Article

Student Teachers' Knowledge to Enable Problem-Solving for Sustainable Development

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Abstract: Education is a central strategy in terms of sustainable development (SD) and can contribute to solving global challenges like biodiversity loss and climate change. Content knowledge represents one base for teaching education for sustainable development (ESD). Therefore, identifying teaching and learning prerequisites regarding SD challenges in teacher education is crucial. The focus of the paper was to assess and learn more about student teachers' procedural knowledge regarding issues of biodiversity and climate change, by using an expert benchmark. The aims of the study are to describe and identify (i) differences between students' and experts' effectiveness estimations, (ii) differences in bachelor and master students' procedural knowledge, and (iii) differences between procedural knowledge of students studying different ESD-relevant subjects. Student teachers at eight German universities (n = 236) evaluated the effectiveness of solution strategies to SD challenges. The results showed high deviations in the effectiveness estimations of experts and students and, therefore, differing procedural knowledge. The lack of student teachers' interdisciplinary knowledge to reduce biodiversity loss and climate change seemed to be largely independent of their study program and ESD-relevant subject. One reason for this may be the generally low number of ESD-relevant courses they attended. This study suggests further longitudinal research in order to make clear statements about changes in SD-related knowledge during teacher education.

Keywords: knowledge; problem-solving; education for sustainable development (ESD); climate change; biodiversity loss; sustainable development

1. Introduction

Global challenges like biodiversity loss, climate change, and poverty require societal transformation toward a more sustainable future that is characterized by knowledge transfer, participatory decision-making, and lifelong learning [1]. Education is a central strategy in terms of sustainable development (SD) and can contribute to solving global challenges [2]. Education for sustainable development (ESD) enables "learners to take informed decisions and responsible actions for environmental integrity, economic viability and a just society for present and future generations" [3] (p. 7). The United Nations (UN) Decade of ESD (2005–2014) sought to foster the implementation of the approach of SD in national education systems [4]. The current Global Action Programme on ESD (GAP), ending in 2019, aims to generate and scale-up ESD actions at all levels and areas of education [2]. The UN 17 Sustainable Development Goals (SDGs) further reflect the importance of education. SDG 4 is exclusively attributed to education. A key for SD is addressed in Target 4.7—it seeks to "ensure that all learners acquire the knowledge and skills needed to promote sustainable development" [5] (p. 21). Furthermore, at least one target within the other 16 SDGs refers to education (e.g., target

13.3 "Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning" [5]). Education can decisively contribute to achieving the SDGs [6,7].

Bagoly-Simó and Hemmer [8] analyzed existing data about national educational standards, curricula, textbooks, and school practical journals to evaluate the state of ESD in German secondary schools. They observed the deepest and broadest implementation of ESD in geography, followed by politics/economy and biology; these represent minor subjects with small course volumes [8]. Nevertheless, "school education in Germany does not demonstrate proactive take-up of ESD diffusion by the majority, due to its top-down-oriented logic" [9] (p. 11). One reason may be found in teacher education. A systematic structural implementation of ESD in German teacher education is still missing in several places, although the GAP declared educators as one of five priority action areas [2,4,10]. However, the "knowledge and competencies [of educators] are crucial for restructuring educational processes and educational institutions towards sustainability" [11]. Therefore, teacher education is fundamentally important for an increased understanding of SDGs and SD [12]. This is also mentioned in the UN program "ESD for 2030", scheduled for 2020 to 2030, to supporting achievement of the SDGs [13].

Professional action competence is essential for successful teaching [14,15] and can therefore substantially affect ESD [16]. Beside motivational, volitional, and social willingness and skills, professional action competence includes professional knowledge consisting of content knowledge (CK), pedagogical content knowledge (PCK), and pedagogical knowledge (PK) cf. [14,17]. Hellberg-Rode and Schrüfer reported that 38% of cognitive competencies for teaching ESD were assigned to CK (23% to PCK, 19% to PK) [18,19]. Consequently, measuring ESD-related content knowledge of student teachers can yield information about the teaching and learning prerequisites needed for dealing with SD challenges.

The current international Fridays for Future movement demonstrates students' growing awareness of global climate change and their interest in forcing SD. Nearly 27,000 German-speaking scientists have endorsed the protests [20]. To educate students to responsible citizens, teachers have to incorporate current societal topics in their teaching [21], but are they prepared to teach science-based SD challenges like climate change and biodiversity loss?

1.1. Student Teachers' Knowledge of SD-Related Topics

The highly important challenges linked to the SDGs, like climate change and biodiversity, are supposed to be included in teaching and learning [3,7]. Recently, Zamora-Polo et al. [22] detected, inter alia, that student teachers had very limited knowledge of the SDGs. The UN defined with the SDGs 17 areas of activity for supporting SD. Context- or lifeworld-orientation is one of the five guiding principles for ESD [21]. According to Herman et al., "there need to be science teachers whose knowledge and perceptions are in line with those of vast majority of scientists" [23]. Investigations of student teachers', pre-service teachers', and teachers' climate change-related knowledge displayed deficits [23–29]. In their study, Herman et al. [23] reported that only 14% of science teachers in Florida and 4% in Puerto Rico gave the correct definition of climate change. Also, they did not correctly identify causes of climate change like the heating and cooling of homes; further, they incorrectly attributed primary causes to nuclear power generation, for example [23]. Among teachers, further misconceptions of climate change differing from scientific knowledge exist: for example, that ozone layer depletion contributes to climate change [23,24]. The same deficit was found in pre-service teachers [25,26]. Furthermore, science teachers in the US were unaware of the extent of scientific consensus about anthropogenic climate change [28]. Concerning biodiversity, previous research suggests that science teachers possess insufficient knowledge [30–34]. British, German, Cypriot, and Swiss student teachers were often found to be not familiar with the term "biodiversity" [31]. Student teachers of science education in Malaysia displayed limited knowledge about threats to biodiversity [34]. Furthermore, Dikmenli's [30] investigation of biology student teachers showed that the important role of biodiversity

in terms of SD often remains unrecognized. Compared to scientific data, secondary pre-service science teachers consistently overestimated the percentages of threatened plant species on different spatial levels (national, transnational, and global) [33]. However, knowledge about highly complex SD challenges, like biodiversity loss and climate change, represents a key requirement for ESD. Specific data on teaching and learning prerequisites are required in order to create evidence-based teacher education.

1.2. Approach for Measuring Procedural Knowledge

One repeatedly used approach for measuring teaching and learning prerequisites in education sciences [35–38] is de Jong and Ferguson-Hessler's model [39]. The model is considered as it explicitly refers to problem-solving and, thus, to knowledge-in-use [39]. Solving problems is of high priority when dealing with remarkably complex SD challenges. Procedural knowledge comprises actions that are suitable for certain types of problems in a specific domain [39] and verbalizable knowledge about the execution of these actions [40].

To solve complex SD issues, it is necessary to weigh economic, ecological, and social perspectives. This important ESD-specific competence of changing perspectives [18,21,41,42] can be addressed in teaching socio-scientific issues. An investigation of procedural knowledge should promote the consideration of different stakeholder perspectives in processing SD-relevant tasks. Therefore, measuring ESD-related procedural knowledge constitutes a special requirement. However, to gain insights into the student teachers' knowledge, there is a need to develop approaches to evaluate procedural knowledge. Thus, respective measures are required.

One approach for measuring procedural knowledge is to evaluate the effectiveness of predefined solution strategies in terms of SD challenges and to use expert evaluations of diverse SD-relevant disciplines as a benchmark cf. [36]. Koch et al. [36] used this method to determine the procedural knowledge of Indonesian students in land use study programs concerning local and regional resource use problems. They detected that both beginner and senior students strongly differed from experts. To the best of the authors' knowledge, biodiversity and climate change-related procedural knowledge has not been systematically analyzed thus far. In order to close this gap, the authors initially developed a measurement instrument. A multilevel Delphi approach combining qualitative and quantitative methods was applied to improve the literature-based items for measuring procedural knowledge concerning biodiversity loss and climate change [43]. An initial outcome of this prior work was a measurement instrument containing 18 solutions to real-world problems regarding (i) insects and pollination and (ii) peatland use. The key of the prior work was creating a benchmark. Here, the answers of experts from SD and ESD-relevant disciplines (e.g., biology, climatology, agroecology, ESD) in the second Delphi round were used to define the benchmark (for further information, see [43]). The expert benchmark served to analyze the procedural knowledge of student teachers regarding the SD challenges of biodiversity loss and climate change. Thus, the aims of the present research were to investigate in what ways

(i)   student teachers' effectiveness estimations differed from experts' procedural knowledge,
(ii)   student teachers in bachelor differed from those in master programs regarding procedural knowledge and
(iii)   student teachers in biology, geography, and politics differed from each other regarding procedural knowledge.

