Article

Knowledge of Student Teachers on Sustainable Land Use Issues–Knowledge Types Relevant for Teacher Education

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Abstract: For restructuring educational processes and institutions toward Sustainable Development, teachers’ knowledge and competences are crucial. Due to the high relevance of teachers’ content knowledge, this study aimed to (i) assess Sustainable Development-relevant knowledge by differentiating between situational, conceptual and procedural knowledge, (ii) find out via item response theory modelling how these theoretically distinguished knowledge types can be empirically supported, and (iii) link the knowledge dimension(s) to related constructs. We developed a paper-and-pencil test to assess these three knowledge types (N = 314). A two-dimensional structure that combines situational and conceptual knowledge and that distinguishes situational/conceptual knowledge from procedural knowledge, fits the data best (EAP/PV situational/conceptual: 0.63; EAP/PV procedural: 0.67). Student teachers at master level outperformed bachelor level students in situational/conceptual knowledge but master level students did not differ from students at bachelor level regarding procedural knowledge. We observed only slight correlations between the two knowledge dimensions and the content-related motivational orientations of professional action competence. Student teachers’ deficits in procedural knowledge can be attributed to the small number of Education for Sustainable Development-relevant courses attended. Systematically fostering procedural knowledge in teacher education could promote achieving cognitive learning objectives associated with Sustainable Development Goals in the long term.

Keywords: knowledge; teacher education; sustainable development; climate change; biodiversity

1. Introduction

Promoting knowledge and competences of Education for Sustainable Development (ESD) enables people to act as informed citizens in creating a more sustainable world [1]. In 2015, the United Nations (UN) adopted 17 Sustainable Development Goals (SDGs) to foster Sustainable Development (SD) according to social, ecological, and economic interests [2]. Among other things, the SDGs aim at ending poverty, reducing inequality, and improving health and education [2]. ESD is one goal among the SDGs (Target 4.7), and it is a key enabler for the remaining 16 goals. The new framework for ESD beyond 2019 highlights the role of education, too [3]. The program covers the period from 2020 to 2030 and concentrates on enhancing “ESD’s contribution to the achievement of all 17 SDGs, focusing on policies, learning environments, teachers and educators, youth as well as communities” [3] (p. 1). Hence, the new framework highlights actions on teacher education as a priority [3].

Schools must face the challenges of society, for example, to enable learners to deal with land use change issues, biodiversity-related issues and climate change issues [4–6]. These exemplary Sustainable Development issues build a subset of Socioscientific Issues (SSIs) [7]. SSIs represent controversial and challenging to resolve real-world problems [8], which “tend to have multiple plausible solutions” [9] (p. 4). SSIs have a high social relevance and are related to science [8]. In science education, for instance,
such complex issues can be used as contexts to better prepare students to “engage in discourses and
decisions related to socially relevant issues associated with science” [9] (p. 4).

Teachers are key persons for changes in classroom practice [10]. To restructure educational
processes and institutions toward SD, teachers’ knowledge and competences are crucial [1].
Generally, teachers require scientific knowledge to teach a subject [11]. Teaching Sustainable
Development issues is challenging because it involves knowledge of multiple disciplines. In several
countries, among them, Germany [12] and Sweden [13], ESD is not an individual subject but the task of
several subjects. However, almost every subject can be linked to Sustainable Development issues [12].
One learning objective of teacher education courses is to “know about sustainable development,
the different SDGs and the related topics and challenges” [1] (p. 52).

For SSIs, content knowledge is of high relevance because it is related to students’ quality of informal
reasoning [14,15]. Thus, “individuals need to have an understanding of an issue in order to render
informed decisions” [15] (p. 73f). Also for dealing with Sustainable Development issues in the context
of ESD, content knowledge is a necessary skill [16–18]. Furthermore, a study in mathematics showed
that teachers’ content knowledge is a predictor of students’ achievement [19]. Therefore, knowing about
teachers’ prerequisites for dealing with Sustainable Development issues is essential for optimising ESD
in teacher education and, thus, in schools. Sustainable Development issues are challenging because
many foci like ecological, economic, social, and political must be considered. Knowledge of different
disciplines and interdisciplinary knowledge in various fields, such as sustainable land use or ecosystem
services, is necessary.

Content knowledge as part of professional action competence [20] can be best investigated via
Item Response Theory (IRT) models. For example, by analysing performance tests the number of
correct answered items is related to a persons’ ability [21]. However, it cannot be assumed that all items
of a performance test measure the ability in the same way. Instead, the items of a performance test
show usually different difficulties [21]. Hence, it is troublesome to make conclusions about the ability
of two persons with the same amount of correct answers without considering the item difficulties [21].
With IRT models, it is possible to consider person ability as well as item difficulty [21]. Thus, “it is
possible to compute the probability that a student succeeds on an item” [22]. Therefore, IRT modelling
allows one to gain valid insights into learners’ knowledge and competences and is frequently used in
current educational research (e.g., [23–25]). However, apart from a few exceptions that have used IRT
modelling [26–28], most studies evaluating knowledge about Sustainable Development issues did not
use IRT-modelling for data analysis. This accounts for studies evaluating knowledge of the SDGs [29],
climate change [30–32], or biodiversity [33]. Furthermore, most of these studies focused on only one
type of knowledge [28,33,34], often without declaring which specific type (declarative, procedural,
explicit/implicit knowledge).

For dealing with remarkably complex Sustainable Development issues, problem-solving is crucial.
According to de Jong and Ferguson-Hessler [35], problem-solving requires situational, conceptual,
and procedural knowledge. Situational knowledge enables learners to sift relevant information out
of a specific problem statement and, if necessary, complete it with additional information outside
of the specific problem statement [35]. Conceptual knowledge comprises the principles, concepts
and facts that apply within a certain domain [35]. These principles, concepts, and facts to solve
problems are not included in the problem statement itself. Hence, the learners have to activate relevant
prior knowledge to solve the problem. Procedural knowledge includes actions that are valid for
certain types of problems within a domain [35]. Procedural knowledge helps the problem solver to
transfer knowledge from one problem situation to another. So far, the knowledge model of de Jong
and Ferguson-Hessler [35] was rarely used in education sciences to evaluate learning and teaching
prerequisites [36,37]. However, especially regarding Sustainable Development issues like resource use
issues in Indonesia [38] or land use issues in Madagascar [39]—where problem-solving is essential—the
model turned out to be suitable [38–40].
To the best of our knowledge, none of the educational studies applying de Jong and Ferguson-Hessler’s model, e.g., [36–38] empirically checked for the independence of single knowledge types using multidimensional IRT modelling. For example, Koch et al. [38] used classical test theory and did not situate type-specific knowledge in relation to similar SD-related constructs. To close this gap, the present study aims to

i. Assess sustainable land use-relevant knowledge in a differentiated way (situational, conceptual, and procedural knowledge);

ii. Find out via IRT modelling how the theoretically distinguished knowledge types can be empirically supported by the resulting knowledge dimension(s);

iii. Link these knowledge dimension(s) to related constructs.

