinary science teaching (dichotomous variables), the phi coefficient was computed [64]. Due to partly different rank sums, phi correlations could react sensitively [64]. We conducted random checks with Odds ratio and Yules Y [64], which showed no major deviations from the phi correlations. The strength of the phi coefficient is interpreted after the guidelines from Cohen [65]: small = $0.1 \leq \varphi < 0.3$, middle = $0.3 \leq \varphi < 0.5$, and strong = $\varphi \geq 0.5$.

Regarding the non-latent statistical analyses, we checked for alpha error inflation [66] precautionarily and found only 6 of 68 phi correlations not to be significant anymore. Since we used the (too) conservative Bonferroni correction [66], this result rather confirms the significance of the results in Tables 11 and 12. Since we could deny alpha error inflation being an issue, we show the not-corrected results in Tables 11 and 12.

5. Results

5.1. Self-Efficacy Beliefs of Interdisciplinary Science Teaching and Their Stability during Teacher Education

Frist, we examine absolute stability of the self-efficacy beliefs of interdisciplinary science teaching. We present the manifest values of the ten factors at all three time points in Table 7.

The means of the factors of self-efficacy beliefs range from 2.85 to 3.49. Factor 4, *Differentiated Fostering of Scientific Inquiry and Communication in Science*, had the lowest mean of 2.85 at time point 1 and Factor 2, *Applying Media*, had the highest mean of 3.49 at time point 3. No mean is below the theoretical mean of the scale of 2.5. This indicates rather positive self-efficacy beliefs of interdisciplinary science teaching. Looking at the development over time, we only see small changes between the means of the same factors. These first insights into the manifest values rather indicate no change and thus absolute stability of the factors of self-efficacy beliefs. We tested the absolute stability with latent change models. The results of the ten models are shown in Tables 8 and 9 and confirm the missing change for all factors. Table 8 presents the changes in all factors between time points 1 and 2. Table 9 presents the changes in all factors between time points 2 and 3.

Table 7. Self-Efficacy Beliefs of Interdisciplinary Science Teaching factors' means and standard deviations at time points T1, T2, and T3. M = mean, SD = standard deviation.

Factor (F) of Self-Efficacy Beliefs of Interdisciplinary Science Teaching	T1 M (SD)	T2 M (SD)	T3 M (SD)
F1: Surveying Dimensions of Scientific Literacy (n = 270)	3.13 (0.59)	3.15 (0.61)	3.12 (0.60)
F2: Applying Media (n = 270)	3.43 (0.59)	3.47 (0.55)	3.49 (0.54)
F3: Teaching Ethically Relevant Issues of Applied Science (n = 271)	3.03 (0.62)	3.08 (0.57)	3.09 (0.58)
F4: Differentiated Fostering of Scientific Inquiry and Communication in Science (n = 271)	2.85 (0.55)	2.91 (0.55)	2.95 (0.57)
F5: Using Subject-Specific Materials in Science (n = 271)	2.95 (0.53)	2.99 (0.52)	3.01 (0.55)
F6: Applying Scientific Working Methods (n = 270)	3.23 (0.55)	3.25 (0.51)	3.21 (0.54)
F7: Applying Methods of Evaluation (n = 270)	2.98 (0.73)	2.95 (0.77)	2.94 (0.76)
F8: Considering Learning Difficulties and Needs of Students in Science (n = 271)	3.21 (0.48)	3.19 (0.48)	3.21 (0.51)
F9: Including Science-Specific and General Instructional Strategies (n = 270)	2.96 (0.70)	3.03 (0.69)	3.06 (0.65)
F10: Surveying and Fostering Science Content Knowledge (n = 271)	3.06 (0.63)	3.08 (0.58)	3.08 (0.62)

Table 8. Latent change models' change factors of the self-efficacy beliefs of interdisciplinary science teaching between time points T1 and T2 (n = 271). Labels of the factors F1–F10: see Table 5 or Table 7. SE = standard error.

Change Factor T1–T2	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Intercept	−0.001	0.052	0.053	0.057	0.019	0.010	−0.024	−0.020	0.061	0.018
SE	0.04	0.04	0.03	0.03	0.03	0.03	0.05	0.03	0.04	0.04
p-value	0.987	0.201	0.059	0.051	0.563	0.748	0.607	0.522	0.125	0.657

Table 9. Latent change models' change factors of the self-efficacy beliefs of interdisciplinary science teaching between time points T2 and T3 (n = 271). Labels of the factors F1–F10: see Table 5 or Table 7. SE = standard error.

Change Factor T2–T3	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Intercept	−0.016	0.025	0.007	0.032	0.022	−0.028	−0.007	0.027	0.037	0.015
SE	0.03	0.04	0.03	0.03	0.03	0.03	0.05	0.03	0.04	0.04
p-value	0.624	0.487	0.822	0.248	0.474	0.319	0.881	0.325	0.343	0.690

Second, we present the results regarding the relative stability of the ten self-efficacy beliefs of interdisciplinary science teaching factors. Table 10 shows the correlations between the same factor at time points 1 and 2, as well as time points 2 and 3.

Table 10. Correlations of each latent factor of self-efficacy beliefs of interdisciplinary science teaching between time points T1 and T2 and time points T2 and T3. All correlations showed a p-value < 0.01.