The Delphi approach first revealed indications of validity of the measurement instrument [43]. At the level of the experts, content validity was reached through qualitative data in the first expert round. Moreover, the large significant correlations between self-assessed knowledge and the indicated certainty about expert effectiveness estimations confirmed the validity of the instrument. Furthermore, at the level of student teachers, the think aloud studies enabled content validity [43]. Nonetheless, indications of validity of quantitative studies, and validation studies with related constructs like attitudes, responsibilities, or interests, are still missing.

Individual interest can be considered as a motivational factor [15] and may influence the acquisition of knowledge [44–46]. According to Renninger and Hidi, "the development of content knowledge is essential for interest development and is also an outcome of interest development" [46] (p. 96). Hence, a relation between interest and knowledge can be assumed. Beyond knowledge, attitudes can also influence students' behavior in terms of SD [47]. Tuncer et al. [48] showed that Turkish teachers were capable of forming environmentally literate students if they showed concern for environmental problems, were equipped with environmental knowledge, and had positive attitudes toward the environment. Therefore, a further aim of the present study was to find out more about the relation between student teachers' procedural knowledge, their attitudes, responsibilities, and interests.

2. Materials and Methods

2.1. Measurement Instrument and Data Collection

The present study used real-world issues concerning the SD challenges of biodiversity loss and climate change to investigate the procedural knowledge of German student teachers. Biodiversity loss and climate change contain numerous fields of action that might contribute to SD. Two contexts with both local and global relevance were chosen to represent these challenges: (i) insects and pollination and (ii) peatland use. Declines in honeybee populations and wild pollinators have recently appeared [49,50]; these have been triggered by intensive agriculture, causing habitat loss and fragmentation, for example [51,52]. However, many wild plants and crops depend on insects as pollinators, particularly, bees. Furthermore, 75% of leading global food crops and 35% of global production rely on animal pollination [53]. Thus, pollination contributes to the conservation of global biodiversity [49]. Climate change is addressed via examining the use of peatlands. Worldwide, the loss of peatlands is highest in Europe, at 52% [54]. Peatlands are terrestrial carbon storages, as they are capable of accumulating more carbon via photosynthesis than releasing carbon by respiration [55]. However, drainage of peatlands, which is inevitable for land use activities like agriculture, forestry, or peat extraction, leads to fostered greenhouse gas emissions [56,57] and contributes to climate change. While peatlands only constitute 6% of land used for agriculture in Germany, they are responsible for 57% of all agriculturally based emissions [58].

In this study, measuring procedural knowledge was operationalized according to de Jong and Ferguson-Hessler's model [39]. Following Koch et al. [36], solution strategies were evaluated in terms of their effectiveness. The developed measure and corresponding benchmark from previous work [43] formed the base for assessing student teachers' knowledge. Further information about the development of the measure and the underlying knowledge model can be found in Richter-Beuschel et al. [43].

The questionnaire for measuring student teachers' procedural knowledge comprised nine solution strategies for each context. A four-point Likert scale was used, ranging from ineffective (1) to very effective (4) for all items. The effectiveness of each solution strategy was evaluated in three fields of action: (i) realization of *sustainable land use*, (ii) provision of *ecosystem services*, and (iii) biodiversity conservation in the insects and pollination context or contribution to climate protection in the peatland use context (in the following, (iii) is summarized by the term *protection*). Students received two scenarios of real-world problems [43]. In addition, they were given an information sheet explaining the terms "ecosystem services", "sustainable land use", and "biodiversity" prior to answering the procedural knowledge items. This served to establish a homogeneous knowledge base of all of the participants before assessing their procedural knowledge. Socio-demographic data of sex, age, and semester were also gathered. All participants received a financial reward. The questionnaire was conducted in German and carried out in a paper and pencil format. To ensure standardized conditions, the lead author of the manuscript, and at one university a representative, conducted the data collection on-site. Participation took place outside of courses, was voluntary, and anonymity was assured.

2.2. Validation Tools

Beside answering instruments for measuring external validity, a self-assessment on knowledge in 13 different topics (diversity of species, diversity of ecosystems, genetic diversity, ecosystem services, climate change, importance of peatlands, sustainable development, environmental policy, agricultural policy, bees and pollination, sustainable land use, sustainable consumption, and ESD) on a five-point Likert scale (very good (1), good (2), satisfactory (3), sufficient (4), and insufficient (5)) was requested. In addition, the students' final school examination grade (German "Abitur") and an estimate of the number of attended courses with ESD relevance during the study were asked for. To gain insight into the participants' experience with ESD, they were invited to indicate predefined occasions in which they had dealt with topics of ESD (e.g., at school/university or watching film and TV).

The attitudes toward sustainable development (ASD) were measured by translating items, which have been suggested by Biasutti and Frate [59] into German. The instrument used was a factor analysis tested on the factors of environment, society, economy, and education, providing five items per factor. The ASD consisted of five-point Likert scale items: strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5). The responsibility toward climate change was assessed with three items from Federal Ministry for the Environment, Nature Conservation and Nuclear Safety [60], which were adapted accordingly for responsibility toward loss of biodiversity. On a five-point Likert scale, students had to indicate their level of agreement with the statements: strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5). All validation tools mentioned above were completed by all of the participants. The instrument for measuring interests in biodiversity issues [61] was only given to a subsample (n = 88) of biology students. This instrument required 15 min (on average) of processing time. Many of the participants' time restrictions kept them from answering this instrument. The measurement instrument to assess interests in biodiversity issues consisted of six subscales of biodiversity (loss of biodiversity, conservation of biodiversity, biodiversity in general, ecosystem services, access and benefit sharing, and biodiversity and climate change), with 6×15 items. Each of the six subscales contained three items related to the domains of (i) research, (ii) politics and law, (iii) economy, (iv) ecology, and (v) society. Interest in each item was evaluated on a five-point Likert scale ranging from very little (1) to very strong (5). The processing time of the questionnaire (procedural knowledge, ASD and responsibilities) was roughly 25 min, and when including interests in biodiversity issues, this rose to about 40 min.

2.3. Sample Composition

The study was carried out from October 2018 to May 2019 with student teachers at eight universities in five federal states of Germany (n = 236). The sample consisted of students who intended to become teachers in German high schools (Gymnasium) or in integrated comprehensive schools. All of the students were studying in the bachelor/master system (bachelor n = 123, master n = 112; one not stated). The participants' age ranged from 18 to 29 (M = 22.7 y, *SD* = 2.3 y), except for two outliers aged 32 and 39 y. The majority of the participants were female (72.5%, male 25.8%, divers 0.8%). The target group consisted of student teachers studying highly relevant subjects for ESD cf. [8]. Thus, all of the participants studied at least one of three ESD-relevant subjects (55.5% biology, 24.6% geography, 10.2% politics, 8.9% combination of two subjects, 0.8% not stated).

2.4. Statistical Analyses

IBM SPSS Statistics 25 and RStudio (Version 1.2.1335) were used for the descriptive and inferential statistical analyses, respectively. Means and standard deviations of students' effectiveness estimations were calculated separately for each field of action (i.e., *sustainable land use*, *ecosystem services*, and *protection*). The items within each field of action were combined into a scale, resulting in three scales. Cronbach's α was calculated to test the internal consistency of scales. One solution strategy of the insects and pollination context was excluded from analyses, resulting in higher reliability of scales.

A repeated measures ANOVA (rmANOVA) was used to analyze significant differences between the fields of action for any solution strategy.

Weighted average experts' answers on the item level from the second Delphi round [43] served as a benchmark to evaluate the student teachers' procedural knowledge [36,43]. Therefore, the effectiveness estimations of the student teachers were subtracted from the expert benchmark. Thus, deviations indicated an under- or overestimation of effectiveness by students compared to experts. Analyses on the level of fields of action required using the absolute values of the deviations.