Therefore, the study focuses on the following three research questions:

1. Which evidence does IRT modelling provide for the distinction between situational, conceptual, and procedural knowledge?

   The authors assume that the three theoretical knowledge types represent separate latent constructs. In the last few decades, digitisation has triggered changes in reading habits [41]. Deep forms of reading shifted to more superficial reading practices [41]. Commonly, situational knowledge refers to information given in specific scenarios cf. [38]. If participants have difficulty processing the extensive information, we could also assume that situational and conceptual knowledge build one dimension of knowledge together.

   Zwickle et al. [28] showed that sustainability knowledge increases with higher educational level. Thus, we make a similar assumption for the present study. Considering different levels of ESD integration among the subjects of geography, biology, and politics in schools [42], evidence for a similar pattern in teacher education is lacking so far. Student teachers (students at universities aiming to become teachers, in the following interchangeably used with “pre-service teacher”) of programs for different school forms, e.g., for primary or secondary schools, show varying prerequisites, such as interest in science [43]. Hence, an assumption of differing student teachers’ knowledge dependent on school form can be made. Thus, a further research question is:

2. How do specifications in teacher education, such as academic progress, form of school, and subjects studied influence student teachers’ knowledge of sustainable land use in the knowledge dimension(s)?

   In addition to cognitive components, motivational orientations belong to professional action competence; they influence teaching [44] and are essential for problem-solving [45]. Thus, we apply existing instruments to SD-related motivational orientations and set them in relation to our knowledge dimension(s) to check for an assumed divergent validity. The assumption derives from the different nature of the constructs, which are compared (i.e., knowledge and motivational orientations). Furthermore, we check for convergent validity to other knowledge constructs. This led to research question three:

3. How do the knowledge dimension(s) resulting from IRT modelling differ from SD-related motivational constructs, such as self-efficacy beliefs of ESD teaching, responsibility toward climate change and biodiversity, attitudes toward SD, self-assessed knowledge of SD-relevant issues, and sustainability knowledge?

   We expect a higher degree of relatedness between the knowledge dimension(s) of our construct and other knowledge scales compared to scales assessing motivational orientations.
2. Method

2.1. Questionnaire Design

The three knowledge types were operationalised according to de Jong and Ferguson-Hessler [35]. The questionnaire development for SD-relevant knowledge followed Koch et al. [38]. Initially, we chose two contexts relevant to the challenges of biodiversity loss and climate change: “insects and pollination” and “use of peatlands”. Both are linked to the overarching topic of sustainable land use. For each of these contexts, we drafted a scenario based on scientific facts. We published short versions of the scenarios in Richter-Beuschel et al. in 2018 [46].

Based on the scenarios, we constructed multiple-choice items (1 attractor, 3 distractors) to test situational and conceptual knowledge (Figure 1). The items testing situational knowledge referred explicitly to the scenarios. Answering the items testing conceptual knowledge requires factual knowledge in the fields of biodiversity loss and climate change. In sum, we designed 47 items testing situational and conceptual knowledge. Two think-aloud studies served to improve the understanding of items and to adjust distractors that are too good or too bad [47]. An additional quantitative pre-study (N = 109) allowed us to revise or exclude items with extremely high or low difficulty. These steps resulted in a questionnaire with 18 situational and 15 conceptual knowledge items. The 33 items have an ecological, socio-economic, or institutional focus (11 items each).

| Situational Knowledge | Conceptual Knowledge |
|-----------------------|----------------------|
| **Item 5:**           | **Item 26:**         |
| What is most likely to apply to wild bee habitats? | Sustainable land use ... |
| a. Grain provides an important food resource for wild bees. | a. requires functioning ecosystem services as a prerequisite. |
| b. Fruit farmers provide only few insect hotels as nesting sites. | b. always has a positive impact on the provision of ecosystem services. |
| c. Cities are growing and offer little food for wild bees compared to cultural landscape. | c. promotes ecosystem services only in industrialised countries. |
| d. In today’s structurally poor cultural landscape there are hardly any nesting opportunities left. | d. can help to maintain or promote ecosystem services. |

| Procedural Knowledge |
|----------------------|
| **Item 10:**         |
| Support pollinator-friendly agriculture by purchasing ecologically produced products. |
| Effectiveness regarding biodiversity conservation: |
| ineffective | very effective |
| 1 | 2 | 3 | 4 |
| **Item 25:**         |
| Cultivate peatlands without fertilisers and pesticides. |
| Effectiveness regarding contribution to climate protection: |
| ineffective | very effective |
| 1 | 2 | 3 | 4 |

**Figure 1.** Exemplary items for assessing situational, conceptual, and procedural knowledge (correct answers of situational and conceptual knowledge in italics; mean experts’ estimations rounded to the integer as benchmark for the evaluation of student teachers’ procedural knowledge are marked by a circle).

We developed items to evaluate student teachers’ procedural knowledge through a two-round Delphi approach [46]. Student teachers had to evaluate resulting potential solution strategies regarding “insects and pollination” and “peatland use” for their effectiveness on a four-point Likert scale (1: ineffective to 4: very effective) (Figure 1). The student teachers rated the effectiveness of each solution strategy concerning the following three fields of action: (i) realisation of sustainable land use, (ii) provision of ecosystem services, and (iii) biodiversity conservation and climate protection (in the following abbreviated as “protection”). These are the investigated facets of sustainable land use issues. A combination of qualitative and quantitative steps in the two-rounded Delphi study with an
intermediated think-aloud study with student teachers reduced the initial number of 123 items to 51 items [46].