Factor (F) of Self-Efficacy Beliefs of Interdisciplinary Science Teaching	T1–T2	T2–T3
F1: Surveying Dimensions of Scientific Literacy (n = 270)	0.45 **	0.64 **
F2: Applying Media (n = 270)	0.38 **	0.50 **
F3: Teaching Ethically Relevant Issues of Applied Science (n = 270)	0.71 **	0.55 **
F4: Differentiated Fostering of Scientific Inquiry and Communication in Science (n = 271)	0.47 **	0.53 **
F5: Using Subject-Specific Materials in Science (n = 271)	0.44 **	0.53 **
F6: Applying Scientific Working Methods (n = 270)	0.58 **	0.63 **
F7: Applying Methods of Evaluation (n = 270)	0.48 **	0.59 **
F8: Considering Learning Difficulties and Needs of Students in Science (n = 271)	0.52 **	0.70 **
F9: Including Science-Specific and General Instructional Strategies (n = 270)	0.58 **	0.52 **
F10: Surveying and Fostering Science Content Knowledge (n = 270)	0.46 **	0.56 **

** = $p < 0.01$.

Overall, the correlations in Table 10 are not very strong. However, they are not small either. The majority of the correlations are middle and positive. The range spans from 0.38 to 0.71, with most of the correlations being between 0.45 and 0.60. Thus, the rank orders of the test persons are relatively time stable, but there are changes.

5.2. Perceived Advantages and Challenges of Interdisciplinary Science Teaching and Their Stability during Teacher Education

Regarding the perceived advantages (Figure 1) and challenges (Figure 2) of interdisciplinary science teaching, we first look at the most frequently mentioned ones and possible changes over time on an absolute level (absolute stability).

Three advantages of interdisciplinary science teaching (Figure 1) are perceived as highly relevant (~70% approval): *Addressing key problems*, *Promoting interest in science*, and *Cross-linking content*. The majority of the (prospective) teachers agree (>50% approval) with nine of the seventeen arguments. On a descriptive absolute level and across all participants, the approvals seem to be relatively time stable. However, three advantages rather stand out regarding their development over time: *Addressing key problems*, *Learning in projects and through experimentation*, and *Practicing general methods of scientific inquiry*. While the number of (prospective) teachers who see the addressing of key problems as an advantage increases during teacher education, the perception of the two last mentioned advantages decreases over time. Thus, with more time in teacher education, the (prospective) teachers judge learning in projects and with experiments as well as the practice of general methods of scientific inquiry less as an advantage of interdisciplinary science teaching.

Four challenges of interdisciplinary science teaching (Figure 2) are perceived as highly relevant (~70% approval): *Lack of depth in content*, *Out-of-field teaching*, *Lack of teacher education*, and *Low motivation of teachers due to low affinity to and education in the subject*. The majority of the (prospective) teachers agree (>50% approval) with seven of the seventeen arguments. On a descriptive absolute level and across all participants, the approvals seem to be relatively time stable. However, the changes in some challenges stand out: *High time and effort required*, *Out-of-field teaching*, *Little or missing material*, *Lack of experience in (dangerous) experiments and with equipment*, and *Lack of collegial cooperation*. These five challenges rather focus on aspects of the practical work in interdisciplinary science teaching, including insights that are gained in practical experiences. These challenges show a rather strong increase over the three time points.

In addition, we examined on a relative level (rank order) how stable the perceived advantages and challenges of interdisciplinary science teaching are (Tables 11 and 12).