In the following, the term "effectiveness estimation" is used when referring to the subjective measure of students' knowledge, thus the initial values the students indicated. The term "deviation" is used to demonstrate the differences between the expert benchmark and the students' estimations, even for the absolute values of the deviations (Figure 1). The deviation represented the objectified measure of students' knowledge and simultaneously served as an indicator of procedural knowledge. High deviations indicated low procedural knowledge, and vice versa.
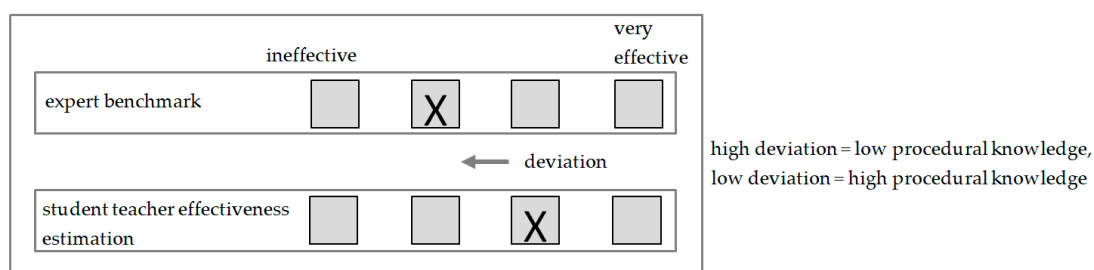
Figure 1. Defining student teachers' procedural knowledge by applying an expert benchmark.

The absolute deviation values were used to execute a mixed ANOVA, with fields of action as within-factor and group membership (study program: bachelor/master) as between-factor for the whole sample and for each of the three subjects (biology, geography, politics). *T*-tests were conducted to test for significant differences in deviation between bachelor and master for each field of action. RmANOVA was used to test for significant differences between fields of action separated by study program.

Checking for external validity, effectiveness estimations, and absolute deviations were correlated with factors of attitudes toward sustainable development, responsibilities toward climate change and biodiversity loss, and subscales of interests in biodiversity issues. Therefore, the means were calculated for different factors of the validation tools. Furthermore, correlations between final school examination grade, bachelor grade, experience in ESD, and procedural knowledge were analyzed. The relationship between the previous bachelor grade of current master students as well as between effectiveness estimations and the total deviation to the expert benchmark were analyzed using linear regression.

3. Results

3.1. Comparison of the Effectiveness Estimations of Student Teachers and Experts

In comparing student teachers' effectiveness estimations with the expert benchmark, in 15 out of 17 solution strategies, the students showed a higher range across fields of action than the experts did (Table 1). RmANOVAs confirmed these descriptive statistics. The rmANOVAs (partially with a Greenhouse–Geisser correction due to lacking sphericity) revealed statistically significant differences between fields of action in all 17 solution strategies (Table 2). Effect sizes (partial η^2) indicated nine large, four medium, and four small effects (Table 2). Thus, for all solution strategies for both contexts, Bonferroni-adjusted post hoc analyses showed 42 statistically significant differences between fields of action (Table A1 Appendix A). In contrast, the experts showed significant differences of effectiveness estimations in only six solution strategies, and the post hoc analyses revealed six statistically significant differences between fields of action [43].

Table 1. Effectiveness estimations of solution strategies regarding insects and pollination and peatland use context (M = mean; SD = standard deviation), for student teachers (black, n = 236) and the expert benchmark (grey, n = 20, values displayed in [43]).

Solution Strategies Regarding Insects and Pollination	Fields of Action					
	Sustainable Land Use		Ecosystem Services		Protection	
	M	*SD*	**M**	*SD*	**M**	*SD*
IP-1 Individuals ask in petitions to introduce bee-friendly laws.	2.48	0.92	2.51	0.89	2.95	0.92
	2.14	0.82	2.24	0.78	2.31	0.85
IP-2 Include contents of pollinator respective bee-related problems in curricula for schools, environment-related vocational training, and university studies.	2.95	0.96	2.73	0.98	3.00	0.87
	2.54	1.03	2.41	1.09	2.69	0.97
IP-3 The government provides financial incentives for using bee-friendly bloomers as biomass in biogas power stations.	2.83	0.87	2.73	0.81	2.97	0.92
	2.68	0.96	2.68	0.69	2.77	0.66
IP-4 Support pollinator-friendly agriculture by purchasing ecologically produced products.	2.99	0.73	2.81	0.73	2.95	0.75
	2.88	0.68	3.00	0.78	2.93	0.85
IP-5 Farmers reduce their use of pesticides and fertilizers.	3.32	0.74	2.70	0.91	3.60	0.59
	3.56	0.60	3.31	0.66	3.58	0.68
IP-6 Realign agricultural subsidies to stop promoting conventional and intensive agriculture.	3.27	0.81	2.59	0.85	3.04	0.81
	3.77	0.44	3.42	0.60	3.47	0.52
IP-7 Design a cultural landscape to serve pollinators as food source and habitat.	3.32	0.74	3.11	0.79	3.62	0.60
	3.60	0.51	3.42	0.60	3.85	0.37
IP-8 Strengthen the protection of wild bees and other pollinating insects.	3.39	0.80	3.41	0.76	3.85	0.39
	3.49	0.88	3.78	0.43	3.86	0.36
Solution Strategies Regarding Peatland Use	Fields of Action					
	Sustainable Land Use		Ecosystem Services		Protection	
	M	*SD*	**M**	*SD*	**M**	*SD*
PU-1 After rewetting of intensively agricultural used peatlands, farmers grow moisture-loving plants, e.g., reed.	2.87	0.84	2.51	0.85	2.84	0.78
	2.75	0.96	2.19	0.91	2.69	0.92
PU-2 Inform the public more intensively about the important role of peatlands, e.g., via media or educational projects.	3.09	0.88	2.81	0.95	3.21	0.82
	2.75	0.71	2.57	0.85	2.78	0.86
PU-3 Allow companies to incorporate CO_2 savings from peatland conservation into the EU emissions trading.	2.66	0.90	2.42	0.87	2.57	0.95
	3.11	0.80	2.88	0.82	2.92	0.68
PU-4 Investigate cultivation methods that preserve peatlands to apply them on agricultural-used peatlands.	3.30	0.67	2.95	0.71	3.14	0.79
	3.09	0.67	2.91	0.64	2.94	0.60
PU-5 Cultivate peatlands without fertilizers and pesticides.	3.34	0.77	2.59	0.95	3.02	1.02
	3.20	0.92	3.08	0.87	2.67	1.20
PU-6 Raise the water level of dehydrated peatlands to the water level of intact, near-nature peatlands.	3.07	0.87	2.86	0.93	3.49	0.72
	3.08	0.82	3.13	0.87	3.48	0.77
PU-7 Intensify the investigation of regenerative peat substitutes.	2.99	0.83	2.82	0.85	3.14	0.77
	3.34	0.69	3.13	0.86	3.31	0.76
PU-8 Apply existing laws stricter, e.g., prohibit the converting of grassland into maize cultivation.	3.46	0.71	2.80	0.95	3.46	0.71
	3.50	0.71	3.28	0.65	3.03	0.97
PU-9 Provide agricultural subsidies only for sustainably managed peatlands.	3.41	0.76	2.74	0.90	3.18	0.78
	3.64	0.64	3.39	0.72	3.47	0.71

The order of solution strategies follows the ascending average effectiveness estimations of experts (student teachers; expert benchmark); ineffective (1) to very effective (4).

Table 2. Differences between fields of action in the effectiveness estimations of solution strategies for insects and pollination and peatland use context using rmANOVA (student teachers, n = 236).