In total, the final paper-and-pencil survey consisted of three main sections:

- General information (e.g., gender, age, study program, semester, final school examination grade where 1 equals school grade A), ESD specific information (e.g., self-assessed knowledge of SD-relevant issues, number of courses attended including ESD and the percentage of ESD in these courses) and sustainability knowledge (10 items of Zwickle et al. published in 2014 [28]);
- Written scenarios and multiple-choice items to test situational and conceptual knowledge as well as Likert scale items to test procedural knowledge;
- Further validation instruments, i.e., self-efficacy beliefs of ESD teaching, attitudes toward sustainable development, responsibility toward climate change and biodiversity, and self-assessed knowledge of SD-relevant issues.

2.2. Validation Instruments

At the beginning of the questionnaire, we asked the participants to self-assess their knowledge. They indicated their knowledge regarding 13 SD-relevant topics which are related to the contexts of “insects and pollination” and “use of peatlands”: 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. We applied a five-point Likert scale with 1: insufficient, 2: sufficient, 3: satisfactory, 4: good, and 5: very good.

Furthermore, we used an instrument to evaluate self-efficacy beliefs of ESD teaching [48]. The instrument comprised 35 four-point Likert scale items: 1: not right, 2: a little right, 3: rather right, and 4: exactly right [48]. Following the confirmatory factor analysis in Lünemann [49], we did not consider one factor with four items out of the eight factors due to correlations > 1 with another factor of the model and due to content dispensability of the removed factor.

A scale used by Biasutti and Frate [50] measured Attitudes toward Sustainable Development (ASD). The instrument comprised 20 five-point Likert scale items with 1: strongly disagree, 2: disagree, 3: neutral, 4: agree, and 5: strongly agree [50]. To assess responsibility toward climate change, we applied three items suggested by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety [51]. Additionally, we adapted them to create three items to assess responsibility toward biodiversity. The resulting items are presented in Figure 2. We used the same scale as for ASD above.

| 1. | Citizens can significantly contribute to the conservation and sustainable use of biodiversity through biodiversity-conscious everyday behaviour. |
| 2. | The pressure of citizens on politics can bring about effective actions for the conservation and sustainable use of biodiversity. |
| 3. | Through their involvement in environmental and nature conservation associations, citizens can significantly contribute to the conservation and sustainable use of biodiversity. |

**Figure 2.** Items for assessing responsibility toward biodiversity.

2.3. Data Collection and Sample Description

The cross-sectional study took place between October 2018 and May 2019. The survey was conducted in German. A total of 314 German student teachers from ten universities in seven federal states participated. They studied to become secondary school teachers in at least one of the subjects...
of biology, geography, or politics. The students were in Bachelor (54.5%), Master (36.6%), or State examination programs (8.3%) and from different semesters. About 80% of the participants were studying to become teachers in German high schools (Gymnasium) and integrated comprehensive schools (hereafter referred to as high schools). Another 20% of the student teachers were studying to become teachers in other school forms, such as vocational school. Most of the participants were female (71.3%; male 26.8%; diverse 1%). The average age of the student teachers was 23.1 years (SD: 3.0, range: 18 to 39).

The survey was conducted onsite at the universities but outside of courses. The mean processing time of the questionnaire was about 60 minutes. Participation was voluntary, anonymity was assured, and students received a financial reward.

2.4. Data Analysis

We applied the dichotomous Rasch model [52] to analyse the dimensionality of situational, conceptual, and procedural knowledge using Acer ConQuest 4 [53]. The student teachers’ answers to the multiple-choice items concerning situational and conceptual knowledge were coded as either correct: 1 or incorrect: 0. For procedural knowledge, an averaged expert rating [46] served as an anchor to judge the “right” answer, even where there is factually uncertain knowledge. For dichotomous modelling, the experts’ answers of second Delphi round [46] were rounded to the nearest integer. We coded student teachers’ answers with 1: correct, when they had chosen the same level as the rounded averaged expert ratings, and with 0: incorrect in all other cases.

We applied all analyses case centered. First, we conducted One-Dimensional (1D) modelling of situational, conceptual, and procedural knowledge. Items with misfit were excluded from further analysis. A misfit is given when discrimination is <0.20 [54,55] or Weighted Mean Squares (wMNSQ) is <0.8 and >1.2 [56]. After 1D-modelling, 16 items remained for situational, 11 for conceptual, and 32 for procedural knowledge.

Second, the items remaining for the three knowledge types were modelled 1D, Two- (2D), and Three-Dimensionally (3D). Two-dimensional modelling combines situational and conceptual knowledge into one dimension. We used information criteria AIC (Akaike’s Information Criterion) and BIC (Bayesian Information Criterion) as indicators for the model fit and χ2-test to test for significant differences of 1D, 2D, and 3D models. Furthermore, we reported the Expected A-Posteriori reliability/Plausible Values (EAP/PV reliability) and person separation reliabilities based on Weighted Likelihood Estimates (WLE). We checked for potentially biased items regarding gender, study program, and educational level by analysing Differential Item Functioning (DIF).

To answer research question two, the WLE person abilities were used. We first z-standardised WLEs with IBM SPSS Statistics 26. One person built a significant outlier (WLE beyond ± 3.29, [57]); we excluded the outlier from further analyses with person abilities. We applied one-way ANOVAs, t-tests, and linear regression analysis. Due to the homogeneity of variances (Levene Test) in all analyses, we applied Tukey’s HSD (honestly significant difference) post-hoc tests to evaluate which specific groups within an ANOVA differ from each other. Shapiro–Wilk test indicated that WLE person abilities are not normally distributed. Therefore, we used Spearman’s rho (rS) to analyse correlations. In all analyses, the pre-defined significance level is 0.05. To test for the impact of academic progress, participants were divided by their semester into two groups: bachelor level students comprise all participants from first to sixth semester. Master level students comprise all participants in their seventh semester or later. We multiplied the number of ESD-related courses by the percentage of ESD in these courses to create the variable “ESD in university”. The product represents the amount of ESD-relevant content taught in the attended lectures, seminars and other courses.