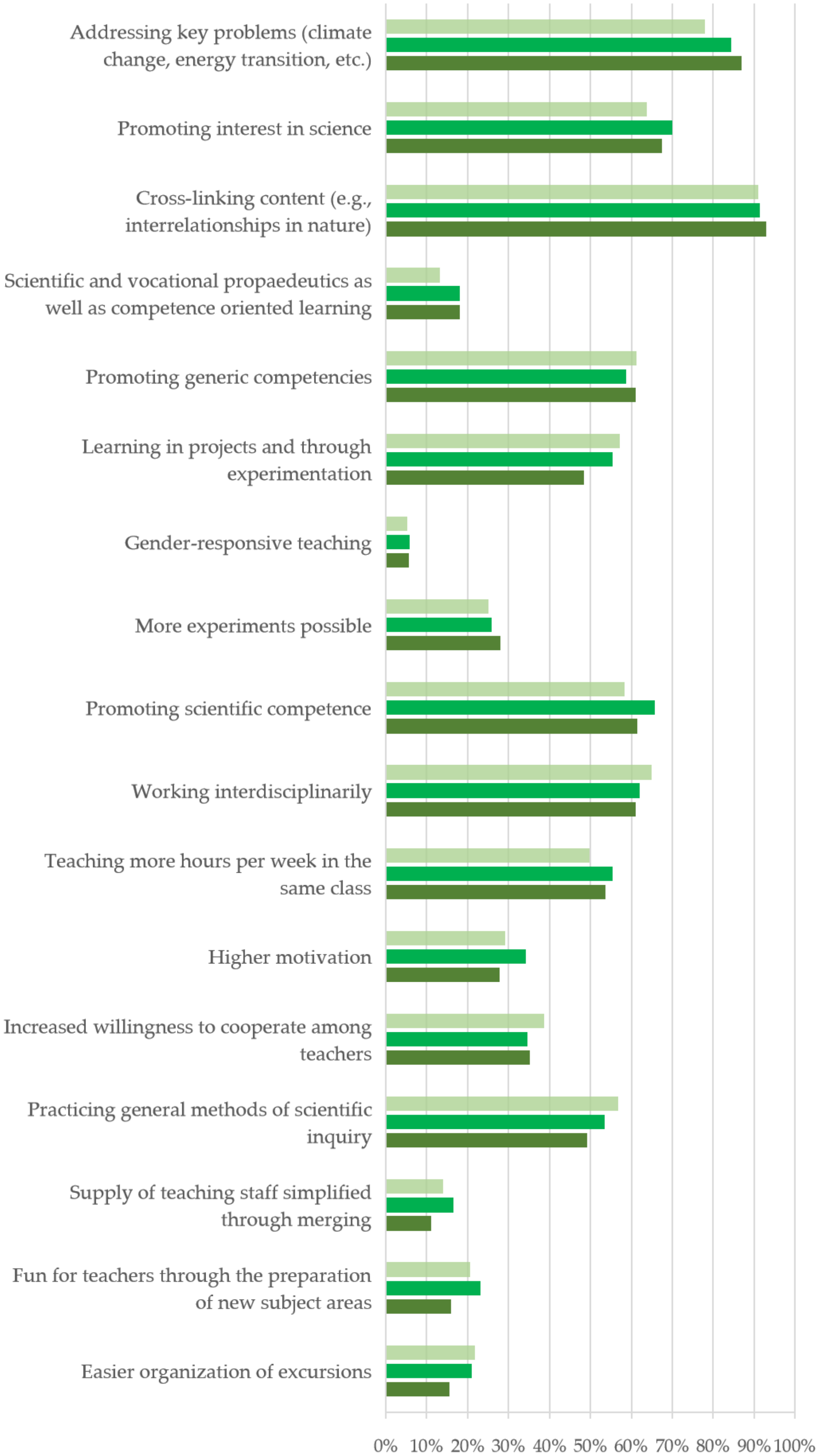

Figure 1. Perceived advantages of interdisciplinary science teaching at three time points (time points 1 and 2: n = 271; time point 3: n = 270)—percentage approval.

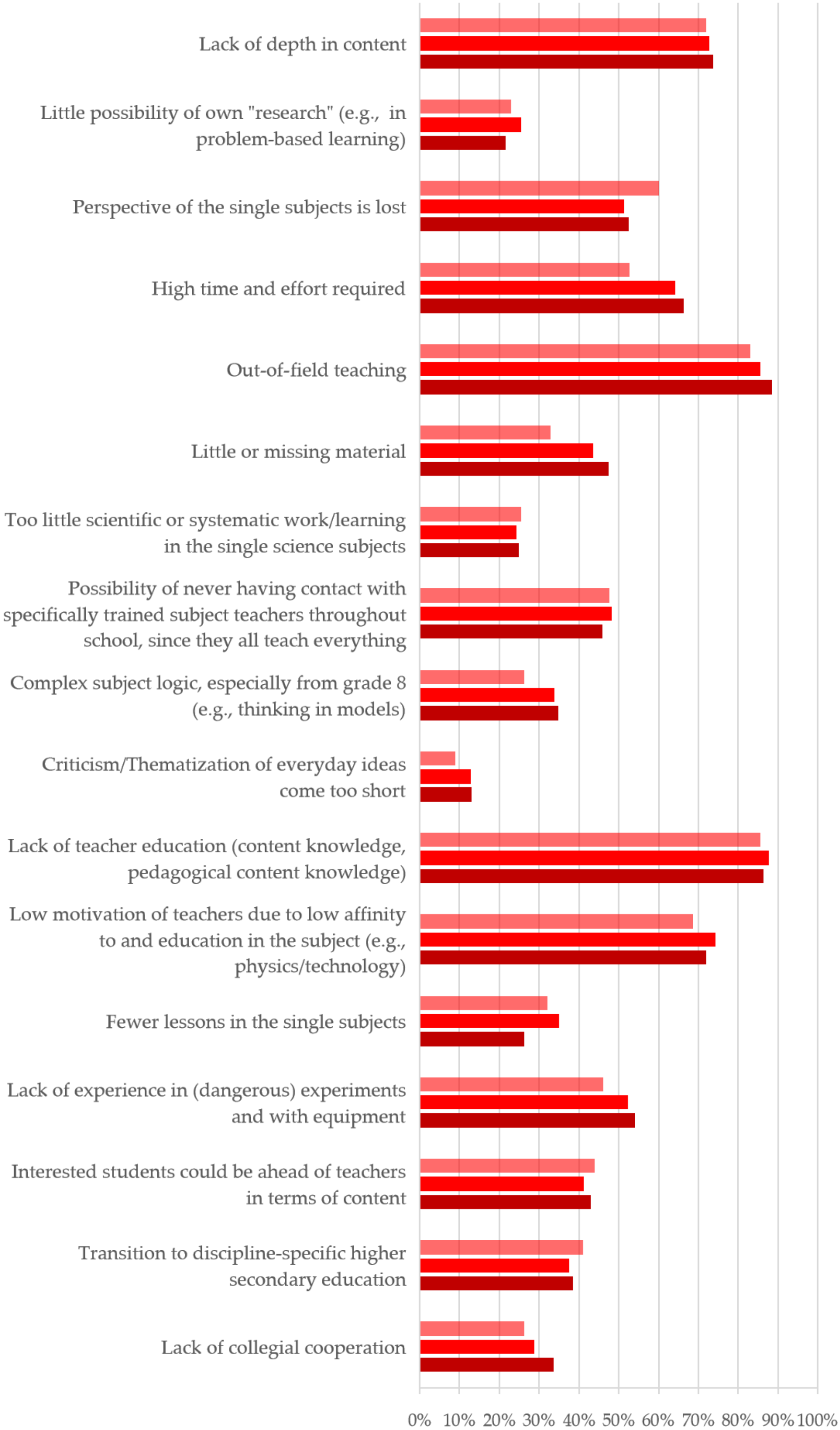

Figure 2. Perceived challenges of interdisciplinary science teaching at three time points (time points 1 and 2: n = 271; time point 3: n = 270)—percentage approval.