	Insects and Pollination				Peatland Use		
Item	rmANOVA	p	Partial η^2	Item	rmANOVA	p	Partial η^2
IP-1	$F(2, 466) = 46.28$	< 0.001	0.166	PU-1	$F(2, 464) = 22.88$	< 0.001	0.090
IP-2 [1]	$F(1.89, 445.12) = 14.72$	< 0.001	0.059	PU-2 [1]	$F(1.88, 439.38) = 28.82$	< 0.001	0.110
IP-3	$F(2, 468) = 7.74$	< 0.001	0.032	PU-3 [1]	$F(1.92, 443.02) = 7.85$	0.001	0.033
IP-4	$F(2, 468) = 7.94$	< 0.001	0.033	PU-4	$F(2, 468) = 20.49$	< 0.001	0.080
IP-5 [1]	$F(1.91, 446.45) = 115.76$	< 0.001	0.331	PU-5 [1]	$F(1.91, 441.32) = 52.95$	< 0.001	0.186
IP-6 [1]	$F(1.86, 433.68) = 68.23$	< 0.001	0.227	PU-6 [1]	$F(1.94, 453.93) = 44.29$	< 0.001	0.159
IP-7 [1]	$F(1.90, 446.26) = 38.42$	< 0.001	0.141	PU-7	$F(2, 466) = 14.95$	< 0.001	0.060
IP-8 [1]	$F(1.84, 432.71) = 84.11$	< 0.001	0.264	PU-8 [1]	$F(1.93, 452.24) = 72.82$	< 0.001	0.237
				PU-9 [1]	$F(1.84, 427.16) = 61.43$	< 0.001	0.209

$F(df, df_{error})$ = F-value, [1] Greenhouse–Geisser correction; IP = solution strategies for insects and pollination context; PU = solution strategies for peatland use context; partial η^2: ≥ 0.01 and < 0.06 = small, ≥ 0.06 and < 0.14 = moderate, and ≥ 0.14 = large effect, cf. [62].

Students' Cronbach's α values were acceptable for the fields of action *sustainable land use* and *protection* and high for *ecosystem services* (Table 3) [63]. In all three fields of action, the reliabilities of the experts' judgments were higher than those of the students.

Table 3. Reliabilities (Cronbach's α) of effectiveness estimations in scales of fields of action, comprising contexts of insects and pollination and peatland use, for student teachers and experts (weighted).

	Fields of Action		
	Sustainable Land Use	Ecosystem Services	Protection
Student teachers (n = 236)	0.741	0.848	0.718
Experts (n = 20)	0.846	0.910	0.861

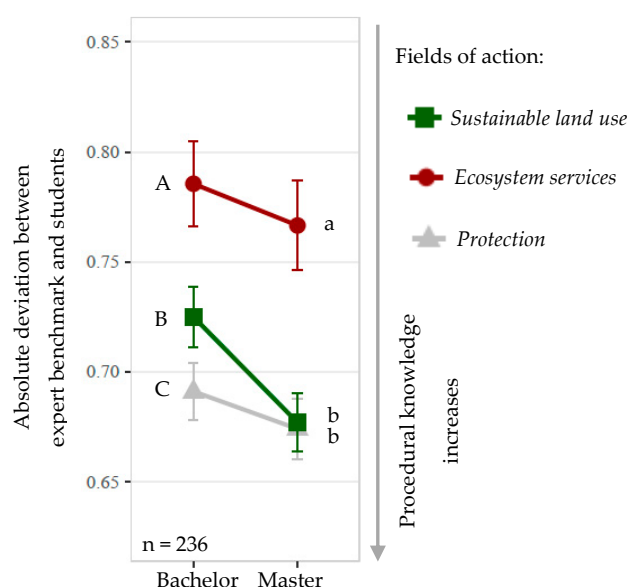## 3.2. Comparing the Procedural Knowledge of Bachelor and Master Students

Considering the bachelor and master students' answers per item, results demonstrated frequently over- or underestimations compared to the expert benchmark. For the insects and pollination context, the three solution strategies containing the least attributed effectiveness by experts were mainly overestimated by students (negative values), whereas solution strategies with the highest attributed effectiveness were underestimated (positive values). A comparable pattern was found within the peatland use context (Figure 2). However, the solution strategy PU-3 and the value of climate protection in PU-8 did not fit the pattern (Figure 2). The averaged absolute deviation between bachelor and master was 0.10 in the insects and pollination context and 0.08 in the peatland use context.
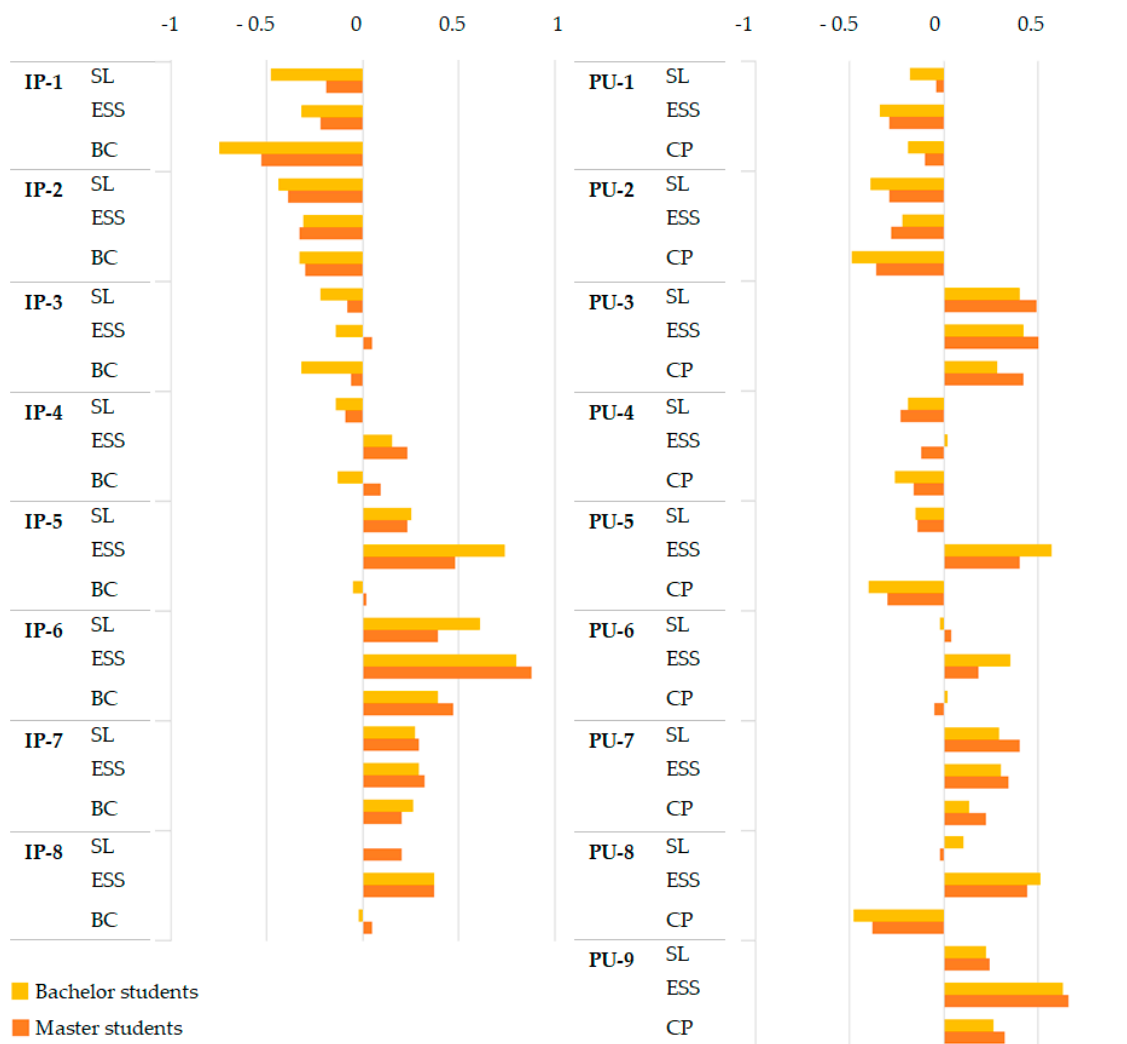
Figure 2. Deviations between expert benchmark and means of student teachers' estimates for the insects and pollination context (IP) and peatland use context (PU) separated by bachelor and master students (SL = *sustainable land use*; ESS = *ecosystem services*; BC = biodiversity conservation; CP = climate protection). The order of solution strategies follows the ascending effectiveness estimations of the experts. Item wording is shown in Table 1, IP-1 to IP-8 and PU-1 to PU-9.