Concerning research question three, we analysed latent correlations between knowledge dimensions and self-efficacy beliefs, responsibility, attitudes, and self-assessed knowledge using Partial Credit Models [58]. In the first step, we modelled the validation instruments one-dimensional by applying Rating Scale Models [59]. To better characterise the content of the validation constructs of
self-efficacy beliefs, responsibility, attitudes, and self-assessed knowledge, we used the reasonably less restricted limit of wMNSQ from 0.7 to 1.3 [56]. Remaining items with misfit were excluded.

The modelling of self-efficacy beliefs started with 31 items; two misfitting items on media use were not considered further. In 26 of the remaining 29 items, less than 5% of participants chose the answer in category one (not right). Thus, by combining categories one and two, the response options were reduced from four to three. For the scales regarding responsibility toward climate change and responsibility toward biodiversity, no misfit occurred. The instrument measuring Attitudes toward SD (ASD) was reduced from 20 to 18 items due to misfit. The response options for both the responsibility and attitudes scale were reduced from five to three options by collapsing categories one, two, and three.

Prior to 1D modelling of self-assessed knowledge of SD-relevant issues, we aggregated the three biodiversity items, diversity of species, diversity of ecosystems, and genetic diversity, into one variable to avoid an overrepresentation of (or bias due to) biodiversity focused items in the scale. We used this new variable alongside the remaining ten variables (11 items in total). We kept the misfitting item “bees and pollination” (wMNSQ = 1.39), due to the high relevance of content.

Regarding sustainability knowledge, we calculated manifest correlations with person abilities in our knowledge dimension(s) because of low information depth of the ten dichotomous items.

3. Results

3.1. Dimensionality of Sustainable Development-Relevant Content Knowledge and Quality of the Instrument

For the 2D and 3D model, AIC and BIC fit nearly equally well (Table 1). The χ2 test for both models displayed significant results (Table 1), and both models are interpretable.

| Model | Deviance | Number of Parameters | Change in Deviance | Change in df | p       | AIC     | BIC     |
|-------|----------|----------------------|--------------------|--------------|---------|---------|---------|
| 1D    | 22,493.13| 60                   |                    |              |         | 22,613  | 22,838.09|
| 2D    | 22,281.05| 62                   | 212                | 2            | <0.001  | 22,405  | 22,637.51|
| 3D    | 22,273.71| 65                   | 8                  | 3            | <0.05   | 22,403  | 22,647.42|

However, looking at the EAP/PV and WLE person separation reliabilities for each dimension of the 2D and 3D model (Table 2), the 2D model is the more reliable solution for situational/conceptual knowledge in the present study. The 2D model combines situational and conceptual knowledge in one dimension.

| Knowledge Dimension | EAP/PV | WLE  |
|---------------------|--------|------|
| Situational/Conceptual Knowledge | 0.63   | 0.60 |
| Procedural Knowledge | 0.68   | 0.67 |
| Situational Knowledge | 0.60   | 0.47 |
| Conceptual Knowledge | 0.56   | 0.39 |
| Procedural Knowledge | 0.66   | 0.67 |

The latent correlation between situational and conceptual knowledge is highest in the 3D model with 0.76 (Table 3). In the 2D model, the latent correlation of 0.07 between situational/conceptual and procedural knowledge clearly indicates two distinct dimensions (data not shown).
Table 3. Latent correlations between the situational, conceptual and procedural knowledge of Three-Dimensional (3D) modelling.

|                        | Situational Knowledge | Conceptual Knowledge |
|------------------------|-----------------------|----------------------|
| Situational Knowledge  | 0.76                  | 0.06                 |
| Conceptual Knowledge   | 0.08                  | 0.08                 |
| Procedural Knowledge   |                       |                      |

Table 4 displays the test characteristics of the resulting dimensions of situational/conceptual and procedural knowledge. Both dimensions show acceptable EAP/PV reliabilities. The average item difficulty is lower for the situational/conceptual than for the procedural knowledge dimension. The Wright Map (Figure 3) illustrates the item difficulties of situational/conceptual and procedural knowledge items.

Table 4. Test characteristics for the dimensions of Situational/Conceptual Knowledge (SCK) and Procedural Knowledge (PK) (N = 314) (SE: Standard Error; wMNSQ: weighted (infit) mean-square).

|                        | SCK     | PK     |
|------------------------|---------|--------|
| (27 Items)             | (32 Items) |
| Item Separation Reliability | 0.98   | 0.83   |
| Variance (SE)          | 0.35 (0.05) | 0.29 (0.04) |
| EAP/PV Reliability     | 0.63    | 0.67   |
| WLE Person Separation Reliability | 0.60 | 0.67 |
| Average Item Difficulty (SE) | −0.89 (0.05) | 0.45 (0.02) |
| Item Difficulty range  | −3.08–1.19 | −0.14–1.00 |
| wMNSQ range            | 0.96–1.05 | 0.96–1.04 |
| Discrimination range   | 0.22–0.42 | 0.22–0.38 |

Situational/conceptual knowledge items with a socio-economic focus on sustainable land use issues were easiest (mean item difficulty: −1.36), followed by—in average—less difficult items with an institutional (−0.78) and ecological focus (−0.50). However, ANOVA showed no significance (F(2,24) = 2.29, p = 0.123) in average difficulty for the items of the socio-economic, institutional, and ecological discipline. All items developed for situational knowledge showed a mean difficulty of −1.01 and items developed for conceptual knowledge a mean difficulty of −0.72. The t-test revealed no difference in difficulty of situational and conceptual knowledge items (t(10) = −0.59, p = 0.571).

In terms of procedural knowledge, the fields of action on sustainable land use (mean item difficulty: 0.36), ecosystem services (0.36), and protection (0.45) show similar mean item difficulties. ANOVA showed no differences between the average difficulty of the items of the three fields of action (F(2,29) = 0.37, p = 0.692).

The 1D model of situational/conceptual knowledge showed no considerable DIF for gender (average logit difference: 0.06, with females (n = 224) higher than males (n = 84)) (<0.4; [60]), except for item 21 (logit difference: 0.50). For procedural knowledge, none of the items showed considerable DIF for gender (maximum logit difference: 0.30; average logit difference 0.08 higher for females).