Table 11. Phi correlations of the same perceived advantages of interdisciplinary science teaching between time points T1 and T2 (n = 271) and time points T2 and T3 (n = 270). Interpretation of the correlations: small = 0.1 ≤ φ < 0.3, middle = 0.3 ≤ φ < 0.5, and strong = φ ≥ 0.5 [65].

Advantage (A)	T1–T2	T2–T3
A1: Addressing key problems (climate change, energy transition, etc.)	0.29 **	0.35 **
A2: Promoting interest in science	0.28 **	0.29 **
A3: Cross-linking content (e.g., interrelationships in nature)	0.23 **	0.33 **
A4: Scientific and vocational propaedeutics as well as competence-oriented learning	0.18 **	0.25 **
A5: Promoting generic competencies	0.30 **	0.32 **
A6: Learning in projects and through experimentation	0.33 **	0.40 **
A7: Gender-responsive teaching	0.15 *	0.21 **
A8: More experiments possible	0.34 **	0.38 **
A9: Promoting scientific competence	0.30 **	0.40 **
A10: Working interdisciplinarily	0.21 **	0.27 **
A11: Teaching more hours per week in the same class	0.45 **	0.40 **
A12: Higher motivation	0.32 **	0.41 **
A13: Increased willingness to cooperate among teachers	0.28 **	0.32 **
A14: Practicing general methods of scientific inquiry	0.28 **	0.35 **
A15: Supply of teaching staff simplified through merging	0.19 **	0.16 **
A16: Fun for teachers through the preparation of new subject areas	0.32 **	0.26 **
A17: Easier organization of excursions	0.21 **	0.30 **

* = $p < 0.05$; ** = $p < 0.01$.

Table 12. Phi correlations of the same perceived challenges of interdisciplinary science teaching between time points T1 and T2 (n = 271) and time points T2 and T3 (n = 270). Interpretation of the correlations: small = 0.1 ≤ φ < 0.3, middle = 0.3 ≤ φ < 0.5, and strong = φ ≥ 0.5 [65].

Challenge ©	T1–T2	T2–T3
C1: Lack of depth in content	0.41 **	0.33 **
C2: Little possibility of own “research” (e.g., in problem-based learning)	0.17 **	0.26 **
C3: Perspective of the single subjects is lost	0.32 **	0.38 **
C4: High time and effort required	0.37 **	0.23 **
C5: Out-of-field teaching	0.40 **	0.32 **
C6: Little or missing material	0.26 **	0.33 **
C7: Too little scientific or systematic work/learning in the single science subjects	0.34 **	0.28 **
C8: Possibility of never having contact with specifically trained subject teachers throughout school, since they all teach everything	0.35 **	0.45 **
C9: Complex subject logic, especially from grade 8 (e.g., thinking in models)	0.19 **	0.24 **
C10: Criticism/Thematization of everyday ideas come too short	0.23 **	0.22 **
C11: Lack of teacher education (content knowledge, pedagogical content knowledge)	0.27 **	0.25 **
C12: Low motivation of teachers due to low affinity to and education in the subject (e.g., physics/technology)	0.35 **	0.29 **
C13: Fewer lessons in the single subjects	0.37 **	0.36 **
C14: Lack of experience in (dangerous) experiments and with equipment	0.36 **	0.34 **
C15: Interested students could be ahead of teachers in terms of content	0.45 **	0.46 **
C16: Transition to discipline-specific higher secondary education	0.34 **	0.33 **
C17: Lack of collegial cooperation	0.36 **	0.34 **

** = $p < 0.01$.

On first sight, Tables 11 and 12 show that all correlations are at least small and no correlation is strong. The correlations range from 0.15 to 0.46. Thus, the perceived advantages and challenges of interdisciplinary science teaching do not seem to change strongly between the time points. However, they also are not very stable over the course of time.

6. Discussion

In the following two subsections, we discuss the development of (prospective) teachers' self-efficacy beliefs as well as perceived advantages and challenges of interdisciplinary science teaching from 2019 to 2021. Thereafter, we present concluding remarks before we shed light on the limitations and provide an outlook on future research.

6.1. Self-Efficacy Beliefs of Interdisciplinary Science Teaching over Two Years of Teacher Education

Previous research on self-efficacy beliefs of interdisciplinary science teaching focused on primary education (e.g., [23,24,26]). Since there were different results regarding a possible increase [29], decrease [19,26], or stability [23,24,26,28] due to teaching experience, we had no specific unidirectional expectation regarding the whole developmental process. In addition, we only integrated a longitudinal perspective currently considering two years. To the best of our knowledge, our study is the first one focusing on the development of self-efficacy beliefs of interdisciplinary science teaching in secondary education (with a multidimensional instrument) over a longer period of teacher education—at least considering the body of published literature.

We found out that self-efficacy beliefs of interdisciplinary science teaching have a high absolute stability (Tables 8 and 9) and a middle relative stability (Table 10). There is no absolute change on average in all of the twenty change factors (ten self-efficacy factors between time points 1 and 2 and between time points 2 and 3). In sum, self-efficacy beliefs of interdisciplinary science teaching show an absolute stability similar to that of self-rated content knowledge of biology, chemistry, and physics [50]. In contrast, the relative stability of the self-efficacy beliefs of interdisciplinary science teaching in our present study is weaker than the high relative stability of the self-rated content knowledge of biology, chemistry, and physics reported in the past [50]. Thus, self-efficacy beliefs of interdisciplinary science teaching have a certain level of stability but changes, especially regarding the study participants' rank order, have occurred.