At the level of fields of action, the absolute values of deviations from the expert benchmark were lower for master than bachelor students (Figure 3). In *ecosystem services*, the highest deviation from the benchmark occurred for both bachelor and master students. The lowest difference between bachelor and master students and the experts was observed in *protection*, and the highest in *sustainable land use*. The latter was the only field of action, where *T*-tests revealed significant differences between bachelor and master students (95% CI (0.01, 0.09), t(233) = 2.52, *p* = 0.013). Significant differences between fields of action separated by study program (results of rmANOVA) are presented in Figure 3.

Figure 3. Procedural knowledge indicated by absolute deviation comparing bachelor and master students (n = 236) and experts (n = 20). The error bars indicate standard errors. According to rmANOVA and Bonferroni post hoc ($p < 0.05$), means with no letter in common indicate significant differences between fields of action, separated by study program. Capital and small letters represent bachelor and master students, respectively.

In total, procedural knowledge differed concerning the field of action ($p < 0.001$), but it did not differ concerning the study program ($p = 0.100$) and the interaction between study program and field of action ($p = 0.357$) (Table 4). The Bonferroni-adjusted post hoc test revealed significant differences between the fields of action of *sustainable land use* and *ecosystem services* (MD = –0.076, $p < 0.001$, 95% CI –0.111, –0.040) and *ecosystem services* and *protection* (MD = 0.093, $p < 0.001$, 95% CI 0.059, 0.126).

Table 4. Mixed ANOVA of procedural knowledge with field of action (*sustainable land use, ecosystem services, protection*) as within-factor and study program (bachelor/master) as between-factor.

Source of Variance	dfw	dfb	F	*p*	eta^2
Study program	1	233	2.72	0.100	0.012
Field of action	2	466	29.19	< 0.001	0.111
Study program * field of action	2	466	1.00	0.357	0.004

dfw = degrees of freedom within group; dfb = between groups; eta^2 = effect size.

The master students demonstrated higher Cronbach's α values in *ecosystem services* and *protection* than the bachelor students (Table 5). Except for the value for bachelor students in *protection*, all the values were satisfactory or high.

Table 5. Student teachers' reliabilities (Cronbach's α) of effectiveness estimations in scales of fields of action separated by study program.

Study Program	Fields of Action		
	Sustainable Land Use	*Ecosystem Services*	*Protection*
Bachelor (n = 123)	0.748	0.837	0.648
Master (n = 112)	0.729	0.861	0.757

### 3.3. Comparing the Procedural Knowledge of Biology, Geography, and Politics Students

Separated by subject, the patterns of over- and underestimation were similar to those of the comparison of bachelor and master students (see Section 3.1) (Figure 4). With a few exceptions (e.g., IP-4 BC), the patterns did not differ between subjects. Nonetheless, some items revealed differences between subjects (e.g., IP-5, PU-2, and PU-5) (Figure 4). The averaged absolute deviation in the insects and pollination context amounted to 0.08 between biology and geography, 0.13 between biology and politics, and 0.12 between geography and politics. In the peatland use context, biology and geography differed by about 0.09, biology and politics about 0.17, and geography and politics by about 0.15.

Figure 4. Deviations between expert benchmark and means of student teachers' estimates for the insects and pollination context (IP) and peatland use context (PU) separated by subjects (SL = *sustainable land use*; ESS = *ecosystem services*; BC = biodiversity conservation; CP = climate protection). The order of solution strategies follows the ascending effectiveness estimations of the experts. Item wording is shown in Table 1, IP-1 to IP-8 and PU-1 to PU-9.

At the level of fields of action, procedural knowledge, separated by the subjects biology, geography, and politics, revealed the same overall pattern (cf. Figure 3), with highest deviations in *ecosystem services* and lowest deviations in *protection* (Figure 5a–c). *T*-tests showed significant differences between geography bachelor and master students in *sustainable land use* (95% CI (0.02, 0.15), t(78) = 2.51, p = 0.014). The averaged absolute deviations were very similar for bachelor and master students in biology (0.71), geography (0.74), and politics (0.73). Results of rmANOVA separated by study program

are contained in Figure 5. Table 6 shows the reliabilities separated by subject. No definite trend in reliability was obvious.
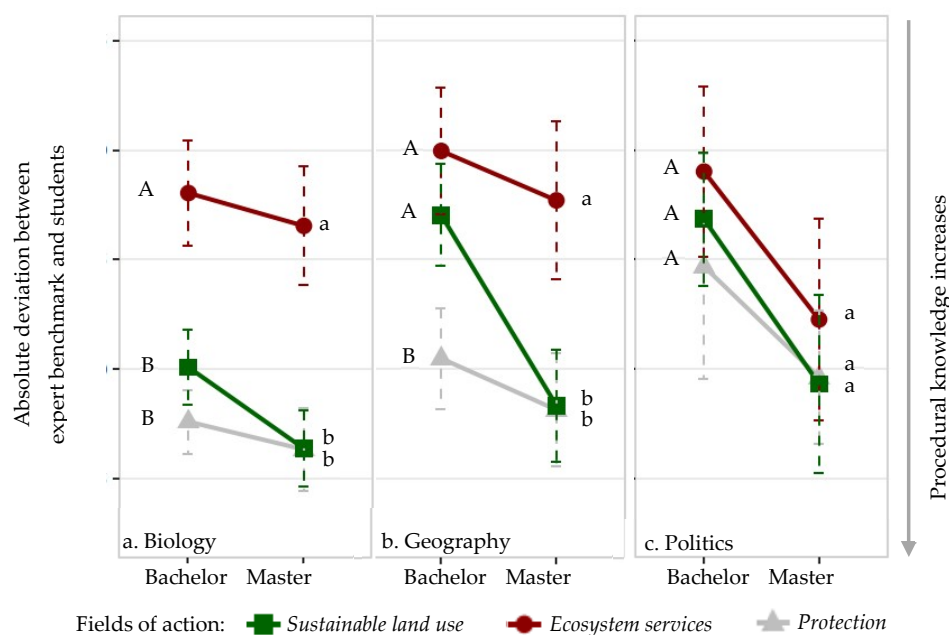
Figure 5. Procedural knowledge indicated by absolute deviations between (**a**) biology students (n = 154), (**b**) geography students (n = 80), (**c**) politics students (n = 24) and experts (n = 20). The error bars indicate standard errors. According to rmANOVA and Bonferroni post hoc ($p < 0.05$), means with no letter in common indicate significant differences between fields of action, separated by study program. Capital and small letters represent bachelor and master students, respectively.

Table 6. Student teachers' reliabilities (Cronbach's α) of effectiveness estimations in scales of fields of action separated by subject.

Subject	Fields of Action		
	Sustainable Land Use	*Ecosystem Services*	*Protection*
Biology (n = 154)	0.744	0.831	0.726
Geography (n = 80)	0.738	0.856	0.703
Politics (n = 24)	0.716	0.823	0.755

3.4. Indications for Validity of Measure

Regarding formal education, 103 participants (43.6%) reported having dealt with ESD at school (Table 7). While more bachelor than master students stated they had encountered ESD at school, the reverse was shown for ESD at university (Table 7). Regarding occasions of having dealt with ESD, the highest level was reached in "university" (55.9%), followed by in "films and TV" (46.6%). Seventeen participants (7.2%) indicated not having dealt with ESD. Divided by subject, a large number of geography students came into contact with ESD at university (76.3%). For biology, this applied to 51% and for politics to 33.3% of students.

Table 7. Formal education where participants dealt with ESD, separated by study program and subject (percentage values).

ESD	Total	Study Program			Subject							
		BA	MA	Biology			Geography			Politics		
	n = 236	n = 123	n = 112	n = 154			n = 80			n = 24		
				Total	BA	MA	Total	BA	MA	Total	BA	MA
At school	43.6	49.6	37.5	40.5	46.5	32.8	55.0	64.4	42.9	58.3	66.7	53.3
At university	55.9	41.5	72.3	51.0	32.6	74.6	76.3	68.9	85.6	33.3	22.2	40.0

BA = bachelor; MA = master.

Participants indicated having attended 1.14 (*SD* = 1.71) courses with ESD-relevance (0.76 in BA (*SD* = 1.66), 1.5 in MA (*SD* = 1.67)); the ESD portion covered on average 39% (*SD* = 24) of these courses (in BA, 43% (*SD* = 23); in MA, 38% (*SD* = 24)). The majority of the courses were attended by geography students, with 1.51 (*SD* = 1.93), followed by 1.18 in biology (*SD* = 1.8) and 0.54 (*SD* = 1.1) in politics. No correlation occurred between participation in ESD-relevant courses and procedural knowledge (r = 0.042, *p* = 0.537).