Bachelor and master level students showed considerable DIF in item 21 on situational/conceptual dimension (logit difference: 0.71). No considerable DIF occurred in procedural knowledge (maximum logit difference: 0.27). For students who seek to be a high school teacher (n = 250) and students who want to become a teacher in other school forms (n = 63), only item 6 of situational/conceptual knowledge displayed considerable DIF (logit difference: 0.44). In procedural knowledge, only item 19 showed noteworthy DIF (logit difference: 0.61).
Figure 3. Wright Maps of Situational/Conceptual Knowledge and Procedural Knowledge (each 'X' represents 1.1 cases) (↓ item difficulty is lower than presented) (N = 314).

3.2. Validation

3.2.1. Influence of Specifications in Teacher Education on Knowledge in Sustainable Land Use Issues

Regarding WLE person abilities, master level students (n = 135) outperformed the bachelor level students (n = 174) in situational/conceptual knowledge (t(307) = −3.96, p < 0.001) but not in procedural knowledge (t(307) = −0.62, p = 0.537) (Figure 4). Master level students scored 0.38 logits higher in
situational/conceptual knowledge and only 0.06 logits higher in procedural knowledge than bachelor level students.

**Figure 4.** Person abilities in Situational/Conceptual Knowledge (SCK) and Procedural Knowledge (PK) from bachelor and master level students (**p < 0.001, ns = not significant) (n = 309). Error bars indicate standard errors.

Students aiming to become high school teachers (n = 250) displayed higher person ability for situational/conceptual knowledge of sustainable land use issues than students aiming to become teachers in other school forms (n = 62) (t(310) = 3.37, p = 0.001) (Figure 5). For procedural knowledge, no differences in person ability occurred (t(310) = 0.28, p = 0.783). Students seeking to become a high school teacher scored 0.35 logits higher in situational/conceptual knowledge and 0.08 logits higher in procedural knowledge than students who chose other school forms for their studies.

**Figure 5.** Person abilities in Situational/Conceptual Knowledge (SCK) and Procedural Knowledge (PK) from student teachers of high school and other school forms (**p = 0.001, ns = not significant) (n = 312). Error bars indicate standard errors.
ANOVA did not reveal differences in person ability for different subjects (biology, geography, politics, and a combination of biology and geography) in the dimensions of situational/conceptual \( (F(4308) = 2.05, p = 0.087) \) and procedural knowledge \( (F(4308) = 1.16, p = 0.329) \). However, final school examination grades were significantly correlated with situational/conceptual \( (r_S = -0.33, p < 0.001) \) but not with procedural knowledge \( (r_S = -0.03, p = 0.597) \). In addition, “ESD in university” was significantly correlated with person ability for procedural knowledge \( (r_S = 0.20, p < 0.001) \) but not with person ability for situational/conceptual knowledge \( (r_S = 0.09, p = 0.118) \). Linear regressions showed that “ESD in university” predicts SD-relevant procedural knowledge with a small effect \( (r^2 = 0.02, p = 0.016) \).

3.2.2. Knowledge Dimensions and Related Constructs

In 1D modelling, all validation instruments showed at least moderately acceptable EAP/PV reliabilities. Further test characteristics of 1D models are presented in Table 5.

| Validation Instrument | Self-Efficacy Beliefs of ESD Teaching (29; 3) | Responsibility toward Climate Change and Biodiversity (6; 3) | Attitudes toward SD (18; 3) | Self-Assessed Knowledge Regarding SD (11; 5) |
|-----------------------|---------------------------------------------|-------------------------------------------------|----------------------------|-----------------------------------------------|
| Item Separation Reliability | 0.97 | 0.96 | 0.98 | 0.99 |
| Variance (SE) | 0.64 (0.06) | 1.46 (0.21) | 0.47 (0.06) | 0.77 (0.09) |
| EAP/PV Reliability | 0.88 | 0.72 | 0.75 | 0.80 |
| WLE Person Separation Reliability | 0.88 | 0.68 | 0.75 | 0.84 |
| Average Item Difficulty (SE) | −0.33 (0.03) | −0.65 (0.03) | −0.43 (0.04) | −0.06 (0.04) |
| Item Difficulty range | −2.45–0.77 | −1.55–0.17 | −1.68–0.78 | −1.25–1.23 |
| wMNSQ range | 0.75–1.22 | 0.87–1.12 | 0.77–1.25 | 0.76–1.39 |
| Discrimination range | 0.26–0.61 | 0.54–0.72 | 0.22–0.54 | 0.46–0.71 |

The highest assumed correlation between knowledge dimensions and self-assessed knowledge of SD-relevant issues can be confirmed only for situational/conceptual knowledge (Table 6). The knowledge dimensions were not (situational/conceptual) or were negatively correlated (procedural) with self-efficacy beliefs of ESD teaching. Furthermore, latent correlations between the knowledge dimensions and responsibility and attitudes were almost negligible. The highest correlations appear between the motivational constructs of self-efficacy beliefs, attitudes, and responsibility (Table 6).

| Dimension | (a) Situational/Conceptual Knowledge | (b) Procedural Knowledge | Self-Efficacy Beliefs ¹ | Responsibility ¹ | Attitudes ¹ |
|-----------|-----------------------------------|-------------------------|-----------------------|-----------------|------------|
| Self-Efficacy Beliefs | 0.02 | −0.14 | 0.04 | 0.18 | 0.35 |
| Responsibility | 0.26 | 0.10 | −0.03 | 0.34 | 0.55 |
| Attitudes | −0.01 | 0.11 | −0.02 | 0.11 | 0.55 |

¹ The latent correlations between the validation instruments itself were calculated as mean of latent correlations of both Five-Dimensional modellings with (a) Situational/Conceptual Knowledge and (b) Procedural Knowledge.
The manifest correlation between the construct of sustainability knowledge and person abilities of the situational/conceptual knowledge dimension is moderate ($r_S = 0.372, p < 0.001$), and no correlation occurs with procedural knowledge ($r_S = 0.018, p = 0.749$).