During the investigated two years (testing in 2019, 2020, and 2021), the self-efficacy beliefs of interdisciplinary science teaching remained rather stable. This could be due to the mostly discipline-specific science teacher education in Germany [8], which does not explicitly train for interdisciplinary science teaching. Therefore, the rather stable self-efficacy beliefs (during two years of teacher education) could be a challenge for teacher education regarding interdisciplinary science teaching.

Despite the mentioned level of absolute stability and its explanation, one could hope for gains in self-efficacy beliefs over the course of teacher education as a whole due to the positive effect of practical experience on self-efficacy beliefs, e.g., stated by Bandura [11]. Up to now, we only surveyed 2 years of at least 6,5 years (teacher education at university and traineeship) plus subsequent in-service teaching and associated (optional) training. Therefore, we could assume gains in self-efficacy beliefs of interdisciplinary science teaching—at least if experiences with and qualification in unstudied science subjects for interdisciplinary science teaching are provided.

6.2. Perceived Advantages and Challenges of Interdisciplinary Science Teaching over Two Years of Teacher Education

Furthermore, we focused on the perception of advantages and challenges of interdisciplinary science teaching. Many arguments have been discussed in research so far (e.g., [30]; see Tables 1–3). However, previous research focused on cross-sectional studies (see Tables 1–3). Thus, our study provides insights into the perceived advantages and challenges of interdisciplinary science teaching on an absolute level and over a period of two years. The (prospective) teachers see the prominent advantages (Figure 1), such as teaching important topics of the 21st century [33] by cross-linking the content of the three subjects [9,30,37], and the promotion of interest [10,30,34–36], e.g., by addressing students' everyday ideas. On the other side, the (prospective) teachers agree with the deficits in teacher education [10,34,39], resulting in out-of-field teaching [9,10] and the lack of motivation to teach unstudied subjects [10,34] (Figure 2). They also fear a lack of depth of content in class [9,34,39]. Perhaps, the prospective teachers would see a lack of collegial collaboration as an even stronger challenge if they were already teachers.

A hint for that assumption can be gained by looking at the development of the perceived advantages and challenges of interdisciplinary science teaching over time. The advantage *Addressing key problems* raises notably over time (Figure 1). The advantages *Learning in projects and through experimentation* and *Practicing general methods of scientific inquiry* notably declined over time (Figure 1). The challenges *High time and effort required*, *Out-of-field teaching*, *Little or missing material*, *Lack of experience in (dangerous) experiments and with equipment*, and *Lack of collegial cooperation* show a notable raise in approval over time (Figure 2). These developments in perceptions seem to reflect the progression in teacher education over the two years, including increasing practical experience at school. It looks like the prospective teachers realize that experiments or methods of scientific work could be more difficult to implement than originally expected. The study participants seem to realize that interdisciplinary science teaching requires high time and effort, that out-of-field teaching is problematic, that material is missing, that they have a lack of experience with experiments, and that collegial cooperation could be improved.

In sum, the progressing teacher education seems to have an influence on changes in the perceptions of advantages and challenges that focus on practical aspects of interdisciplinary science teaching—already detected in surveying 2 out of 6,5 years of teacher education and traineeship. The other advantages and challenges seem to be rather stable during the two investigated years.

On the one hand, the results show advantages and challenges of interdisciplinary science teaching that are mentioned very often (*Addressing key problems* and *Cross-linking content* vs. *Out-of-field teaching* and *Lack of teacher education*) and, thus, are supported by our study. On the other hand, the changes over time could additionally hint at problems specific to the practical implementation of interdisciplinary science teaching in school, focusing on the extra effort needed, missing material, the challenge of experiments and methods of scientific inquiry, or collegial cooperation. Perhaps this is not only a problem of the two years accompanied in this study; perhaps, these challenges are present in the entirety of German science teacher education and need to be addressed specifically with progressing teacher education.

In addition, flexible interdisciplinary teaching settings could be considered to avoid some challenges of the strict format as a single interdisciplinary subject science such as *Lack of teacher education* (see Section 6.3 for more explanations and recommendations).

6.3. Conclusions Regarding Self-Efficacy Beliefs as Well as Perceived Advantages and Challenges of Interdisciplinary Science Teaching from a Longitudinal Perspective

In sum, we presented new results for two fields of research regarding interdisciplinary science teaching in secondary education: self-efficacy beliefs as well as perceived advantages and challenges. The rather stable self-efficacy beliefs of interdisciplinary science teaching over a remarkable period could be a challenge for supporting prospective teachers, especially those with rather low self-efficacy beliefs of interdisciplinary science teaching.

In addition, the rather stable self-efficacy beliefs could be explained by the notably and plausibly restricted impact of discipline-specific science teacher education on self-efficacy beliefs of interdisciplinary science teaching—at least during the two investigated years.

The rather stable perceptions of advantages and challenges of interdisciplinary science teaching show *Addressing key problems* and *Cross-linking content* as continuously perceived advantages (Figure 1) and *Out-of-field teaching* and *Lack of teacher education* as continuously perceived challenges (Figure 2) of interdisciplinary science teaching over the two years. In addition, some practical issues out of the challenges of interdisciplinary science teaching, such as *Little or missing material* or High time and effort required (Figure 2), showed a more critical perception by the (prospective) teachers since they increase over time—even if they are not the most perceived challenges like *Out-of-field teaching* or *Lack of teacher education*.

At this point, we return to the recommendations to overcome challenges such as *Lack of teacher education* by more flexible interdisciplinary science teaching settings (Section 6.2). Perhaps sometimes a thematic interdisciplinary approach is reasonable to address topics such as climate change [31]. Sometimes, it could be sufficient to integrate knowledge from another science subject such as chemistry into biology teaching [31], e.g., regarding cellular respiration to elaborate on biochemistry.