Self-assessment of knowledge ranged from 2.10 (2 = good) in climate change to 3.75 (4 = sufficient) in agricultural policy (Table 8). Means of self-assessed knowledge separated by subject showed the highest knowledge among the biology students in ecologically focused topics such as "bees and pollination". Geography students reported the highest knowledge, compared to students of other disciplines, in more interdisciplinary topics like "sustainable land use"; politics students reported the highest knowledge in policy topics (Table 8).

Table 8. Self-assessed knowledge in 13 different topics (n = 236) for all subjects and separated by subject.

Topic	All Subjects			Biology		Geography		Politics	
	Mean	*SD*	Rank	Mean	*SD*	Mean	*SD*	Mean	*SD*
Diversity of species	2.63	0.80	5	2.41	0.76	2.72	0.83	2.91	0.90
Diversity of ecosystems	2.59	0.80	4	2.42	0.72	2.58	0.80	2.96	1.07
Genetic diversity	2.76	1.03	6	2.41	0.86	3.14	1.04	3.13	1.06
Bees and pollination	2.76	1.09	7	2.55	1.01	2.95	1.13	3.30	1.15
Ecosystem services	3.38	1.05	11	3.36	1.04	3.12	1.02	3.78	1.09
Climate change	2.10	0.79	1	2.15	0.81	1.84	0.67	2.35	0.83
Importance of peatlands	3.68	1.10	12	3.67	1.08	3.59	1.10	3.83	1.27
Sustainable development	2.54	0.87	3	2.68	0.88	2.12	0.63	2.57	1.04
Sustainable consumption	2.19	0.84	2	2.28	0.89	1.96	0.74	2.13	0.69
Sustainable land use	2.96	1.04	8	3.05	1.00	2.49	0.90	3.52	1.10
Education for sustainable development	3.25	1.13	10	3.45	1.10	2.74	1.10	3.39	1.23
Environmental policy	3.11	1.08	9	3.34	1.01	2.89	0.97	2.00	0.74
Agricultural policy	3.75	1.00	13	3.93	0.93	3.50	0.97	3.22	1.17

SD = standard deviation; very good (1), good (2), satisfactory (3), sufficient (4), and insufficient (5); subject with highest self-assessed knowledge.

There was no correlation between final school examination grade and total procedural knowledge (r = 0.092, *p* = 0.162). However, the bachelor grade was a weak, statistically significant predictor (R^2 = 0.048, adjusted R^2 = 0.039) of procedural knowledge for SD (F(1,101) = 5.09, *p* = 0.026) cf. [62]. Also, the effectiveness estimations weakly significantly predict procedural knowledge (R^2 = 0.032, adjusted R^2 = 0.028; F(1,234) = 7.78, *p* = 0.006).

According to only small differences in procedural knowledge of bachelor and master students and between subjects, the analyses of validation measurement instruments were conducted with the whole sample (n = 236). Existing measures for assessing attitudes, responsibilities, and interests were applied to check for external validity. In the factor analytical proofed scale for ASD, there were no significant differences between bachelor and master students in the factors of environment, economy, society, and education ($p > 0.05$). All of the participants showed positive attitudes toward SD. There was a moderate correlation of averaged effectiveness estimation and averaged ASD (Table 9). Weak correlations were identified between the effectiveness estimations in fields of action and related constructs of ASD (Table 9). However, by correlating procedural knowledge instead of an effectiveness estimation with ASD, no significances appeared (Table 9). The same pattern was detected for the relations between effectiveness estimations/procedural knowledge and responsibilities toward climate change and biodiversity loss (Table 9). Students indicated high responsibilities toward biodiversity loss (M = 3.97) and climate change (M = 4.12) (4 = agree, 5 = strongly agree). The averaged ASD showed a moderate correlation with averaged responsibilities toward climate change and biodiversity loss (r = 0.434, $p < 0.001$).

Table 9. Correlations between effectiveness estimations (italics)/procedural knowledge (bold) and attitudes toward sustainable development (ASD) and responsibilities.

Validation Tool		Sustainable Land Use		Ecosystem Services		Protection		Average	
ASD	Environ-ment	*r = 0.230* *p < 0.001*	**r = −0.044** **p = 0.499**			*r = 0.207* *p < 0.001*	**r = 0.024** **p = 0.719**		
	Economy			*r = 0.239* *p < 0.001*	**r = −0.052** **p = 0.424**				
	Society			*r = 0.21* *p = 0.001*	**r = −0.029** **p = 0.658**				
	Average							*r = 0.425* *p < 0.001*	**r = −0.044** **p = 0.499**
Responsibilities	Total							*r = 0.396* *p < 0.001*	**r = −0.022** **p = 0.740**

Respondents' (n = 88) indicated interests in biodiversity issues are presented in Table 10. Relating the interests in biodiversity issues to the effectiveness estimations of students, fields of action were separated by the two contexts. In contrast to the insects and pollination context, in the peatland use context, the fields of action hardly correlated with the subscales of interests in biodiversity (Table 11). After correlating interests in biodiversity issues with procedural knowledge separated by contexts, no significances were detected (except between insects and pollination context and interest in access and benefit sharing).

Table 10. Interests in biodiversity issues (means (M) and standard deviations (*SD*) for subscales and contexts, n = 88).

Subscale			Domain		
	M	*SD*		**M**	*SD*
Biodiversity loss	3.71	0.48	Research	3.82	0.49
Biodiversity protection	3.59	0.56	Politics and law	3.21	0.65
Access and benefit-sharing	3.39	0.58	Economy	3.46	0.60
Ecosystem services	3.43	0.48	Ecology	3.88	0.49
Biodiversity in general	3.55	0.51	Society	3.80	0.56
Biodiversity and climate change	3.73	0.59			

Very little interest (1) to very strong interest (5).

Table 11. Correlation between subscales of interests in biodiversity issues and fields of action of students' effectiveness estimation separated by contexts (n = 88).

Subscale of Interests in Biodiversity Issues	Sustainable Land Use		Ecosystem Services		Protection	
	IP	**PU**	**IP**	**PU**	**IP**	**PU**
Biodiversity loss	r = 0.282 p = 0.008	r = 0.129 p = 0.231	r = 0.204 p = 0.057	r = 0.099 p = 0.360	r = −0.248 p = 0.020	r = −0.038 p = 0.722
Biodiversity conservation	r = 0.251 p = 0.018	r = 0.140 p = 0.194	r = 0.194 p = 0.080	r = 0.106 p = 0.327	r = 0.220 p = 0.039	r = −0.036 p = 0.736
Access and benefit sharing	r = 0.446 p < 0.001	r = 0.229 p = 0.033	r = 0.303 p = 0.004	r = 0.093 p = 0.393	r = 0.358 p = 0.001	r = 0.168 p = 0.119
Ecosystem services	r = 0.169 p = 0.115	r = 0.028 p = 0.795	r = 0.097 p = 0.368	r = 0.025 p = 0.818	r = 0.109 p = 0.313	r = −0.058 p = 0.592
Biodiversity in general	r = 0.326 p = 0.002	r = 0.156 p = 0.148	r = 0.196 p = 0.069	r = 0.132 p = 0.223	r = 0.193 p = 0.074	r = 0.031 p = 0.777
Climate change	r = 0.309 p = 0.003	r = 0.197 p = 0.065	r = 0.227 p = 0.033	r = 0.141 p = 0.191	r = 0.259 p = 0.015	r = 0.025 p = 0.816

IP = solution strategies for insects and pollination context; PU = solution strategies for peatland use context.

4. Discussion

The study on student teachers' procedural knowledge addresses two key issues: biodiversity loss and climate change. Student teachers evaluated solution strategies regarding their effectiveness in three fields of action, which are essential in terms of SD: *sustainable land use*, *ecosystem services*, and *protection*. Student teachers' procedural knowledge was assessed by using a benchmark from an expert study [43]. The effectiveness judgments of student teachers were subtracted from the values of the expert benchmark. When referring to initial values, indicated by students, the term "effectiveness estimation" is used. In contrast, deviations between expert benchmark and students' estimations indicate students' procedural knowledge. Estimations on effectiveness of experts and students deviated remarkably. Regarding procedural knowledge, between bachelor and master students, only small differences were observed. The same applies to the comparison of students of biology, geography, and politics, where the same overall pattern occurred. The advantage of the present study is the sample composition of different study programs and subjects with the highest ESD relevance (biology, geography, politics) from eight universities of five federal states in Germany.