4. Discussion

4.1. Arguments for a Two-Dimensional Structure of Sustainable Development-Related Knowledge

The study aimed at empirically supporting the structure of the three theoretically distinguished knowledge types of situational, conceptual, and procedural knowledge, proposed by de Jong and Ferguson-Hessler [35]. The knowledge types were contextualised for sustainable land use. We tested our assumed 3D model against a 1D and 2D model. The global fit statistics suggest that either 2D- or 3D-modelling is applicable. We chose the 2D model due to its better EAP/PV and WLE person reliabilities for the combined situational/conceptual dimension compared to split dimensions of situational and conceptual knowledge in the 3D model (Table 2). The two resulting dimensions of 2D modelling, i.e., situational/conceptual knowledge and procedural knowledge, are interpretable.

Combining situational and conceptual knowledge in one dimension is plausible: To answer situational knowledge items, student teachers had to read two extensive and complex scenarios cf. [46]. We did not explicitly request the student teachers to read the scenarios carefully before working on the multiple-choice items of situational and conceptual knowledge. They did not know that they had to perform a knowledge test which checks for processing information from the scenarios. Changes in reading habits due to digitisation could have led to more superficial reading practices [41]. This could have affected the participants’ information processing of the scenarios and of the multiple-choice answer options. Thus, student teachers who did not carefully read the information given were perhaps not sufficiently able to integrate information provided in their answers to situational knowledge questions. Therefore, conceptual, rather than situational knowledge, would have been assessed by the multiple-choice items. This is in line with lacking difference in item difficulties between the developed situational and conceptual knowledge items. The phenomenon of working superficially on the multiple-choice options could have occurred for both knowledge types that were assessed by the multiple-choice items.

The latent correlation between situational and conceptual knowledge in the 3D model (Table 3) could have been positively influenced by the use of the same multiple-choice item test format. Furthermore, the use of the same test format could be one reason that—in our modelling—a single dimension for situational/conceptual knowledge was an obvious option considering their EAP/PV and WLE (Table 2). In contrast, Binder et al. [61] used four different methods to measure four types of prior knowledge of biology and physics university students. They interpreted that knowledge of facts, knowledge of meaning, integration of knowledge, and application of knowledge are distinct [61]. However, latent correlations between these knowledge types ranged between 0.24 and 0.86 [61]. Compared with our latent correlations of 0.76 between situational and conceptual knowledge, the 3D theory-driven structure could be chosen if concerns of reliability (WLE values for the 3D model) had not intervened.

Regarding the Wright Maps shown in Figure 3, situational/conceptual knowledge items range from $-3.08$ to 1.19 logits and procedural knowledge items from $-0.14$ to 1.00 logits. Figure 3 depicts the item distributions as well. It shows several areas of precise and some areas of less precise measurement. Especially items with low difficulty are rare in the procedural knowledge dimension. This could be an artefact of dichotomising the student teachers’ answers. We handled all student teachers’ answers deviating from the experts’ answers (rounded to the integer) by one unit or more as incorrect (score 0). This loss of differentiated information about the weaker student teachers may have resulted in missing items at the lower end of the Wright Map of procedural knowledge.

Solaz-Portolés and López [62] wrote an overview of knowledge types that are involved in problem-solving regarding science education. The authors stated that while “conceptually it is
possible to distinguish knowledge types, in practice they are difficult to distinguish" [62] (p. 106). A reason for this difficulty may be the assessment methods, which were not adequately adjusted to knowledge types [62]. However, the low latent correlation in our study shows a clear distinction between the dimensions of situational/conceptual knowledge and procedural knowledge in the 2D model (0.07)—and even acceptable latent correlations for the theoretically underlying 3D model structure (Table 3). In sum, at least two different types of knowledge can be measured with the proposed instrument.

4.2. Arguments for the Suitability of the Measurement Instrument

Altogether, no Differential Item Functioning (DIF) considerably impaired the measurement of the situational/conceptual and procedural knowledge dimensions. When the participants were grouped by gender, only item 21 of the situational/conceptual dimension displayed DIF. This can be explained by the extremely low difficulty of item 21 (Figure 3) and therefore, the comparably imprecise measurement. For the groups of bachelor and master level students, DIF occurred again only in item 21 of the situational/conceptual dimension.

When students were grouped by the different school forms they wished to work in, DIF existed for item 19 in the procedural dimension—explainable by its content. For the situational/conceptual dimension, the DIF displayed in item 6 can be traced back to the same reasons as item 21 (imprecise estimation).

The DIF of items 6 and 21 in situational/conceptual dimension and item 19 for procedural knowledge can, additionally, be plausibly explained by the content they covered. Items 6 and 21 cover the genetic diversity of honeybees. In item 6, genetic diversity functions as a force for vulnerability toward diseases and parasites, and in item 21, genetic diversity influences the threat of extinction in general. Therefore, the DIF in item 21 indicates that bachelor level students have difficulty in understanding biodiversity at the level of genes. This is in line with the findings of Jiwa and Esa [33]. They report that definitions of the term biodiversity of student teachers lack explicitly stated aspects of genetic diversity. Additionally, Fiebelkorn and Menzel [63] showed that German biology student teachers were not sufficiently conscious of the genetic level of biodiversity. The same explanation can be applied to the DIF of item 6, resulting of the subsample compositions: the subsample of student teachers who wish to teach in high school is balanced (bachelor level: 49.6%, master level: 49.2%), whereas the subsample of student teachers for other school forms is somewhat unbalanced (bachelor level: 81%, master level: 19%).

Item 19 in the procedural knowledge dimension requested participants to evaluate the effectiveness of intensifying the investigation of regenerative peat substitutes, regarding their contribution to climate protection. High school student teachers showed higher ability to answer this item than student teachers for other school forms. High school teachers are trained more specifically in the sciences than teachers for other school forms, and they have the task to qualify their students in a research-oriented way to prepare them for university studies [64]. Additionally, the higher ability of high school student teachers to answer item 19 may be aligned with their generally higher person ability. High school and integrated comprehensive school student teachers show higher professional and scientific interest than student teachers for other school types [43]. Persons with lower final school examination grades prefer to choose school forms other than high school and integrated comprehensive school [43,65].

As shown above, the developed instrument is suitable for the following groups of student teachers: (i) females and males, (ii) bachelor and master level students, and (iii) students aiming to become high school teachers and teachers at other school forms.