The idea of different science subject teachers teaching as a team could be a flexible approach to address science topics more adequately inside the single subject science—given the mostly discipline-specific science teacher education in Germany [8]. In such an approach, the teachers' different competencies could complement each other. This could also help overcome challenges such as *Perspective of the single subjects is lost*. In addition to the benefits for in-service teachers, the approach of "mixed" teams, e.g., in the certificate focus regarding interdisciplinary science teaching [13], can strengthen pre-service teachers' professional development regarding interdisciplinary science teaching. The presented results, conclusions, and recommendations indicate obstacles and starting points that could enrich current and future concepts of teacher education regarding interdisciplinary science teaching.

6.4. Limitations and Future Research

Despite the advantages of our longitudinal study, some limitations have to be discussed. In addition, we will present starting points for future research. First, it should be mentioned that the COVID-19 pandemic could have had an effect on our study. On the one hand, the certificate modules had to be taught online at time point 2. On the other hand, the (prospective) teachers eventually were influenced by the public scientific discussions and the relevance of collaborating in science interdisciplinarily. However, the results do not suggest a strong impact.

Regarding the sample, we have a large amount of (prospective) teachers in biology (see Table 4). On the one hand, future research could try to survey more chemistry and physics (prospective) teachers. On the other hand, the large amount of (prospective) biology teachers reflects the much larger number of pre-service biology teachers in Germany [51]. Thus, the subject distribution of our sample corresponds to the real situation.

Looking at the statistical analyses, it has to be stated that the perceived advantages and challenges of interdisciplinary science teaching are only measured as dichotomous variables. Thus, we only have the information whether (prospective) teachers think of the described issues as an advantage or a challenge. We have no information on how importantly the (prospective) teachers rate the advantages and challenges. This could be an additional focus for further research to gain an even deeper insight into (prospective) teachers' perceptions.

Regarding the non-latent statistical analyses, we checked for alpha error inflation [66]. We used the conservative Bonferroni correction for the phi correlations (not-corrected results in Tables 11 and 12) [66]. Treating the results of both tables as two sub-hypotheses, we had 34 phi correlations in each table (17 advantages/challenges between time points 1 and 2 as well as 2 and 3). Thus, the Bonferroni-corrected alpha level would be 0.05/34 = 0.00147. According to this alpha level, 62 of the 68 phi-correlations would remain significant. Due to the (too) conservative Bonferroni-correction, these results argue for the significance of the (not corrected) phi correlations in Tables 11 and 12.

We rewarded all (prospective) teachers with 5€ per time point [50], regardless of their participation in the last part of the survey about the advantages and challenges of interdisciplinary science teaching. While it was possible to omit the last part of the survey and obtain the reward, the part regarding the self-efficacy beliefs had to be answered to receive the reward. Since all participants received a reward, it is not possible to test its influence.

Based on the results in this paper, future research could focus on the relationship of the perceived advantages and challenges of interdisciplinary science teaching with self-efficacy beliefs of interdisciplinary science teaching and other constructs such as the (self-rated) content knowledge of biology, chemistry, and physics, also present in our data set [50]. It could be helpful to know about the effects of the perception of interdisciplinary science teaching on (prospective) teachers' competencies and motivational orientations. In addition, it could be of interest to figure out what shapes (prospective) teachers' opinions about the advantages and challenges of interdisciplinary science teaching. Importantly, the rising critical view regarding several practice-related interdisciplinary science teaching issues over time, such as experimentation or missing material, should be further investigated.

Our present contribution does not allow any suggestions for a specific phase of teacher education due to our specific sample composition. This is due to the fact that not all study participants started at the same phase or semester of teacher education. Their entry points in our longitudinal study differed notably, e.g., some were at the beginning of the Bachelor program, and some at the end of the Master of Education program. We followed pre-service teachers in the Bachelor as well as the Master of Education program and trainee teachers in their progressions into the next phase of their professional development. Even if our study only surveyed the development over 2 out of 6,5 years of teacher education at university and the traineeship plus additional development on the job, it already sheds light on important issues that facilitate interdisciplinary science teaching (advantages are supposed to be beneficial) and obstacles to overcome (challenges). In addition, we could show that the two years of teacher education and traineeship led to no gains in self-efficacy beliefs of interdisciplinary science teaching. However, we cannot state conclusions about specific single phases of teacher education due to the different entry points of the study participants. We have to keep in mind that hardly any longitudinal results exist regarding the addressed issues in this paper. Thus, two years of teacher education are valuable to report; they already provide important insights about the discipline-specific German science teacher education, since several German universities (n = 9) were represented in our sample. Moreover, they allow us to assume crucial points regarding the entire discipline-specific German science teacher education.

At the same time, our paper reveals focuses relevant for future research that can enhance interdisciplinary science teaching in secondary education based on evidence, including in countries with conditions of science (teacher) education comparable to Germany's.

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Institutional Review Board Statement: The study was conducted in accordance with all relevant requirements of the Declaration of Helsinki. Ethical review and approval were waived for this study since at the University of Göttingen, ethical review is voluntary. We did not consider an official review due to the following reasons: All personal data were recorded pseudo-anonymously and are only published anonymously. The data are treated as strictly confidential. We surveyed no persons requiring special protection, the participation was voluntary, and no disadvantages in case of non-participation had to be expected. There were no special physiological or physical stresses and we assume that no strong negative emotions have been triggered. No very personal experiences or traumas are reported. The self-image of the test persons should not be questioned, since they are not trained for teaching all subjects of interdisciplinary science teaching. At most, it is conceivable that the requirements of teaching interdisciplinary science will be reflected upon. They are not induced to behave in an ethically problematic manner and are not deceived about the study. Therefore, no explicit clarification about the study is necessary. In sum, we assume that we had no critical or problematic ethical aspects in our study.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available in an anonymized form on request from the authors. The data are not publicly available due to the General Data Protection Regulation and the informed consent given by the participants.