4.1. Student Teachers' Procedural Knowledge

The study showed deviating effectiveness estimations between experts and students. These findings are in line with previous research. For example, Koch et al. [36] reported differing judgements of students and experts regarding the effectiveness of solution strategies for resource use problems in Indonesia. Furthermore, studies show discrepancies in comparing (student) teachers' estimations with scientific consensus or data regarding climate change or biodiversity. Plutzer et al. [28] asked US science teachers to estimate the proportion of global warming scientists relate to humans. On average, only 37.5% of the respondents selected the correct answer of "81% to 100%" human caused global warming [28]. Therefore, teachers' views differ from those of scientists. According to Wynes and Nicholas [64], the reason for this may lie in curricula documents and textbooks. They assessed Canadian secondary school science curricula documents and textbooks and found that, for example, the documents cast doubt on the scientific consensus on human-caused climate change and the trend of global warming [64]. Regarding biodiversity, it was shown that student teachers' estimations of threats to plant species markedly differed from scientific data by overestimations [33]. One explanation would be the cognitive performance required to balance the total number of plants against the number of threatened plants [33].

The deviations between experts and students in the present study became plausible when considering the following: the participants self-assessed their knowledge in ESD as hardly satisfactory, and not even half of the students stated that they dealt with ESD at school. The remarkably higher

proportion of bachelor students indicated dealing with ESD at school is probably the result of several efforts, like the UN Decade of ESD [4] and the GAP [2], as both have supported the implementation of ESD in schools. Only 55.9% of the participants stated that university was one of the most prominent contexts in which ESD played a role. Because they spent more time at university, this was higher for master than bachelor students. TV and internet also represented important sources of dealing with SD contexts. When teacher education is completed, according to Cini and Mifsud [65], mainly internet (91.1%) and television (73.3%) served as sources to obtain environmental knowledge.

Because of the missing correlation between procedural knowledge and the number of ESD-relevant courses attended, there seemed to be no considerable impact on procedural knowledge. However, the workload of ESD-relevant courses equated to 51.3 h for master and 26 h for bachelor students (one course was equivalent to 3 credit points (ECTS) and 90 h workload).

Furthermore, the deviations between experts and students partly reflected the students' self-assessed knowledge. For example, the lowest self-assessed knowledge in agricultural politics supported the lowest procedural knowledge in solution strategies to agricultural subsidies (IP-6 and PU-9 in Figures 2 and 4). The latter was also in line with the lowest interest in biodiversity issues in the domain of politics and law (Table 10). Additionally, the students indicated comparable high knowledge for sustainable consumption (Table 8). Consumer decision and behavior are often contained in curricula (e.g., [66]). This was in agreement with the highest procedural knowledge in the consumption solution strategy (IP-4 in Figure 2).

Over- and underestimating solution strategies resulted of the students' higher range in estimations compared to experts. Overestimation seemed to occur mainly in areas where students felt themselves addressed because of their teacher education. Therefore, three of the four solution strategies with large overestimations contained a term like "curricula" (IP-2), "public" (PU-2), or "petition" (IP-1). Underestimation especially occurred in areas where the students felt uncertain, most frequently in the field of *ecosystem services.*

The pattern of the highest procedural knowledge in *protection*, followed by *sustainable land use* and *ecosystem services* (Figures 3 and 5), could be attributed to the level of awareness and the degree of interdisciplinarity of the fields. Education seems to address fields of action to varying extents. This is supported by the rmANOVAs, revealing 42 significant differences between fields of action. *Protection* and *sustainable land use* can be more ecologically focused, whereas *ecosystem services* require a stronger integration of economic and social knowledge. The general pattern of higher procedural knowledge in *sustainable land use* than in *ecosystem services* is also supported by the half unit higher self-assessed knowledge in *sustainable land use* than in *ecosystem services* (Table 8). Furthermore, the pattern with the highest procedural knowledge in *protection* and the lowest in *ecosystem services* may be explained by the order in which corresponding issues are implemented in formal education. In Germany, issues of environmental protection were integrated into the curricula in the 1980s [67] and are largely established today. Through nation-wide initiatives since 1999, the implementation of sustainability issues at schools has increased. Sustainable land use can be considered, for example, in terms of sustainable consumption and production [4]. However, it seems that ecosystem services are hardly considered [68–75].

Small differences in procedural knowledge occurred between bachelor and master students (Figure 2). For the majority of items, the pattern of over- or underestimation at the level of solution strategies was independent of study program. Master students showed higher procedural knowledge in all fields of action. Thus, rating scale judgments of master students were closer to the experts' judgments than the bachelor students' judgments. Despite the procedural knowledge of master students suspected to be higher than the bachelor students', significance was only detected in *sustainable land use*. This is similar to the results of Effeney and Davis [76]: they assessed student teachers separated by first to fourth year of study and detected significant differences in knowledge of sustainability issues only between first and third years.

On average, few differences in procedural knowledge were detected between the three highly ESD-relevant subjects of biology, geography, and politics (Figure 4). The single significant difference between bachelor and master students in *sustainable land use* was observed in geography. This may be attributed to more interdisciplinary-oriented curricula and geography's nature of combining natural and social sciences, compared to biology or politics cf. [66]. The highest ESD-related workload of 49.9 h was reported in geography; this is in line with the broadest implementation of ESD at school [8].

4.2. Validity of the Measure

Participants with greater pro-sustainable attitudes evaluated the solution strategies for SD challenges as being more effective. This significant correlation of attitudes and effectiveness estimations seems logical, as both are subjective in nature (Figure 6). Only by relating the estimations to expert benchmark can an objectified level be reached. Hence, a statement about procedural knowledge can be derived (Figure 6). In the present study, procedural knowledge did not correlate with attitudes and responsibilities (Table 9). It seems plausible that the subjective measure of students' knowledge (effectiveness estimations) correlates stronger with other subjective measures than the objectified measure (students' deviations to expert benchmark) does. Results are in line with Tuncer et al. [48], who could not identify a significant correlation between environmental knowledge and environmental attitudes of pre-service teachers in Turkey. In contrast, for tenth grade students, Michalos et al. [47] detected a high correlation between knowledge and attitudes toward SD. One reason for the missing correlation of knowledge and attitudes in the present study may be that investigated attitudes were assessed much more generally than measured procedural knowledge cf. [77]. As procedural knowledge is defined as knowledge-in-use [39], the attitude–action gap may be one more reason for the absence of any correlations [77]. Several situational barriers could hinder executions [78,79]. Especially, studies about sustainable consumption demonstrate that a positive attitude is no guarantee of action [80].
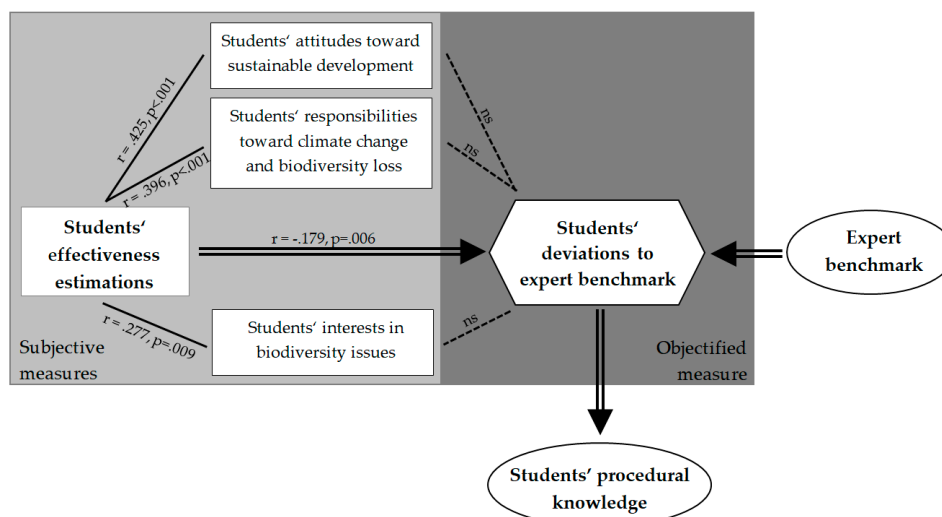
Figure 6. Relations between subjective measures and objectified students' procedural knowledge with related constructs (ns = not significant; effectiveness estimations underlying the expert benchmark are displayed in Table 1).