4.3. Arguments for Validity

On average, items measuring procedural knowledge were more difficult than items measuring situational/conceptual knowledge. This is explainable due to the interdisciplinary knowledge needed to solve procedural knowledge items. The higher abilities of master level students to answer
situational/conceptual items, compared to bachelor level students (Figure 4), could be partly explained by their knowledge acquired during teacher education. Another reason to consider is that a small number of student teachers at the master level may have changed into a Master of Education program after their bachelor’s degrees in science. Probably, more intensive studies of conceptual knowledge in the science bachelor studies than in the bachelor qualifying for becoming a teacher might create a slight bias in the results of master level student teachers. The higher situational/conceptual knowledge of master than bachelor level students is in line with Koch et al. [38]. They reported no difference in situational knowledge of Indonesian university students from third to seventh semester, but in two of three domains in conceptual knowledge [38]. In addition, Zwickle et al. [28], who measured sustainability knowledge—which is comparable with knowledge defined as conceptual in the present research—found higher levels of sustainability knowledge in upperclassmen than in underclassmen. The lack of difference in person ability between bachelor and master level students for the dimension of procedural knowledge in our study (Figure 4) is also in line with Koch et al. [38]. They detected that third- and seventh-semester Indonesian university students both showed low procedural knowledge, with high deviations from expert judgments of solutions’ effectiveness [38]. The missing correlation between final school examination grades and procedural knowledge in our study is also understandable: up to now, solution strategies for interdisciplinary problems are rarely part of upper secondary education, with its subject-specific curricula and examinations [64].

Despite the higher person ability of master level students in situational/conceptual knowledge, the results of the present study revealed no correlation between “ESD in university” and situational/conceptual knowledge. The missing correlation matches German teacher education curricular requirements of studying pedagogical content knowledge regarding two school subjects and studying corresponding natural or social sciences. Natural or social science courses probably foster situational/conceptual knowledge, but maybe they are not represented in the “ESD in university” indicator. Furthermore, other sources of knowledge can be considered: for example, participants who indicated having dealt with ESD through “private research in the internet” showed significantly higher abilities in situational/conceptual knowledge ($r_S = 0.13, p = 0.028$). This finding is in line with Burmeister and Eilks [66], who report that German chemistry pre-service teachers gained their knowledge of sustainability and ESD from media and the internet instead of their formal education. In contrast to situational/conceptual knowledge, for the procedural knowledge dimension, higher “ESD in university” was accompanied by higher person abilities. This leads to the assumption that a higher proportion of ESD in teacher education courses may foster procedural knowledge. Thus, interdisciplinary knowledge could equip student teachers with the necessary procedural knowledge (e.g., for making land use more sustainable), and enables the teaching of such knowledge to students—the next generation of decision-makers.

Our results do not contradict the results of a prior study with only a subsample of student teachers, which revealed no correlation between the number of attended ESD-relevant courses and procedural knowledge [40]. This result was attributed to the extremely low number of courses with ESD relevance [40]. In the prior study, no correction by the percentage of ESD in the courses has been applied. However, without this correction, a significant but weak correlation between procedural knowledge and the amount of ESD taught is revealed ($r_S = 0.19, p = 0.001$). Furthermore, the differentiated, more diverse sample composition of the present study—comprising not only students becoming a teacher at high schools and integrated comprehensive schools as in Richter-Beuschel and Bögeholz [40]—may contribute to these differing results. Two further reasons—perhaps most important—are: first, the IRT analyses of the present study consider only 32 of the 51 items used in the prior study with analyses only considering classical test theory. Second, the present study analysed procedural knowledge in a dichotomous format (rounded to integer), whereas the prior study used the precise deviation between experts’ and students’ effectiveness estimations to build the specific value (decimal without rounding) for procedural knowledge [40]. Thus, different information was processed in the final analyses of the present and prior study. Overall, considering the more restrictive prerequisites for data analyses and
the more sophisticated requirements connected with IRT modelling, the results of the present study are more valid.

In the following, we give first insights into the distribution of the items on the Wright Maps. Item 5 measuring situational/conceptual knowledge (Figure 1) was one of the most difficult items (Figure 3). The distractor “cities… offer little food for wild bees” was derived from a common misconception and was chosen by many participants—indeed, urban areas provide important resources for insects [67]. Item 26 (Figure 1) revealed a low difficulty level (Figure 3). Through formulations like “always” or “only” in distractors, the item was already easy because of its structure, apart from its content. Within the dimension of procedural knowledge, item 10 (Figure 1), for example, was relatively easy to answer (Figure 3). This seems plausible because the solution strategy, “Support pollinator-friendly agriculture by purchasing ecologically produced products”, is an omnipresent option to take if one wants to. This strategy does not include any visible barrier and does not require any personal action. In contrast, item 25 (Figure 1) was of highest difficulty (Figure 3). The realisation of “Cultivate peatlands without fertilisers and pesticides” depends on diverse external conditions. For example, a change of personal routines and common working behaviours of relevant stakeholders influences income depending on sensitive and complex cultivation and farm management. Such a complex situation is hard to estimate for student teachers, and even for other non-experts without the corresponding background.

The present study used multidimensional IRT modelling to investigate divergent validity of knowledge dimensions and motivational factors and to locate situational/conceptual and procedural knowledge in the nomological net of professional action competence. In sum, both, the situational/conceptual and procedural knowledge dimensions, showed little to no correlation with the constructs of self-efficacy beliefs of ESD teaching, responsibility toward climate change and biodiversity, and attitudes toward sustainable development. Due to findings in science education [68], one might think that content knowledge is related to self-efficacy beliefs. In our study on dimensions of situational/conceptual and procedural knowledge contextualised for sustainable land use, this is not the case. This could be explained by the subject matter addressed by self-efficacy beliefs of ESD teaching. The content of the construct content knowledge about sustainable land use cannot be equated with the content of the perceived competences in ESD teaching.

Neuhaus and Vogt [69] identified three types of German biology student teachers: the pedagogical-innovative, the scientific-innovative, and the scientific-conventional teacher types. In the present study, due to voluntary participation outside of courses, we cannot exclude an overrepresentation of the two scientific-oriented types. The participants’ scientific focus may have led to lower self-efficacy beliefs of ESD teaching and, thus, to missing or negative correlations with the dimension of situational/conceptual and procedural knowledge.