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Appendix A

Table A1. Fit indices of the measurement invariance steps of Factor 2: Applying Media (n = 270). The following guidelines approve the next step of invariance: ΔCFI < 0.005, ΔRMSEA < 0.01 [59], smaller values for AIC and BIC [63], non-significant (p > 0.05) chi-square difference test [62]. Values indicating non-invariance are bold.

Factor 2	Configural	Metric	Scalar	Residual
Robust X^2/df (p-value)	80.30/39 (<0.001)	84.60/45 (<0.001)	96.67/51 (<0.001)	100.04/59 (0.001)
X^2-difference/df-difference (p-value)	-	4.94/6 (0.552)	12.21/6 (0.057)	7.62/8 (0.472)
Robust CFI (ΔCFI)	0.964 (-)	0.965 (+0.001)	0.960 **(−0.005)**	0.961 (+0.001)
AIC	5599.48	5593.73	5593.63	5592.57
BIC	5783.00	5755.66	5733.97	5704.12
Adjusted BIC	5621.29	5612.98	5610.31	5605.83
Robust RMSEA (ΔRMSEA)	0.067 (-)	0.062 (−0.005)	0.062 (-)	0.057 (−0.005)

Table A2. Fit indices of the measurement invariance steps of Factor 3: Teaching Ethically Relevant Issues of Applied Science ($n = 270$). The following guidelines approve the next step of invariance: ΔCFI < 0.005, ΔRMSEA < 0.01 [59], smaller values for AIC and BIC [63], non-significant ($p > 0.05$) chi-square difference test [62]. All values indicate invariance.

Factor 3	Configural	Metric	Scalar	Residual
Robust X^2/df (*p*-value)	44.70/39 (0.245)	50.16/45 (0.276)	53.39/51 (0.383)	62.79/59 (0.344)
X^2-difference/df-difference (*p*-value)	-	5.42/6 (0.492)	2.93/6 (0.818)	9.22/8 (0.324)
Robust CFI (ΔCFI)	0.995 (-)	0.995 (-)	0.998 (+0.003)	0.996 (−0.002)
AIC	6230.45	6224.22	6215.13	6211.59
BIC	6413.97	6386.15	6355.47	6323.14
Adjusted BIC	6252.26	6243.47	6231.82	6224.85
Robust RMSEA (ΔRMSEA)	0.024 (-)	0.022 (−0.002)	0.014 (−0.008)	0.016 (+0.002)

Table A3. Fit indices of the measurement invariance steps of Factor 4: Differentiated Fostering of Scientific Inquiry and Communication in Science ($n = 271$). The following guidelines approve the next step of invariance: ΔCFI < 0.005, ΔRMSEA < 0.01 [59], smaller values for AIC and BIC [63], non-significant ($p > 0.05$) chi-square difference test [62]. Values indicating non-invariance are bold.

Factor 4	Configural	Metric	Scalar	Residual
Robust X^2/df (*p*-value)	197.07/72 (<0.001)	213.51/80 (<0.001)	218.77/88 (<0.001)	222.13/98 (<0.001)
X^2-difference/df-difference (*p*-value)	-	15.89/8 **(0.044)**	4.17/8 (0.841)	3.71/10 (0.960)
Robust CFI (ΔCFI)	0.927 (-)	0.923 (−0.004)	0.925 (+0.002)	0.929 (+0.004)
AIC	7068.93	7068.50	7056.70	7040.75
BIC	7295.86	7266.62	7226.00	7174.03
Adjusted BIC	7096.11	7092.23	7076.98	7056.71
Robust RMSEA (ΔRMSEA)	0.084 (-)	0.082 (−0.002)	0.077 (−0.005)	0.071 (−0.006)

Table A4. Fit indices of the measurement invariance steps of Factor 5: Using Subject-Specific Materials in Science ($n = 271$). The following guidelines approve the next step of invariance: ΔCFI < 0.005, ΔRMSEA < 0.01 [59], smaller values for AIC and BIC [63], non-significant ($p > 0.05$) chi-square difference test [62]. Values indicating non-invariance are bold.

Factor 5	Configural	Metric	Scalar	Residual
Robust X^2/df (*p*-value)	79.68/39 (<0.001)	83.40/45 (<0.001)	92.53/51 (<0.001)	92.32/59 (0.004)
X^2-difference/df-difference (*p*-value)	-	4.06/6 (0.669)	9.05/6 (0.171)	2.16/8 (0.976)
Robust CFI (ΔCFI)	0.961 (-)	0.963 (+0.002)	0.960 (−0.003)	0.967 **(+0.007)**
AIC	5863.53	5855.95	5853.08	5839.84
BIC	6047.24	6018.05	5993.56	5951.51
Adjusted BIC	5885.53	5875.36	5869.90	5853.22
Robust RMSEA (ΔRMSEA)	0.063 (-)	0.057 (−0.006)	0.056 (−0.001)	0.047 (−0.009)

Table A5. Fit indices of the measurement invariance steps of Factor 6: Applying Scientific Working Methods (n = 270). The following guidelines approve the next step of invariance: ΔCFI < 0.005, ΔRMSEA < 0.01 [59], smaller values for AIC and BIC [63], non-significant (p > 0.05) chi-square difference test [62]. All values indicate invariance.