Data concerning the interests in biodiversity and effectiveness estimations supported the expected higher correlations for the insects and pollination context than for the peatland use context. Hardly any correlations between interests in biodiversity issues and procedural knowledge were observed. Missing correlations between procedural knowledge and external validation instruments were in accordance with only weak prediction of procedural knowledge by student teachers' effectiveness estimations ($R^2 = 0.032$).

4.3. Limitations of the Study

The trend of overestimation on the level of solution strategies (Figures 2 and 4) can be assumed to be a phenomenon of social desirability. In other words, the respondents may have misrepresented themselves in order to appear to comply with social norms cf. [81]. In the present study, participants had to evaluate items declared to be solution strategies in the contexts of insects and pollination and peatland use. This could lead to an exaggerated indication of desired behavior [82]. It is possible that the participants wanted to present themselves in a positive light by indicating high effectiveness. Concerning the underestimation, uncertainty in the specific contexts may have inhibited choosing high-effectiveness estimations. Furthermore, the complexity of SD challenges may have required a high cognitive performance cf. [33] and led to incorrect estimations. Moreover, differences between subjects might have been underestimated, as the respondents who studied two ESD-relevant subjects (n = 24) were assigned to both subjects, and sample sizes differ.

In Germany, currently it is difficult to compile a large sample for a time-consuming questionnaire, as the nation-wide "Qualitätsoffensive Lehrerbildung" includes intensive evaluation studies in many teacher education institutions. Because of voluntary participation beyond courses, the risk of selection bias cannot be excluded. The students knew that the survey dealt with challenges of SD. Probably, students with a relatively high interest and knowledge regarding SD were overrepresented in the sample; however, this effect may have been mitigated by the financial incentive.

5. Conclusions and Future Work

The relevance of the addressed issues of biodiversity loss and climate change manifests through being represented mainly in the SDGs of "Life on Land", "Life Below Water", and "Climate Action" [83] and, thus, in the education for SDGs [3]. The present research provides insights into student teachers' procedural knowledge. The deviations between students' effectiveness estimations and expert benchmark demonstrate that students who are becoming teachers can improve their procedural knowledge in order to adequately solve real-world challenges of SD. Student teachers' content knowledge as an essential competence for teaching ESD should be fostered.

So far, the level of study program (bachelor/master) seems to have only a little influence on procedural knowledge. However, the almost double workload in ESD of master students compared to bachelor students showed a small effect. Therefore, it can be assumed that approaches of the German "Qualitätsoffensive Lehrerbildung", which foster the integration of ESD at certain universities [84–86], could affect student teachers' procedural knowledge. Results suggest that students in the subjects of biology, geography, and politics would all benefit to the same extent from enriching their education with ESD. This study took teacher education at eight universities into account, revealing a rather poor consideration of ESD issues in courses (a maximum average of 1.5 for master students during their entire study). Thus, we are still far from the desirable extent of the ESD implementation in Germany. The results regarding expandable teaching and learning prerequisites can enrich teacher education, as they can serve as a base for strengthening ESD; thus, they contribute to achieving core facets of the SDGs.

In terms of SD, it is essential that (student) teachers possess knowledge on real-world SD challenges. According to Lawson et al. [87], by taking into account teaching SD-relevant issues, not only does a multiplier effect occur, but also a positive effect of intergenerational learning is possible. Researchers recently found that parents' concern about climate change may be fostered by their children [87]. Furthermore, politics tend to pick up the topic to improve their policies toward the SDG "Climate action".

So far, literature-based solution-strategies and, especially, the input of experts in the first Delphi-round [43] contributed to ensure content validity of the measure. With the present quantitative study, the final step of the measurement development was reached. By calculating the deviation, the expert benchmark served as a normative standard for student teachers' procedural knowledge and force validity. The evaluation of student teachers' procedural knowledge provided plausible

results. Therefore, together with the Delphi study [43], this research developed an approach to evaluate highly complex procedural knowledge for problem-solving in SD-relevant issues. The SDGs provide numerous topics for teaching SD [3]. Therefore, it would be possible to adapt the approach of this research instrument to other highly complex and controversial SD challenges (e.g., health issues in the global south). The instrument can also be used for other target groups like senior high school students.

In the future, it would be interesting to examine if other subjects like physics or languages show deviating levels of procedural knowledge regarding SD issues. Concerning the over- and underestimation on the level of solution strategies, qualitative studies and quantitative studies with an intervention or experimental design could reveal reasons for the detected patterns. In this way, greater insight into the influence of social desirability could be gained.

The instrument of procedural knowledge was combined with the evaluation of situational and conceptual knowledge cf. [39]. A joint analysis of all three types of knowledge is planned in a next step. Furthermore, a longitudinal study design with a large sample will be applied in order to make clear statements about changes in SD-related knowledge during teacher education. The described further projects will allow evidence-based and more precisely drawn conclusions on how to enrich ESD in teacher education.

Appendix A

Table A1. Bonferroni-adjusted post hoc analyses of student teachers' effectiveness estimations (n = 236).

Solution Strategy	Sustainable Land Use vs. Ecosystem Services			Sustainable Land Use vs. Biodiversity Conservation/Climate Protection			Ecosystem Services vs. Biodiversity Conservation/Climate Protection		
	MD	*p*	**95% CI**	**MD**	*p*	**95% CI**	**MD**	*p*	**95% CI**
IP-1	−0.030	1.00	−0.157 0.097	−0.466	<0.001	−0.605 −0.326	−0.436	<0.001	−0.561 −0.310
IP-2	0.225	0.001	0.082 0.367	−0.051	1.00	−0.183 0.081	−0.275	<0.001	−0.391 −0.160
IP-3	0.094	0.326	−0.047 −0.234	−0.136	*0.070*	−0.280 0.008	−0.230	<0.001	−0.371 −0.089
IP-4	0.183	0.001	0.062 0.304	0.043	1.00	−0.065 0.150	−0.140	0.014	−0.259 −0.022
IP-5	0.626	<0.001	0.467 0.784	−0.277	<0.001	−0.407 −0.146	−0.902	<0.001	−1.051 −0.753
IP-6	0.684	<0.001	0.531 0.836	0.226	<0.001	0.104 0.349	−0.457	<0.001	−0.611 −0.303
IP-7	0.203	0.006	0.047 0.359	−0.305	<0.001	−0.435 −0.175	−0.508	<0.001	−0.643 −0.374
IP-8	−0.013	1.00	−0.159 0.134	−0.453	<0.001	−0.588 −0.319	−0.441	<0.001	−0.570 −0.311
PU-1	−0.361	<0.001	0.214 0.507	0.026	1.00	−0.110 0.162	−0.335	<0.001	−0.482 −0.187
PU-2	0.277	<0.001	0.148 0.405	−0.119	0.037	−0.233 −0.005	−0.396	<0.001	−0.538 −0.253
PU-3	0.246	<0.001	0.102 0.390	0.091	0.381	−0.052 0.233	−0.155	*0.076*	−0.321 0.011
PU-4	0.349	<0.001	0.223 0.475	0.153	0.017	0.021 0.285	−0.196	0.002	−0.334 −0.057
PU-5	0.754	<0.001	0.591 0.918	0.328	<0.001	0.156 0.499	−0.427	<0.001	−0.622 −0.232
PU-6	0.209	0.015	0.031 0.386	−0.421	<0.001	−0.574 −0.269	−0.630	<0.001	−0.793 −0.467
PU-7	0.175	0.015	0.026 0.324	−0.145	0.029	−0.280 −0.011	−0.321	<0.001	−0.462 −0.179
PU-8	0.655	<0.001	0.497 0.814	−0.004	1.00	−0.141 0.133	−0.660	<0.001	−0.818 −0.501
PU-9	0.670	<0.001	0.506 0.833	0.232	<0.001	0.106 0.358	−0.438	<0.001	−0.589 −0.286

MD = mean difference; CI = confidence interval; IP = solution strategies for insects and pollination context; PU = solution strategies for peatland use context; tendencies.

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