The absent or slight correlations between situational/conceptual knowledge and responsibility or attitudes, as well as between procedural knowledge and responsibility or attitudes, are in line with previous research. Pre-service teachers in chemistry showed to have a positive attitude toward ESD despite lacking theory-based knowledge about sustainability and ESD [66]. Similarly, Kagawa [70] reported that Plymouth University students’ knowledge about concepts of sustainability and SD and their attitude were not correlated. In addition, pre-service teachers’ knowledge of the impact of mitigative climate actions has been shown to not correlate with their willingness to undertake these actions [71]. The authors attributed the lacking correlation to the insufficient knowledge of the participants [71]. Our missing correlations between situational/conceptual, procedural knowledge and motivational orientations may further result from measuring responsibility and attitudes more general instead of specific to the used contexts. According to Ajzen and Fishbein (1980, in [72]), satisfactory correlations between behaviour and attitude require the measurement of attitudes toward a specific action. Probably, the requirement of specificity also accounts for the operationalisation of knowledge and attitudes.

For our self-assessed knowledge scale, the specificity was given, and the highest correlation between situational/conceptual knowledge and self-assessed knowledge of SD-relevant issues (Table 6)
compared to other validation constructs occurred. However, despite the same construct being investigated (knowledge of specific land use context), the results show low correlation (0.26) between situational/conceptual knowledge and self-assessed knowledge. The reason may be that self-reported knowledge cannot be equated with performance in situational/conceptual knowledge dimension. The lack of correlation between self-assessed knowledge of SD-relevant issues and procedural knowledge may be attributed to the characteristics of the knowledge types: in answering the self-assessed knowledge scale, knowledge about facts and principles and, thus, situational/conceptual knowledge will be considered rather than unsolved, uncertain solution strategies for Sustainable Development issues of procedural knowledge. The highest correlations between self-efficacy beliefs, responsibility, and attitudes (Table 6) are plausible, because they all assess motivational orientations instead of knowledge.

5. Conclusions

This research presents an instrument for assessing disciplinary and interdisciplinary knowledge of student teachers about sustainable land use issues. We operationalised situational, conceptual, and procedural knowledge types according to de Jong and Ferguson-Hessler [35]. Their knowledge model forms a reasonable basis for evaluating knowledge in Sustainable Development issues because it focuses on problem-solving. One strength of the presented study lies in the application of IRT analysis, which considers person abilities as well as item difficulties. Differentiated knowledge assessments, including an empirical support of theoretically underlying knowledge types, were rare in educational research so far. Thus, we aimed to obtain empirical support for a 3D model that reflects the three theory-driven types of situational, conceptual and procedural knowledge. Following the EAP/PV and WLE person reliabilities, in the current state, we consider situational and conceptual knowledge together as one dimension. Furthermore, the study provides first insights into the situational/conceptual and procedural knowledge of student teachers. The results show that it is difficult for prospective teachers to deal with global challenges, which have no simple or unambiguous solution. This could be one reason for an inadequate implementation of ESD in German school education cf. [73].

The measurement instrument was constructed using three different foci of situational and conceptual knowledge (ecological, socio-economic, and institutional) and different fields of action in procedural knowledge (sustainable land use, ecosystem services, and biodiversity conservation/climate protection). The similarity of item difficulty between the SD-relevant foci and the fields of action shows that operationalising an instrument with comparable difficulty levels, covering multiple disciplinary and interdisciplinary knowledge and SD-associated objectives, was successful.

By interpreting the results of the study, it must be considered that we conducted a one-time survey. For conclusions about knowledge acquisition during teacher education, it would be much more adequate to conduct a longitudinal study. When applying the questionnaire in future, we will examine dimensionality more closely. We will use the full item set again and request the participants to read the scenarios very carefully before working on the questionnaire, as the scenarios’ contents are essential for the following knowledge questions. In this way, it may be possible to prove whether reading habits and information processing influence the lacking differentiation between situational and conceptual knowledge.

By analysing student teachers’ procedural knowledge in a more differentiated way than dichotomous evaluation, we will use student teachers’ deviation from the rounded averaged expert answers. Thus, we will not equate one-unit deviation and more together as incorrect (score 0); we will consider partial credit reflecting the factual units of deviation to the rounded averaged expert answers to the next integer. With these changes, we assume to produce even better and more sophisticated modelling, through more precise measurement and better coverage of the low difficulty area of procedural knowledge.

The developed instrument shows several strengths: One strength is the broad content coverage of SD-related knowledge. This includes SD-related foci and SD-related fields of action concerning highly
relevant Sustainable Development issues regarding the challenges of biodiversity loss and climate change. A second strength of the instrument is the evaluation of disciplinary (situational/conceptual) knowledge and interdisciplinary (procedural) knowledge. A third strength is the broad coverage of knowledge types or rather empirically supported dimensions relevant to solve SD-related problems regarding sustainable land use issues. All strengths together, the content coverage, the disciplinary and interdisciplinary knowledge considered, and the problem-solving relevant knowledge dimensions, clearly address important prerequisites for teaching according to the objectives of education for SDGs [1]. As ESD is one important task of teacher education, we can conclude the following from our study: Student teachers attended only a small number of ESD-relevant courses during their university studies. The small effect of ESD-relevant courses on procedural knowledge in sustainable land use issues gives a first hint that procedural knowledge can be fostered during teacher education. However, enhancing procedural knowledge in the context of ESD to solve Sustainable Development issues remains expandable. Up to now, the disciplinary knowledge is fostered by German teacher education [64]. Therefore, further developments should especially consider interdisciplinary ESD teaching in teacher education—integrated in the subject-specific courses and in additional qualifications, (e.g., [74]).

In addition to skills, attitudes, values, motivation, and commitment, knowledge is one of the key factors to improve SD-related competences worldwide [1]. Qualified teachers could promote ESD at school. Therefore, equipping teachers as change agents with situational/conceptual and procedural knowledge in SD-related challenges of biodiversity and climate change, could be a decisive contribution toward sustainable land use and achieving core SDGs.

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