Factor 6	Configural	Metric	Scalar	Residual
Robust X^2/df (p-value)	130.74/72 (<0.001)	134.06/80 (<0.001)	144.47/88 (<0.001)	158.95/98 (<0.001)
X^2-difference/df-difference (p-value)	-	2.98/8 (0.936)	10.15/8 (0.255)	14.46/10 (0.153)
Robust CFI (ΔCFI)	0.956 (-)	0.960 (+0.004)	0.958 (−0.002)	0.955 (−0.003)
AIC	7374.76	7361.91	7356.01	7351.49
BIC	7601.46	7559.83	7525.13	7484.63
Adjusted BIC	7401.71	7385.44	7376.11	7367.32
Robust RMSEA (ΔRMSEA)	0.058 (-)	0.052 (−0.006)	0.051 (−0.001)	0.050 (−0.001)

Table A6. Fit indices of the measurement invariance steps of Factor 7: Applying Methods of Evaluation (n = 270). The following guidelines approve the next step of invariance: ΔCFI < 0.005, ΔRMSEA < 0.01 [59], smaller values for AIC and BIC [63], non-significant (p > 0.05) chi-square difference test [62]. Values indicating non-invariance are bold.

Factor 7	Configural	Metric	Scalar	Residual
Robust X^2/df (p-value)	21.52/15 (0.121)	24.38/19 (0.182)	32.84/23 (0.084)	37.82/29 (0.127)
X^2-difference/df-difference (p-value)	-	2.69/4 (0.611)	8.89/4 (0.064)	4.99/6 (0.545)
Robust CFI (ΔCFI)	0.994 (-)	0.995 (+0.001)	0.991 (−0.004)	0.992 (+0.001)
AIC	5006.53	5001.35	**5001.90**	4995.34
BIC	5146.87	5127.29	5113.45	5085.30
Adjusted BIC	5023.21	5016.32	5015.16	5006.03
Robust RMSEA (ΔRMSEA)	0.043 (-)	0.034 (−0.009)	0.041 (+0.007)	0.035 (−0.006)

Table A7. Fit indices of the measurement invariance steps of Factor 8: Considering Learning Difficulties and Needs of Students in Science (n = 271). The following guidelines approve the next step of invariance: ΔCFI < 0.005, ΔRMSEA < 0.01 [59], smaller values for AIC and BIC [63], non-significant (p > 0.05) chi-square difference test [62]. Values indicating non-invariance are bold.

Factor 8	Configural	Metric	Scalar	Residual
Robust X^2/df (p-value)	177.88/72 (<0.001)	183.16/80 (<0.001)	194.86/88 (<0.001)	213.76/98 (<0.001)
X^2-difference/df-difference (p-value)	-	6.54/8 (0.587)	11.29/8 (0.186)	18.61/10 **(0.045)**
Robust CFI (ΔCFI)	0.909 (-)	0.910 (+0.001)	0.908 (−0.002)	0.901 **(−0.007)**
AIC	7402.76	7394.34	7389.53	7387.36
BIC	7629.69	7592.46	7558.83	7520.64
Adjusted BIC	7429.94	7418.07	7409.81	7403.32
Robust RMSEA (ΔRMSEA)	0.075 (-)	0.071 (−0.004)	0.069 (−0.002)	0.067 (−0.002)

Table A8. Fit indices of the measurement invariance steps of Factor 9: Including Science-Specific and General Instructional Strategies (n = 270). The following guidelines approve the next step of invariance: ΔCFI < 0.005, ΔRMSEA < 0.01 [59], smaller values for AIC and BIC [63], non-significant (p > 0.05) chi-square difference test [62]. Values indicating non-invariance are bold.

Factor 9	Configural	Metric	Scalar	Residual
Robust X^2/df (p-value)	17.62/15 (0.283)	20.06/19 (0.391)	23.62/23 (0.425)	36.59/29 (0.157)
X^2-difference/df-difference (p-value)	-	2.18/4 (0.703)	3.51/4 (0.477)	13.12/6 **(0.041)**
Robust CFI (ΔCFI)	0.997 (-)	0.999 (+0.002)	0.999 (-)	0.992 **(−0.007)**
AIC	4740.63	4734.76	4730.22	**4731.96**
BIC	4880.96	4860.71	4841.77	4821.92
Adjusted BIC	4757.31	4749.73	4743.48	4742.65
Robust RMSEA (ΔRMSEA)	0.027 (-)	0.015 **(−0.012)**	0.010 (−0.005)	0.032 **(+0.022)**

Table A9. Fit indices of the measurement invariance steps of Factor 10: Surveying and Fostering Science Content Knowledge (n = 270). The following guidelines approve the next step of invariance: ΔCFI < 0.005, ΔRMSEA < 0.01 [59], smaller values for AIC and BIC [63], non-significant (p > 0.05) chi-square difference test [62]. Values indicating non-invariance are bold.

Factor 10	Configural	Metric	Scalar	Residual
Robust X^2/df (p-value)	18.70/15 (0.228)	20.90/19 (0.343)	24.38/23 (0.383)	28.50/29 (0.492)
X^2-difference/df-difference (p-value)	-	2.28/4 (0.684)	3.40/4 (0.493)	4.41/6 (0.621)
Robust CFI (ΔCFI)	0.996 (-)	0.998 (+0.002)	0.998 (-)	1.000 (+0.002)
AIC	4525.63	4520.19	4515.56	4509.25
BIC	4665.97	4646.14	4627.11	4599.21
Adjusted BIC	4542.31	4535.17	4528.82	4519.94
Robust RMSEA (ΔRMSEA)	0.031 (-)	0.020 **(−0.011)**	0.015 (−0.005)	0.000 **(−0.015)**

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